The New World

Early spring, 1905 CE. Eirian Ross, a woman retiring from her post at Cavendish Laboratory, looks back over her bright career, which began when she was trained, surreptitiously, in advanced mathematics at the University of Edinburgh, after working with scientist James Clerk Maxwell at his rural estate in nearby Glenlair. Together, they will test and document the partial differential equations that Maxwell has developed to define electromagnetism. Eirian also reflects on her time studying the writings of Ada Lovelace and attending offbeat lectures by Charles Dodgson.



As she packs up her office to retire from the prestigious Cavendish Laboratory at the University of Cambridge, Eirian Ross reflects on her career as a woman in mathematics and science, especially in conjunction with scientist James Clerk Maxwell.

Maxwell had mastered the basics of science and mathematics from his earliest days at school. In 1865 — well along in his career as a scientist, mathematician, and builder of lab equipment to support his experiments — he sought the help of farm girl Eirian Ross, his neighbor and now his protégé, in preparing and checking his experimental notes and papers on electromagnetism for publication.

Despite his deep investment in science Maxwell was a generous and caring man. His work with the Episcopal Church of Scotland, alongside his wife, Katherine, helped him to keep close contact with the world outside science, and with the human and personal needs of

that world. Eirian had not been raised in a particularly religious household, but she was open to all of the ideas that gave persistence to the dogmas of the church, especially when her mentor James Clerk Maxwell articulated them for her benefit.

Unfortunately, in these, days, young women were not allowed to attend university as regular students. However, for Eirian and her dear friend Bethan, both eager for education beyond reading, writing, arithmetic, and homemaking, Maxwell promised his full support for their interests in learning at the University of Edinburgh, even though that school had never allowed female students. Maxwell assured both their parents that he would make arrangements for tutoring when necessary. He would supply them with an encyclopedia and books; he would give them assignments and then mentor their scholarship as often as he could, given his own busy schedule.

3 March 1905

I had to stop packing, if only for a moment. I am sitting in my office at the end of the hall, and every action I take is an indirect correlation, making it less and less mine, the office I was afforded finally, based on merit and my applied knowledge of electromagnetism. I have shared it with another woman, much younger, an amanuensis, though she rolled her eyes and goggled at my math's abilities.

Now, the time has come. I feel my age more each year, and this spring marks my departure from the Cavendish Laboratory.

Years spent in one place accumulate a great deal of belongings. Papers, awards, discarded bits and bobs. I have stopped to write this entry because I found "Flyology" tucked haphazardly between two volumes I must have hastily put away—Five years ago? Fifteen? —in the years since 1874. I traced my

hand over my once beloved copy of twelve-year-old Ada Lovelace's treatise on bird wings, the book that started it all for me.

A starling squabbled just now as it passed my mullioned window. I can look down and see the melting snow in the Old Court, and I think that the English complain so easily. We had much harsher, bitterer winters in my girlhood in Scotland. We curled up fireside and told stories; we read books.

I have often wondered where I put it, "Flyology"—thought I misplaced it, blaming my aging memory. Today, I feel as though I am greeted by an old friend.

Bethan Sutherland has been my best friend since our earliest childhood. We were born and raised on adjacent dairy farms near the tiny southwest Scottish community of Corsock. A little over a two-mile hike due south of Corsock brought the hiker to Glenlair, the family estate of James Clerk Maxwell. The hiking trail connecting Corsock with Glenlair was well worn. We began visiting Mr. Maxwell's estate early in our lives.

Bethan is a little less so, but I am a curious person with a rich imagination.

Each day in my wanderings with Bethan, we were almost certain to come into contact with Mr. Maxwell, who had just become Dr. Maxwell, one of Scotland's brightest young men. I was sure he would soon occupy a position at the top rank of the world's scientists. I was sure he would stand alongside Sir Isaac Newton as one of Britain's brightest minds someday.

On one particularly cold morning in my nineteenth year, I found myself in Edinburgh, shivering even while wearing my warm coat, hat, and mittens as I waited for the small coal stove in Dr. Maxwell's office to heat up. Dr. Maxwell had sent me up from his private office on his family estate at Glenlair, a day's train ride away, to do some research in the university library. I'dscrounged a copy of Edinburgh's *Scotsman* from a desk in the office. The tea would be hot soon.

The office had been provided to Maxwell as a courtesy by the University of Edinburgh in recognition of his graduation from the school and his likely future contributions to physics following his brilliant work as an undergraduate. He had gotten to Cambridge for his advanced degrees, as well as, more recently, King's College, London.

My parents were teachers and farmers, and our house was full of books. Our conversations at dinner were full of grand ideas, travel, and detailed mathematics. Maxwell was a personal and family friend, a teacher, and a mentor and physicist.

Remembering Maxwell's attention to me as a young girl always makes me feel happy. From my earliest memories, he always treated me like a good friend and, once I worked alongside him, very much like a professional colleague. I remember all the puzzles and games he would bring to my attention when I was younger. As I stumbled over the challenges presented by these entertainments, Maxwell would offer suggestions on how to work through the knottiest problems. For the very most difficult problems of all, we would work together. I remember these moments, especially, with great fondness.

Around the age of twelve my parents decided I had progressed much further in my learning than they could keep up with by homeschooling in Corsock. They asked for Maxwell's help in getting me enrolled in the Edinburgh Academy, the school he himself had attended.

I was not happy to remember that I experienced my first rude awakening to life's realities when Maxwell came to our home to tell us that enrollment in the Academy would not be possible. "The Academy is an all-boys school," he told us. "It is a very old tradition, and they are very protective of it."

Surely, he could see my disappointment because I could not hide it any more than I could hide my tears as he spoke the words. My parents were downcast, tears were flowing down my face, and all was quiet in the room for some moments.

The New World

Eventually, Maxwell spoke. "Let me think on this. You all, as a family, should continue to think in terms of sending Eirian to Edinburgh. I am now a senior professor at the university there, and I have complete access to all the teaching resources it has to offer. I have developed good relationships with several members of the teaching staff, and I believe I can encourage them to act as her tutors from time to time.

"For myself, I will continue to oversee Eirian's coursework, and will agree, here and now, to read and grade all of her papers. The important thing, however, is her moral upbringing. I think it is very important that you both accompany her and continue with the most important work of parenting and encouragement in her studies until she feels she has gained enough confidence inherself and awareness of the world to be on her own. You are both excellent teachers, and I can help you find appropriate employment, introductions, and housing around the university community."

He concluded by saying: "My family will take care of your properties at Corsock while you are away. You will always have your home to come back to."

I recall that day in Corsock as being one full of extreme emotions, even at my age of twelve years. My parents and I walked with Maxwell back

to his carriage. The sun had broken through the usual clouds and drizzly rain. The rolling green hills suddenly exploded in the distance, filled with sunlight.

In Maxwell's Edinburgh office, I felt a little guilty as my mind wandered to the long walk to a stand where the horse-drawn cabs usually waited.

I had not slept well in the rooming house near campus the night before because the difficulties of Maxwell's assignment were roiling my brain. I rubbed my eyes at the thought of another night with a few hours of restless sleep — if, indeed, I would enjoy any sleep at all.

I picked up the notes on the statistical problem that Dr. Maxwell asked that I bring with me so that I would be able to do the necessary research in the university library. In particular, he asked me to carefully examine his recent paper titled "ADynamical Theory of the Electromagnetic Field." I knew I would have to build my skills in partial differential equations and statistics, and I would need to gain some level of understanding of his formulations of the so-called operators "div," "grad," and "curl."

These concepts were the result of his deep thinking about the "shapes" of forces at work when concepts of electricity are joined with concepts of magnetism in ways that Michael Faraday had investigated and published in his 1859 book *The Forces of Matter*. I knew that these concepts would be at the heart of any of Maxwell's future writings on electromagnetism.

I tried, initially without much success, to envision what these terms might mean in describing shapes occurring in a space that had no physical connection with the three-dimensional world I could see with my eyes, touch with my hands, hear with my ears, taste with my tongue and smell with my nose. Maxwell suggested that by envisioning these shapes turning freely in space I would more easily see how to apply the mathematical formulations he had developed.

He believed that Newton had developed his calculus in this way, by envisioning the shapes of the forces that connected the planets. I found this idea of experimentation occurring in the laboratory of the mind rather than in the laboratory of flasks, beakers, sinks, and gas jets profoundly difficult, but I resolved to continue until I got it right was what Maxwell wanted. I knew also that what Maxwell needed if he was to communicate his complex and not-yet-popular ideas to a less scientific public who might sit in judgement on his funding requests, or even to the more scientifically literate members among his professional colleagues who might be persuaded to support his efforts had to be a lot of care and imagination in the preparation of his supporting documentation and presentation materials; ... the story-telling in other words.

One of the many reasons Maxwell brought me into his laboratory was his appreciation for my deep curiosity, almost a match for his own, and my probing intelligence and facility with math. He also knew I was ready to get my hands dirty in the lab. He enjoyed reminding me of the time he came to

visit my family when I was barely six years old. I was down in the mud trying to pull a screaming piglet out from under a pile of wood, where his tiny hoof had gotten stuck, so I could reattach the small animal to his mother's nipple.

When he told these stories in public, especially to his professional colleagues, I could not help but turn away to hide my deeply flushed face.

Maxwell's concerns about education and schooling were limitless. WheneverinGlenlair, he worked tirelessly to establish a school and church. While at Mariscal College in Aberdeen, he had established workingmen's colleges and conducted regular lectures to those who would become engineering aides, builders, mechanics, draftsmen, and administrators. In Maxwell's expansive vision these young men—and as many women as he could entice into the work despite the many obstacles to women working outside the home—would have the responsibility of assembling and maintaining the environment and structures housing the electrical and steam machines that would power the Industrial Age.

His concerns about the need for technical training across the Industrial Age were not limited to the factory floor and the machine shop. He also held regular weekly lectures and hands-on instruction for university students who were then able to build lab equipment and do the lab work and calculations in support of the work of scientists like him.

Maxwell's strength as a scientist, as yet unrecognized by many of his professional peers, lay in his refusal to fully accept ideas that could not be tested. His scientific thinking on electricity and magnetism, for example, was far ahead of most of his colleagues in that they held firm to the concept of a mechanistic, clockwork universe as shown by Sir Isaac Newton almost two hundred years before. Maxwell's testing of the ideas of Michael Faraday, and the frequent electrical shocks he got from wires and gizmos when the testing went awry, gave him profound doubts about this dogmatically traditional view of how the universe works.

Testing Faraday's insights also meant that my mentor must devise the tests and, more often than not, design and build the test equipment in his workshop in order to do testing on new, unorthodox ideas that had never been tested before. Indeed, the equipment for testing the ideas had never been built before.

Ilooked around the little office at the pieces of testing gear that Maxwell brought with him when he leftKing'sCollege, London. Of all of these pieces, I found myself most interested in his color top. This device was a step along the way to a separation and definition of the spectrum of colors contained within sunlight, a step that would lead eventually to his creation of the world's first color photograph.

This photograph would also illustrate his ideas about the electromagnetic spectrum.

Maxwellhad asked me, when Ihad some free time, to look over the draft of his paper "On Reciprocal Figures, Frames, and Diagrams of Forces." I knew that this paper was a step beneath the level of his work on electricity and magnetism. Though the paper applied to his interest in architecture, and the details of building construction, I could not help but think that there was a larger message at hand. This was a method for the formulation—the "forming," if you will—of general solutions to problems involving Newton's "Action at a Distance" ideas that were at the heart of our investigations into electromagnetism.

I cannot help but think that I was very privileged to have been given this assignment. I resolved to never allow myself the luxury of a mistake when I developed my own work on this project or what came to be the many future projects I would undertake.

My working relationship with Maxwell at this time was somewhat complicated by the fact that he was living and working mostly at Glenlair, about eighty miles southwest of Edinburgh. There, he was only partly concerned with advanced mathematics. Mostly, he was engaged with his family in a plan

of architectural work and development on the main buildings of the estate, which was in line with the vision of his father, John, who had died in 1856.

Occasionally, I clamber onto the train, arms full of reference materials and mathematical formulas, to bring to Glenlair because I needed Maxwell's close attention on the solution of some problem. I would also do most of my editing work there, since he was close at hand to consult on test results, wording, and presentation. He would knock on the door of my workroom at the family estate and ask, "Areyou ready to go over your work with me?"

Sometimes Maxwell would return with me to Edinburgh to meet with banks, carpenters, and stonemasons involved with the expansion work at Glenlair. Sometimes he would sit through a peer review of his scientific work and discuss any changes in direction that were indicated by his most recent findings. Occasionally, I went with him to whatever social events might accompany these professional meetings.

Iknow that Dr. Maxwell received a lot of inquiring looks when he introduced me to his professional colleagues who might not have met his wife, Katherine. After all, there were no women enrolled in a degree

program at the University of Edinburgh. His colleagues wondered why he did not choose one of the many very bright, very talented young men in physics or math from the rich academic communities in Edinburgh, or, indeed, from any of the many institutions of higher learning in Scotland.

Also, because I was made more attractive to many of those same young men because of my status with Maxwell, I saw the rather knowing looks I got from older women and men outside the scientific community. Ilong ago gave up being concerned by these provocative, but also, often, rude and insulting social cues.

Whenever in London, Maxwell took every opportunity to meet with Charles Babbage and the aging Faraday to discuss the future of science in this new industrial age — an age based on coal, the manufacture of steel, and the technology of the steam engine, and, of greatest importance to their common interests, the telegraph.

I remember a visit to the Oxford University campus in July of 1862. I and my childhood friend from Corsock, Bethan, had been invited by Maxwell to travel with him to that ancient and prestigious university to attend a summer lecture by Charles Dodgson on the mathematics of Euclid. Rumor had it, according to Maxwell, that Dodgson intended, someday, to put the axioms of Euclid into a Shakespearean theatrical format; each axiom would start a new scene.

Maxwell thought Dodgson's idea was preposterous, but also thought the lecture would give us an interesting insight into the weird, wonderful, and magical mind of Charles Dodgson.

Dodgson was a sometime mathematician, many times a storyteller, always brilliant and totally creative in bringing far-flung ideas into his ambit as senior lecturer in mathematics at Oxford. His skills as a mathematician were not stellar, and due to his stuttering, his ability to present and lecture was erratic at best, but he fashioned wonderful and fantastic characters, figures, and situations to bring dimensions, color, smells, and life to his narratives. In the lecture we attended, he sprinkled references to hookah-smoking, talking blue caterpillars; disappearing Cheshire cats; waist coated white rabbits; and officious dodobirds with abandon.

Maxwell believed there was a connection between heaven and earth, and he had dedicated his life to finding it. Despite the Scottish conservatism in his point of view, Maxwell sometimes let his mind wander along the pathways suggested by Dodgson's imaginative creatures and fantastic events. Maxwell had other business with Babbage and Faraday in Cambridge and London on this trip, so he excused himself after the Dodgson lecture to catch a train for the sixty-five-mile trek to Cambridge.

Despite his fairly clumsy presentation, Bethan and I decided to see if we could get some time

face-to-face with Dodgson. We knew little about him except for the interesting stories that Maxwell had told us.

After the lecture, we approached Dodgson with a couple of carefully thought-out questions, but before we could pose them, he immediately invited us to join him and some of his friends on Oxford's rowing ponds. His friends included H.J. Liddell, dean of Christ Church, Dodgson's College; Liddell's wife, Lorina; and their daughter, Alice.

As an after thought, Dodgson invited one of his bright young freshmen in mathematics, Sean McCabe, who had attended the lecture, to act as our guide and interpreter.

Sean was a nice young man, but he seemed very shy. When he introduced himself to Bethan and me, he stuttered as well. "H-h-hello. M-mmy name is Sean. I'm-m-m happy to meet you."

I had been working to take the hard edges off the deep Scottish brogue I inherited from my parents and our surrounding farming community, but it was still strong enough that I could nothope to fool a member of the English upper class like Sean. Because Sean stuttered, however, I hoped he would be sympathetic to my difficulties with speech and dialect on the grounds of this most traditional of English institutions.

We introduced ourselves and walked together to the boating ramps.

Later, as Sean stepped away to speak with someone, Bethan turned to me and whispered, "Sean is a very nice-looking young man. Do you think he will someday get over his stutter and his shyness?"

"Yes, I think so. Perhaps he stutters because his mentor Dodgson stutters," I replied.

As the day on the rowing pond evolved into an afternoon of tea and conversation, I took note of Dodgson's fondness for the young Alice. She was not more than ten years old, but very pretty, charming, and quite mature for her age.

"They seem quite infatuated with each other," I said to Bethan as we looked upon Dodgson and Alice. Dodgson had found a deep hole among the roots of a large tree near the stream, where rowers passed by in their punts. Alice leaned over to look into the hole, and it looked for an instant that she might fall in. Dodgson caught her by her waist and pulled her back out. She looked at him and began to giggle.

Dodgson stepped a few paces away and sat on a nearby bench. He looked toward Alice, then motioned for her to come over. He pulled a set of loose notes out of his satchel. She sat down beside him as he began to read to her the story that would become *Alice's Adventures in Wonderland*.

"Look at the father," Bethan said. "He seems a little uncomfortable with their behavior."

I looked in the direction of Alice's parents for a moment. "But not so much that he wants to try to break it up. I wonder what's in that manuscript."

"Maybe more strange caricatures of Mother Goose rhymes or the Brothers Grimm or Hans Christian Andersen fairy tales, like in his lectures."

I turned to my friend. "Before we decided to come down here, Dr. Maxwell told me that, in addition to the business at Cambridge, the other reason he wanted to come down to Oxford was that Dodgson had been working on a book of fantasy, and James thought I might enjoy meeting Dodgson. He told me to think of the trip as a bonus payment for the editing and testing work, I have been doing for him on the equations. I am glad you decided to come with me, Bethan."

"I'm very happy you invited me to come with you, Eirian. Thank you." We held hands for a moment, then Sean returned and suggested that they join the others for refreshments.

When I asked him about the nature of Mr. Dodgson's planned manuscript, he explained that Mr. Dodgson was writing a book of fantasy that featured the girl. "He is concerned about her reaction to it," Sean said, "so he reads from it, to her, at every opportunity."

The recently published writings of Michael Faraday were also important to me at this time, though not because I was personally interested so much as because my mentor insisted that I become familiar with it. In Faraday's lab work in the 1830s, he had developed ideas and demonstrations around the concept of fields of force such as those that curve to connect the positive and negative poles of a bar magnet. These lines of force can be persuaded to show themselves by laying a piece of paper over the magnet, sprinkling some iron filings on the paper, then lifting slightly and lightly shuffling the paper while moving it around above the magnet.

During the shuffling, the filings fall into the curved lines that represent current flow — the force fields between the two poles of the bar magnet. These curved lines represent action at a distance; in other words, the action of one object transmitted to another object without an obvious connecting medium. Understanding these lines of force and the methods of transmitting force from one object to another across what appeared to be empty space were very important to all the work in electricity and magnetism being done and described by Maxwell himself.

Faraday's findings established the basis for the concept of the electromagnetic field in physics. These studies in turn had evolved into the electromagnetic spectrum that Maxwell had investigated and further developed with methods in advanced calculus while a department head at King's College.

Further development of these concepts was now Maxwell's life's work. Testing, documentation, and publication of these findings would consume much of my time over the next few years.

As I previously stated, Maxwell had asked me to focus on the mathematics of statistical methods. When I asked why these methods were important, he replied that he was trying to account for the actions of individual molecules in agas.

"Obviously, such molecules, in their billions, cannot be counted or tallied like children through a turnstile," he said, "so there must be some other way that satisfies, or comes close to satisfying, the rigors of mathematical formulations without the work of some kind of tally counts that would be enormously expensive.

"I have envisioned a thought experiment where there is a chamber with a permeable membrane separating a gas that is cooler from a portion of the same gas that is warmer. Imagine there is some kind of a mechanism that acts like a gatekeeper, judging each molecule according to its temperature in comparison with the average temperature of all the cool molecules.

"If the temperature of a molecule of cool gas contrasts with the average temperature of all the molecules in a way that lets it cross the membrane, then it will have the effect of cooling the average temperature of the molecules of warm gas."

He rubbed his chin. "Of course, the gatekeeper works the same way on the warm side, except it is judging a single molecule in terms of the average temperature of all the molecules on the warm side. One of my general questions is: How would we design a statistical method to help determine within some range of error how much time must pass until the temperature of the cool side of the membrane matches the temperature of the warm side? What are the attributes of that method, of that gatekeeper?"

My mind had begun to spin. I remembered one of Dodgson's stories in the lecture hall at Oxford two years ago last July, about the blue caterpillar sitting atop a mushroom, and how he had become so pontifical. In my mind I could see the caterpillar smoking his hookah, sitting in judgment of the temperature of a particular gas molecule when compared with the average temperature of all molecules of the same gas. Somehow it seemed an appropriate image.

"It seems almost demonic," I thought aloud.

"Do you mean like a 'demon,' Eirian?" Maxwell asked, rhetorically.

I didn't respond. The answer seemed a little too close to a truth that I was not yet ready for.

Maxwell, however, moved on. "Can you craft some methods that integrate changes in temperature and pressure over time for the gases on both sides of the membrane, and then link these changes to the numbers of molecules that must pass through the membrane in order to achieve equilibrium on both sides?" he asked.

Despite my muddled head, I must have mumbled that I would domy best, as I was soon put on the case.

In later years, of course, the "gatekeeper" membrane between the warm and cold quantities of gas became known, among scientists as "Maxwell's Demon."

Soon after our discussion on the movements of gas molecules, I asked Maxwell to describe his equations of electricity and magnetism and what exactly he was trying to measure.

"Of course," Maxwell replied. "I'll put them on the board for you." He hastened over to the blackboard and snatched up a bit of chalk.

"Start by thinking of things that float or move in space without any visible connection to the ground, or to any other nearby physical object," he said. "Your imaginary object could be a hot air balloon, an arrow in flight, a cloud, or a puff of smoke. The question is: what force or forces causes each of those objects to change? In the balloon you might think the gradual loss of heat would eventually cause it to collapse and fall to the ground. The arrow will eventually fall from the sky, but from what cause? The airitmust push against. The speed it will lose with time as it flies.

"How about the cloud? What causes the cloud or the puff of smoke to change its shape or its color? Is it the sun? Is it changes in the cloud's moisture content? Is it the pressure of the changing wind? Actually, it is probably all of those things in some complex and unmeasurable combination."

He paused to gather his thoughts. "Think about the clouds again. This time think about the dark, windblown thunderclouds in the late spring. Of all the things that are roiling about inside the cloud, what will cause the tornado spout to drop to the ground, or the lightning to come down from the cloud to strike the ground, possibly catching something on fire, or even killing some person or animal? The power of that lightning bolt, the force of it, the heat of it, and the bright flash of light can all be measured over time using Newton's calculus, and an extension of that calculus called a 'vector,' which has measurable values for both direction and force.

"Now think of a bar magnet that you move slowly toward a piece of metal plate. Depending on the size of the magnet, you might not be able to ultimately stop it from hitting the metal and sticking to it in a way that may be stronger than your ability to pull it back.

"The power of that magnet, the force that draws it inexorably to the metal plate — like the lightning bolt, but without the flash, the noise, and the drama — can be measured over time using Newton's calculus, and the same vector extension, but with a math that works for magnets.

"To link an electric force and a magnetic force to create an electromagnetic force with a given magnitude, you must use the partial differential equations that I have developed while at King's College."

Maxwell then took me through a deep thicket of calculus. In that way he hoped to get me started on a path to a true understanding of his work. I scribbled furiously along behind him.

At the end of it he finished with: "Curl H can be read as 1 over the constant c-c, Eirian, is defined as a gearing ratio between the E and M force — times the change in E over the x, y, and z axes over time.

"I'll assume you have got all that," Maxwell said. "I'll emphasize the fundamentals once again, just in case."

He turned away from the blackboard and winked at me.

"The terms 'div,' short for divergence, and 'curl' are ways of representing how the forces E and H—the EM force I mentioned earlier—vary in the space immediately surrounding the point of our inquiry. Div is either more outwards than inwards, and is called div greater than zero, or more inwards than outwards, and is called div less than zero. Curl, on the other hand, measures the tendency of the force to curl, or loop, around the point of inquiry, and gives the direction of the axis about which it curls."

Maxwell sat down in a chair facing me. I felt more than saw this as my head was down as I quickly tried to capture all the insights into the magic of electromagnetism that Maxwell had so willingly and effectively given me over these past few minutes. When I realized he was watching me intently, I stopped my scribbling and looked at it. The page was an overwhelming maze of numbers, letters, and signs I felt I could lose myself in.

"I don't know if I will ever understand this," I said, resignedly. "Don't feel alone in that," Maxwell said. "I don't think that either I or Faraday have a deep enough understanding of these forces to explain them well, even to those of my professional colleagues who believe, following Newton, that the universe is a finely tuned machine. Newton's comforting machine is very much like a Swiss watch—a machine with gears and winding mechanisms and hands to show the time, each connected one to the other with no empty space between.

"Faraday and I are talking about those spaces, the empty spaces where the power of these forces of electricity and magnetism reside and do their work. To proceed from a lifetime of belief in a clockwork universe to a universe where forces work at a distance with nothing connecting one object to another is hard for anyone to grasp, scientist or not.

"The introduction of these ideas of field and of actions at a distance disconnects the forces of the universe from the movements of the objects these forces are thought to influence. Our case will be a very difficult one to make in the face of such thinking, entrenched as it has become.

"Even so," he continued, "it will be your job to carefully watch and record the details of my experiments with electricity and magnetism. Then, though I won'trequire it of you, I'dlike it best of all if you would at least try to repeat them without any guidance from me, to see if you can get the same results.

"Whether you try to do your own tests or not, your final task for me on each experiment will be the preparation of text and illustrations describing each of the experiments as you saw them. Expect my very careful review because it is in these descriptions that we may all find the best way to present our findings on electromagnetism to the very large group of my skeptics in the scientific community."

And so it is that I found myself in January 1866 that I find myself working at Glenlair. Charles Ludwig Dodgson, whom Bethan and I met at Oxford in 1864, published a book titled *Alice's Adventures in Wonderland*. He published the book in November 1865, using the penname Lewis Carroll. Maxwell alerted me to the publication and asked if Bethan and I would like to travel to England in March with him and his wife.

"I will be at Cambridge, but I can make travel arrangements for you both to go to the Oxford campus for a day or two," he said. "Perhaps you can meet with Dodgson there and have him autograph his book for you. Then you can come down to Cambridge to join Katherine and me for dinner with some friends of ours."

Maxwell said later that he thought he saw an actual glow in my eyes. In any case, he noted that I did seem briefly incapable of speaking.

"Oh, thank you, Dr. Maxwell," I said, once I'd recovered. "I am overwhelmed by your kind and generous offer. Are you sure?"

He smiled at me, so I did not wait for an answer.

"Imust go today to discuss this with Bethan. We have so many things to prepare for before we leave!"

Before returning to Glenlair, Maxwell, his wife Katherine, Bethan, and I were invited to a London dinner party at the house of Maxwell's longtime mentor and friend, Michael Faraday. According to Dr. Maxwell the party would honor Benjamin Disraeli. Though not yet resolved, the collapse of the Gladstone government was virtually assured. Gladstone, a bitter enemy of Disraeli, would clearly be dispatched from office, along with his liberal party in the upcoming elections of June 1866.

Disraeli was now sixty-one years old. He was a friend of Queen Victoria, a novelist, a member of Parliament, and a continuing supporter of Tory governments and politics. He would soon be appointed chancellor of the exchequer, and Conservative leader of the House of Commons in the third minority government to be organized by Lord Derby, a Tory, as soon as he was sworn into office.

The dinner took place at Faraday's home in Hampton Court, Middlesex. Though without formal education beyond the eighth grade, the elderly Faraday had been greatly honored by his scientific peers and by Queen Victoria herself. He had been offered an opportunity to be buried at Westminster Abbey among the resting places of England's royalty, but he refused, preferring to remain with the common man even in his final resting place.

In fact, this particular get-together was Queen Victoria's idea in the hopes of exposing the conservative and sometimes prickly Disraeli to some liberal thinking in advance of the coming change of governments. The choice of other guests at the party, the queen suggested, would be up to Faraday.

Faraday had been living in Middlesex for the seven years following his retirement. When told of my visit to hear a lecture by Dodgson, Faraday insisted that I invite the man and whoever else might be good company for him. Charles Babbage, another of Faraday's guests, had recently read Dodgson's new novel. He expressed delight at the prospect of his joining us at dinner.

"Dodgson's novel is the talk of London," Babbage said. His eyes were all aglitter at the thought of Dodgson with his stumbling speech arguing with the articulate Disraeli about the parliamentary intrigues of the day. Apparently, when he thought of Disraeli parrying Dodgson's literary wit with some parliamentary and political fantasies that Disraeli would try to promote, Babbage could not restrain himself and broke into gales of laughter.

At one point, Babbage even excused himself to go to another room where he gave in to bouts of uncontrollable laughter and fits of coughing. Other members of our dinner party began to worry about his health, but he returned after a few minutes, waving away any health concerns.

"I apologize to my host for my behavior. I hope you will all forgive me for my ill-mannered behavior regarding a guest who may not be as fully articulate as others of us. Please trust me when I say that it is not the impediment that I find comical, nor the speaker, whom I admire and consider a friend and professional colleague in mathematics. The problem is that I imagined the sounds and conversational tension such a debate would carry to the rest of us. It tickled my funny bone, and my imagination got the better of me."

Though I found such a joke odious in its humor, I nodded my approval of his conciliatory remarks along with the other dinner guests. We all turned back to our conversations.

Shortly after, an aide to Faraday, acting as butler, announced the arrival of Charles Dodgson and Sean McCabe of Christ Church, Oxford. All

of us rose to congratulate the new author on the publication of his very successful first novel. Though we had all been together on the Oxford campus over the past two days, Bethan and I approached Sean and asked that he join us at the table when convenient after introductions.

"Th-th-thank you," Sean said. "I will join you sh-sh-shortly."

In an aside to Bethan on our way back to the table, I noted that Babbage would not find the speech problems of the guests so entertaining if we reminded him of his many crusades against minor issues of minimal public interest.

Sean had told us of Babbage being denounced during debate in Parliament two years ago for "commencing acrusade against the popular game of tip-cat and the trundling of hoops."

The issue was a serious one having to do with interference with traffic along crowded roads, and with frightening horses pulling carriages into public rights-of-way. But the tabloid press in London has, historically, liked to bring public celebrities down to size with humiliation. They are always looking for targets. They picked up on the issue of 'trundling of hoops' from the parliamentary debate and turned it into a riotous play on language. This had caused Babbage to become a laughingstock — one that I was feeling at the time, with righteous anger on the behalf of my friend, was well deserved.

We waited patiently while Sean explained all this in his halting voice. He was very grateful to us for our kind of patience with his speaking. As a matter of fact, we were both wonderfully entertained by the way Sean manipulated his speech defect into comedic descriptions of the popular news of the day.

I privately noticed that Sean's speech improved as he spent more time with Bethan. When I asked her about it later, she gave a coy smile and said, "Why, yes. Sean's stutter seemed to go away after a while. I think the stutter is only really there as long as he is under the spell of Dodgson. He is really quiet an unusual young man."

"I am delighted to hear it," I said.

The next day, we Scottish travelers began our three-day journey back to Glenlair and Corsock. We all agreed that it had been a wonderful trip. The stories we could tell about all the wonderful people we met and the events we participated in would last us the rest of our lives.

I was mulling over the ideas in the book *Alice's Adventures in Wonderland*, though I was not sure I could see any value in them that would benefit my work for Maxwell. I did love the book, though, and all of the fantastic imagery and wordplay in it. I resolved to keep thinking about ways to link the magic of the Cheshire Cat or the Mad Hatter or the March Hare to the hard realities of Newtonian math.

Maxwell would later share with me all of the things he had been told in his business meetings at Cambridge. The university wanted him to have a leading role to play in the rapidly emerging sciences of the Industrial Age. The development of new industrial materials and sources of energy were moving fast across all of Europe, and Cambridge wanted to build a science laboratory worthy of that role.

More important to Maxwell, they recognized his lifelong dedication to all aspects of science and, in particular, his collaborative work with Faraday to perfect the scientific understanding of electromagnetism. The leaders, statesmen, and financiers putting the project together proposed to hire Maxwell to build and runit. It would be called the Cavendish Laboratory, after our nation's acclaimed chemist and physicist Henry Cavendish.

"James Clerk Maxwell will build the lab, and, once built, he will become the first Cavendish Professor of Physics," they said. "If, of course, he decides to take the job."

But first, Maxwell had an obligation to his beloved father, John, to complete the expansion of Glenlair. Other than our work together, there would not be much new science at Glenlair during the next few years.

Katherine, Maxwell's wife, an accomplished scientist in her own right and indispensable helpmate, was not at his meetings at Cambridge in 1866, but she confided in me later that she could see the

faraway look in his eyes. She knew that big things were brewing, as they always were with her husband, and she would find out more about them in due course.

Maxwell spent the rest of his life developing the Cavendish Laboratory, particularly the pioneering physics labs that would move physics out from under the unbending intellectual influences of pure mathematicians and into the hands of experimenters like us, in materials, objects, light, and the fundamental forces of nature. I stayed in his employ the entire time, helping with the design, development, contractor management, and high-level staff recruiting through the Cavendish opening in 1874 and his appointment as first Cavendish Professor of Experimental Physics.

Maxwell died in 1879. Because of my deep association with him over somany years and my deep understanding of his work the Cavendish has kept me on until now, as a teaching and lab associate.

But I feel it in my bones. Each winter, even if it is one of these puny, balmy English ones, is harder on them. It is time to enjoy the spaces in between, while there's still time left to do so.

As I finish packing, I consider seeking out the beautiful, bluish violet stone that held a special place on Maxwell's most favored library shelf in his office, wherever that office happened to be. Perhaps the stone is just down the corridor, fallen behind a cabinet or stacked between two books, as had been my beloved "Flyology."

Many visitors commented on its' rare beauty. No one had ever seen a stone like it. When asked about the origins of the stone Maxwell had to beg ignorance. It had been given to him by a neighboring family of wealthy sheep herders in Corsock in celebration of his Cavendish appointment. They had held the stone for several generations after the founder of the family's fortune had acquired it from the owner of an art studio partner of Leonardo da Vinci in Florence during the early years of the Renaissance.

That is as much as anybody knew, or knows, of the stone's provenance.

But I am sorry to say, my wish to find the stone is not to be. The stone disappeared shortly after Maxwell's death, lost, it was thought, in the general scramble to gather all of his scientific papers for safe-keeping.

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