Introduction

Charles Darwin and the *Origin of Species*

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Charles Robert Darwin was born on February 12, 1809, the same day as Abraham Lincoln across the Atlantic. He died on April 19, 1882. Unlike the future president, there was no log-cabin birth for the man who is known as the "father of evolution." The Darwins were an upper-middle-class family living in the town of Shrewsbury, in the British Midlands. Charles's father Robert was a physician like his father, Erasmus. In those days, physicians were university-educated men with significant social status. Robert Darwin was also a very canny money man, acting as a link between aristocrats, with money needs and land to mortgage, and the new crop of businessmen being produced by the industrial revolution, looking for safe places to park their cash. But the real source of Darwin's wealth came from his mother's family. Charles's maternal grandfather Josiah Wedgwood was the founder of the pottery firm that bore his name, and had become one of the richest magnates of his day. Charles further secured his financial independence when, in 1839, he married his first cousin, Emma Wedgwood, the daughter of Josiah's oldest son, also called Josiah Wedgwood.

Early Years

The background and the money tell us much about Charles Darwin and his place in British society. He was not an aristocrat, but he was a gentleman, with a very secure background and expectations. As a child and grandchild

of the world of business and technology, he would be properly educated, starting with one of England's leading private schools; he was going to be committed to a world of change but not revolution (manufacturers appreciated societal stability); he would be liberal in a nineteenth-century sense, which meant being strongly against slavery but prepared to let the working classes labor for minimal wages as the political economy of the day demanded; and he probably would be religious but not obsessively so. The Darwins were Anglicans, something important where the elite English universities, Oxford and Cambridge, were concerned because membership in that state church was a necessary condition for graduation. The Wedgwoods were "dissenters" or "nonconformists," being Unitarians, which meant that they believed in God but denied the Trinity, thinking Jesus just a good man and not divine.

Charles was the fourth of five children. Although his mother died when he was young, his childhood was happy, with two older sisters taking charge of the care of their younger siblings. Father Robert was a large and rather forbidding person, but Charles respected him greatly. As a child, Charles did not seem particularly gifted academically, perhaps excusable in a world where education consisted of huge amounts of translation from and into Greek and Latin, interspersed with solving geometry problems from Euclid. But he was fascinated by the world of nature, and living in rural Britain was ideal training for a future naturalist. This was helped by frequent visits to Maier Hall, the home of the Wedgwoods. Uncle Josiah was a man of learning and understanding, a great favorite of the whole Darwin family. As Darwin got older, his visits with the Wedgwoods included learning to ride a horse and to become a good shot with a hunting rifle, which were skills that served him well in unexpected ways later in life. No one could have then imagined that he would someday be a provider of fresh meat to a ship's crew camping out on the unpopulated shores of South America or ride across the wild pampas of Argentina with gauchos as companions.

After school days, Charles was packed off to Edinburgh University, then one of the great European centers of learning, to follow in the family tradition of medicine. It was not to be. Young Darwin (he was only seventeen when he went north) hated the operations he was forced to watch. Even more he hated having to rise early to listen to dry old Scotsmen lecture on dry old subjects. After two years he had had enough. But the time in Edinburgh was far from wasted, for Darwin now was starting to get serious about natural history, mixing with people more learned than he, includ-

ing Robert Grant, who had unorthodox ideas about the origins of species. His activities at Edinburgh included attending a natural history course that gave him an introduction to geology and paleontology, hanging out at the natural history museum to talk to the director and look at the collections, and being tutored by John Edmonston, a freed slave from the West Indies, on how to prepare bird skins. Grant mentored Darwin on his first research project, which was to describe the free-swimming larvae of a marine invertebrate. Darwin also joined the local student science club, the Plinian Society, and attended some meetings of the professional Wernerian Natural History Society. He got his first introduction to the ideas of some of the great natural scientists of his day, including Georges Cuvier, Etienne Geoffroy Saint-Hilaire, and Jean-Baptiste de Lamarck. He also studied his grandfather Erasmus's eighteenth-century writings, in which he joined Lamarck as one of the earliest proponents of evolution.

There was no question of Darwin now switching into a program of biological studies, as do so many present-day premedical students who were initially fulfilling their parents' desires rather than their own. Although there was enough family money that he would never need to work for a living, it was not part of the Darwin-Wedgwood creed that young men should grow up idle, although Darwin's slightly older brother Erasmus did precisely that, living the life of a London gentleman of leisure.

After serious family discussion, Charles Darwin was redirected toward the church—that is, toward the prospect of becoming a parson in the Church of England. There was a certain amount of cynicism in this from Robert Darwin, for it is clear that religious belief lay lightly upon him, a polite way of saying that he was an atheist or near. Charles at this time however believed in conventional Christianity, being even a bit more of a literalist than most of his set. However, the main attraction of parsonhood was not strictly theological. It was a respectable profession for a gentleman, especially one of private means who could thereby supplement his income and afford a curate to do much of the daily work. A parsonhood could leave one with abundant free time and provide an excellent forum for pursuing an interest in natural history.

Entry into the church as a man of the cloth demanded a degree from Oxford or Cambridge, and so in 1828 Charles Darwin was packed off to Christ's College, Cambridge, where he was to spend three very happy years. A university education in those days was like Darwin's earlier training—devoted to classics with a bit of mathematics mixed in, unless one was brave

enough to pursue an honors degree, which Darwin was not. However, when Darwin arrived at Cambridge, things were beginning to change. There was a growing interest in science. Although there were few courses in science, there were a number of professorships. To this point, most holders of the posts had simply enjoyed the perks but felt little need to do anything. Now these professors were taking their responsibilities seriously. Adam Sedgwick, professor of geology, John Henslow, professor of botany, and William Whewell, professor of mineralogy, were uniting and creating a space for empirical studies, although it was not until the middle of the century that they managed to get degrees in scientific subjects incorporated into the university curriculum.

It is clear that these reformers were talent spotting, and when the young Darwin appeared on the scene—sharp, ambitious, well connected—he was welcomed into the group. He was invited to evening socials with professors and was able to interact with them one-on-one and gain tutoring beyond what would come in the lecture hall. For three years he attended the lectures of John Henslow, the professor of botany, becoming his pet pupil. He pursued natural history during his abundant free time, and became a fanatic for collecting beetles. During the summer after graduation, he took a walking tour through Scotland with Adam Sedgwick and received a two-week crash course in the practice and theory of geology. Above all, he was taken under the wing of one of the most remarkable men of his age, William Whewell (pronounced "Hule"), who was later to make the peculiar switch from being the professor of mineralogy to become professor of moral philosophy and later the most powerful man in Cambridge, as the crown-appointed master of Trinity College. Whewell wrote mathematics textbooks but already he was planning his magni opera, the three-volume *History of the Inductive Sciences* (1837) and the subsequent two-volume *Philosophy of the Inductive Sciences* (1840). Knowledgeable about everything, Whewell lectured everyone on science, its history and its methodology. Also, it was he who urged Darwin to read what was to become a very popular handbook on the nature of science, *A Preliminary Discourse on Natural Philosophy* (1831) by the astronomer-philosopher John F. W. Herschel. In those days, "natural philosophy" was what we call science. "Moral philosophy" was what we call philosophy. Some British universities still use the old language.

Darwin, who was now a tall and strong young man, was obviously popular with his fellows. Much of the university time was spent most enjoyably—riding, dining, playing at those things that occupied young men of his class.

But it is clear that he was starting to mature intellectually and to show the drive so typical of his class and background.

The Beagle Voyage

By 1831, when Darwin graduated from Cambridge, he was already half-trained as a scientist and recognized as an up-and-coming young man, from the right sort of background and with both talent and enthusiasm that recommended him to those with authority and influence. It was therefore fortuitous but perhaps not too surprising when Darwin was offered the chance to join a British warship, HMS *Beagle*, that was about to set out to South America with the charge to bring home much-improved maps and charts. Being captain of such a ship was an awesome task and a lonely prospect—one was of a social class separate from all others and with the responsibilities for the ship and its crew, not to mention the assigned tasks. Robert FitzRoy, the captain (and incidentally an aristocrat, a nephew of the former foreign secretary Viscount Castlereagh), was but twenty-three. He was looking for someone, a gentleman rich enough to pay for his own board, who would come along as a kind of captain's friend. Darwin's father initially opposed the voyage because he was reluctant to keep spending money on a son who seemed always to be putting off getting a real job. Uncle Josiah persuaded Darwin's father that the voyage was an opportunity that should not be missed. Charles joined the ship, but not as the ship's naturalist; the surgeon doubled as the official naturalist, as was often the case on such voyages. Darwin's talents and enthusiasm soon gained the attention of the captain and, as the captain's companion, gained him special favors and attention from the crew. The official naturalist resigned early in the voyage in protest of Darwin's favored treatment.

Much of what naturalists did in those days was collect, preserve, and catalog to create a record of expeditionary travels. Darwin spent the whole of the voyage, which stretched for some five years, from 1831 to 1836, making massive collections of rocks, plants, and animals, and at the same time studying and theorizing on the magnificent world unfurling before him. Because Darwin came officially as the captain's companion and was paying his own way, all his collections were his own, rather than the property of the Royal Navy. These valuable collections were his calling card to enter the world of science after he returned to England.

Darwin became as popular with the officers of the *Beagle* as he had been with his contemporaries in Oxford. Many of the officers shared his interests in natural history and were making collections of their own. Darwin's diverse activities and broad knowledge of natural history and geology earned him the nickname "Philos," or the philosopher, and he was sometimes referred to as the man who knew everything. His marksmanship and riding ability also made him one of the providers of fresh meat when the *Beagle* moored and the crew spent time on land in thinly populated parts of South America. When at sea, Darwin continued to pursue natural history, but also helped provide food with the trawls and fishing lines that he used to sample sea life. Hunting and natural history were two sides of the same coin.

Although Darwin was ecumenical in his tastes and interests, his central scientific motivation was geology. Geology was a very trendy science at the time, with significant industrial applications: no investor wanted to sink a shaft in a part of the world that would not yield coal or other valuable minerals or natural products. By one of those strokes of extreme good luck—Darwin tended to be lucky; his genius was to take advantage of it—just as the *Beagle* was setting off, the Scottish lawyer-turned-geologist Charles Lyell published the first volume of what was to prove a lasting and respected vision of the geological history of the earth. FitzRoy presented Darwin with this first edition as a gift just before the *Beagle*'s departure; it was a measure of the interests they would share on the voyage.

In his *Principles of Geology*, Lyell argued for what Whewell was to call "uniformitarianism." Lyell proposed that forces of a kind and intensity that we see about us today caused all the geological features of the earth. Wind, rain, deposition, erosion, earthquakes, and the like can do everything, including build mountain ranges, excavate canyons, or carve seaside cliffs from a sloping coastline, given sufficient time.

Lyell also argued for a steady-state view of the earth's history. Thus he opposed more traditional geologists like Sedgwick who embraced what Whewell was to label "catastrophism," or the belief that the earth's history was punctuated by times of extreme upheaval, and that the planet was changing progressively as it cooled from a molten state to its present form. Lyell realized that the evidence did not speak directly to a steady-state view—there are fossil palms around Paris suggesting that the climate was once much warmer—and so to defend his thinking Lyell introduced his "grand theory of climate." Apparently the earth is a bit like a water bed; some parts of the surface that are now dry land were once under the sea,

while others that are now inundated were once dry land. Hence, distributions of land and water are always changing, which affects ocean currents and climate. England today is warmer than we might expect of its latitude, which is the same as that of Hudson Bay, Canada, where polar bears roam. The British can thank the Gulf Stream for their mild weather. In a similar fashion, historical changes in landmass distributions and ocean currents account for historical changes in climate.

Darwin was seduced by Lyell's easy prose and subtle arguments and was soon converted to Lyell's principles. At the very first landfall of the *Beagle*, at St. Jago in the Cape Verde Islands, he saw rocks bearing fossil shells similar to animals that could still be found living along the shoreline, but the fossils were well above sea level. He inferred that land that had once been under the sea had been elevated above the waterline.

Darwin spent the whole of the *Beagle* voyage looking for further evidence of Lyellian processes. Indeed, it was through this dedication to Lyell's ideas that Darwin made his first great scientific move, which ironically was to propose a different explanation from Lyell's for the origin of coral atolls. Lyell had argued that these curious rings of coral reefs in the middle of the ocean were simply the tops of extinct volcanoes peeking out above the waves. Darwin thought it highly improbable that so many volcanoes had all reached exactly the height of the sea surface. It seemed much more likely that the tips of the volcanoes once emerged from the ocean, then sank back into the sea as the land beneath them subsided. The reefs formed as the coral grew ever upward from the subsiding volcano. Coral can survive and grow only in shallow water. Darwin may have disagreed with Lyell's proposed mechanism for the formation of coral atolls, but he used Lyell's principles to develop his alternative. Lyell very much appreciated Darwin's initiative. Darwin has proven to be correct.

Darwin's conversion to the Lyellian perspective fit in with changes that were happening in his religious convictions. There was no road-to-Damascus experience in reverse, but the Lyellian emphasis on causes operating today as the clues to causes operating in the past was clearly one of the factors leading Darwin to question the authenticity of miracles. Miracles are causes that lie outside our day-to-day experience. As his belief in these started to go, so did Darwin's belief in Christianity. Of course, today no liberal Christians takes seriously stories about turning water into wine, but Darwin's faith was especially vulnerable here. A standard text read at that time by all students at Cambridge was *The Evidences of Christianity* by Archdeacon William Paley

of Carlyle. Paley's proof of revealed religion was simply that the disciples who suffered unto death for their faith would not have done so had the miracles been inauthentic. For Darwin, with the miracles so went the faith.

This does not mean that Darwin became an atheist. This never happened. But his beliefs did start to move in the direction of a God as unmoved Mover, one who set the world in motion and who then achieved everything through unbroken law. This was a popular position among intellectuals at the end of the eighteenth century, especially those denying the divinity of Christ, and hence the miracles attributed to him.

An important by-product of Darwin's switch to uniformitarianism is that suddenly a question like the origins of organisms is transformed. In moving toward evolution, you are moving toward denial of the miraculous origins of life. But no longer are you cutting against your philosophy and your religious convictions. Your God now is one who works through unbroken law, rather than individual acts of creation. Showing that all plants and animals have a natural origin, meaning an origin that is a function of unbroken law and hence not supernatural, is a proof of your God and a testament to His great power. Tie this in to the fact that Darwin came from a family of industrialists, who saw their great achievements as doing with machines (which function in accord with the natural laws defined by Newton) what previously had been done by hand, and the recipe is virtually complete. Charles Babbage, the inventor of a kind of proto-computer, was then showing how he could program his machine to do the same thing a million times, then on the million and first do something else, and then back to the original for all time. Babbage was explicit in his claim that this was the right way to consider miracles—unexpected yes, outside of law, no.

As with religion, however, there was no immediate road-to-Damascus experience leading to Darwin's theory of evolution. It is only the cumulative effect of all that he saw during the voyage and what he learned after his return to England that can be credited with his conversion.

Much of the time that the *Beagle* spent around South America (four years in all) found Darwin engaged in regular activities of sampling wildlife in the ocean or collecting and traveling on land. He was often terribly seasick, and there was limited attraction in staying on board as the ship moved slowly up and down the coast taking readings. The geology and land life of South America beckoned, so he organized expeditions to the mainland while the *Beagle* did its surveying. He made some long, and at times thrilling, trips into the interior.

In an early outing, he spent May and June 1832 in a cottage on Botofogo Bay, near Rio de Janeiro. The equipment that he brought along on his daily trips into the rain forest reflected his diverse interests. His tool kit included a geology hammer, nets, shotgun, and pistol. Guns may seem an odd accessory for natural history studies, but a priority then was to collect and preserve specimens for storage in museum cabinets and eventual study. Darwin described his natural history studies as being very much like a hunting holiday. His experience as a beetle hunter was a key to his success, since he was well schooled in the virtues of turning over stones, peeling bark, and pawing through leaf litter. One early passion was colorful flatworms. Others were bioluminescent insects, butterflies, moths, beetles, and spiders.

During his time in Brazil and throughout his travels, Darwin remained faithful to the rigors of field science. He identified whatever plants, animals, and fossils he could from the *Beagle*'s library and got his brother Erasmus to send more reference books during the voyage. He kept detailed journals and properly preserved and cataloged all specimens. He remained in constant contact with the outside world through correspondence.

In September 1832, the *Beagle* rounded the headland of Punta Alta, near Bahia Blanca, Argentina. Men on board spotted bones and shells eroding out of the banks on the shoreline. The ship anchored for a week while Darwin and the crew excavated fossils. The fauna, represented in what Darwin described as 200 square yards of beach, included gigantic mammals in the size range of a rhinoceros or elephant. They included giant ground sloths and a glyptodont, which was like a giant armadillo. Darwin identified some fossils with use of the *Beagle* reference library and found that one, a *Megalonyx* or *Megatherium*, had been identified by Georges Cuvier thirty years earlier. A remarkable feature of these fossils, other than their size, was that they were all clearly related to the much smaller sloths and armadillos still found in South America. Darwin augmented this collection of fossils with others obtained throughout the voyage. They were Darwin's "in" to meet and collaborate with Richard Owen after he returned to England. Owen's monograph on the fossils of the *Beagle* voyage was awarded the Wollaston Medal from the Geological Society in 1838.

Darwin made five trips across Argentina and Uruguay, often in the company of soldiers or gauchos. These travels were during Indian and civil wars, through a countryside that was at times populated by soldiers, of whom Darwin said, "I should think such a villainous, banditti-like army was never before collected together" (Darwin [1860] 1962, p. 70). He traveled up the

Santa Cruz River, through the barren plains of southern Argentina, with Captain FitzRoy and a company of men from the *Beagle* (where they were shadowed by the local Indians), with the unfulfilled hope of reaching its headwaters in the Andes. He rode through the dense, temperate rain forest of Chiloe Island, off the coast of Chile, and later through the Portillo Pass, from the Pacific to Atlantic slopes of the Andes, then back again to the Pacific slope through the Upsallata Pass. He saw how the Andes were a divide between two distinct faunas, one that occupied the steep Pacific slopes of the Andes, the other the Atlantic slopes and diverse habitats that lay between the mountains and the Atlantic Ocean. All the while, he added to his collections of rocks, plants, and animals and made observations of geology.

Darwin also turned his critical eye to the diversity of peoples he encountered along the way. He saw African slaves in Brazil, Indian tribes throughout South America, the natives of Tahiti, and the Maori of New Zealand. He observed and took notes on the people he encountered during his travels in the same way that he kept notes on zoology, botany, and geology.

One formative experience for Darwin came as the *Beagle* rounded the Horn, passing from the Atlantic to the Pacific. FitzRoy had returned to England from a previous voyage with three natives from Tierra del Fuego, one of the islands at the tip of South America. These islands are persistently cold and wet, and the natives lived in a very primitive state. The three natives that FitzRoy had taken away were now aboard the *Beagle*. His idea was to return his "guests" to their homeland, together with a Christian missionary, to start an outpost of European civilization at the bottom of the world. The plan proved disastrous, for the natives robbed the missionary (who had to be rescued), and the three returnees turned, in a matter of weeks, from dandified Englishmen to the "savages," to use Darwin's Victorian descriptor, that they had once been. Darwin learned a lesson never to be forgotten: civilization is just a thin veneer that is easily stripped away. We humans are close to the apes. This is perhaps one of the most striking things about the thought of Charles Darwin. Virtually every one of his contemporaries was picking at the scab of humankind. Charles Lyell could never be really true to his principles and always wanted miracles for our appearance. He sadly sighed in later life that he could not "go the whole orang"—meaning attribute to humans a simian origin. Darwin's great supporter Thomas Henry Huxley (the grandfather of Aldous Huxley, the novelist) came from the other side, never letting anyone forget the common origins of humans

and their close relatives the great apes. Darwin was calm and placid in the middle: We are part of the animal world. It is worth talking about but not worth worrying about. It is neither frightening nor amazing.

As well as collecting and cataloging, Darwin kept a detailed diary, parts of which were sent home together with lengthy letters. These were read avidly by the Cambridge circle, who arranged for the publication of some of them, as well as by the family. It was becoming clear to all that Dr. Darwin's younger son was more talented than anyone had realized. Darwin returned from the voyage to find that he was already a minor celebrity, based on the publication of some of his letters. After the voyage, his diary was used as the basis of an official account of the *Beagle* voyage and then republished in popular form as the *Voyage of the* Beagle. In the middle of the nineteenth century, people loved travel books. Long before Darwin achieved fame as an evolutionist, Darwin of the *Beagle* was a household name.

Evolution

As most everybody knows, key experiences came when the *Beagle* left South America and cut across the Pacific to a group of volcanic islands on the equator, the Galapagos archipelago. Darwin was an expert on the flora and fauna of South America when he arrived on the islands. Teeming with life, these islands proved to have inhabitants that bore similarities to those that Darwin had seen in South America, yet many were distinct species. To Darwin's great amazement, the giant tortoises that are found there differ from island to island. So also do the small birds, the finches (now known as Darwin's finches), and the mockingbirds. Darwin had just spent years in South America, where he had observed that you might find the same or closely related species in the steamy jungles of the Amazon and the snowy deserts of Patagonia. Now, apparently, God so loved the Galapagos that he put different species on little islands but a few miles from each other. There had to be something up. Darwin puzzled about this all the way home.

Upon his return home, Darwin at once plunged into detailed examinations of his collections, which included parceling prize specimens out to selected experts for identification and description. The Galapagos birds were examined by a leading ornithologist, John Gould, who at once declared them to be different species. All the other details of his journey, such as the giant fossils of extinct animals that were related to those still alive in the

same place or the Andean divide between two distinct faunas, began to sink in. At some point early in the spring of 1837, all that he had seen and all that he was learning from experts like Gould and Owen caused him to slip over to being an evolutionist or, as people called it then, a transmutationist. This was no light or casual thing to do. On the one hand, Darwin knew that his scientific set would be appalled, since they strongly opposed such thinking; so he would do well to keep his ideas to himself. On the other hand, Darwin knew that discovering how species originated was the prize above all worth getting. Herschel, the same Cambridge mentor who so strongly influenced Darwin, named the origins of organisms as the "mystery of mysteries." Darwin glowed at the thought of being the one to make the big hit. Note that we do not say this in any sense of disapproval. Great science demands great talent and great effort. It does not come to the unprepared or to the indifferent. Our point is that Darwin was very human and hence, in this respect, understandable scientist.

Darwin knew that becoming an evolutionist was only the first stage. Now he had to find a mechanism, a cause. Here again Darwin was not working or thinking blind. He was a graduate of the University of Cambridge, the university of Newton. Herschel, Sedgwick, Henslow, and above all Whewell (who was now president of the London Geological Society and who had pressed Darwin onto the managing board of that organization) stressed again and again that Newton's great achievement was to find a force, gravity, that explained the universal laws of motion, including the orbits of the planets established through the Copernican Revolution and its aftermath. Darwin wanted to be the Newton of biology, so he had to find the biological equivalent of the Newtonian force of attraction.

What would such a bright, ambitious young scientist consider the right model or archetype of a scientific theory? His Cambridge mentors, Herschel and Whewell, were trying to articulate the definition of good science. They were the ones lifting Newton to a pedestal far above all others, and it was their interpretation of a Newtonian science that influenced young Darwin. He had read Herschel's work on the philosophy of science and spoke highly of its influence in his autobiography. He also knew Whewell both at college and after the *Beagle* voyage and, again in his autobiography, spoke highly of him and his books.

So what was the Newtonian ideal of a theory? In respects it was to be what today's philosophers of science call a "hypothetico-deductive system." By this is meant that it is supposed to be axiomatic, like Euclidean geome-

try—one starts with a number of premises or axioms and then deduces everything from them. So in Newtonian mechanics you start with the laws of motion and of gravitational attraction and then deduce Kepler's laws, such as planets going in ellipses, and Galileo's laws, including cannonballs flying in parabolic trajectories. The difference between mathematics and an empirical science is that the former makes claims that are in some sense true by virtue of their form while the latter makes claims that are true because they correctly describe the physical universe.

But there was more to the picture than this. Newton's real claim to fame was that he had come up with the cause of the precisely observed but as yet unexplained orbits of the Copernican Revolution—gravity. It was this that made him the icon of science to Darwin's mentors. However, what exactly does one mean when one talks of "cause"? It is clearly something that makes other things work or move, but how does one know that one has a cause? How does one know that one has what Newton somewhat mysteriously called a *vera causa* or "true cause"? Here the authorities divided somewhat. Herschel was more of an empiricist and wanted observational evidence, direct or indirect. Whewell was more of a rationalist and wanted a sufficient explanation of all the facts, even if we do not see the cause at all.

Thus, for Herschel, the example was of the attraction between the earth and the moon. How do we know that gravity is a vera causa keeping the two together? Because we have all seen objects drop to the ground or have swung a stone around at the end of a piece of string and felt the pull required to keep the stone from flying off. We have directly sensed the cause—or something analogous. Empiricist though he may have been, Herschel thought that all natural force was a product of God's will, as the tug on the circling stone is a product of our will. Whewell would have none of that. He wanted a kind of global explanation, with the vera causa to bring together and unite diverse phenomena under a single explanation. He referred to this unifying feature of a theory as a "consilience of inductions."

> The Consilience of Inductions takes place when an Induction obtained from one class of facts, coincides with an Induction from another different class. This Consilience is a test of the truth of the Theory in which it occurs." (William Whewell, Philosophy of the Inductive Sciences, p. 1840)

"Consilience" comes from the same root as "reconcile," and inductions are logical arguments based on observations. Thus a consilience of induc-

tions is the bringing together of scientific observations derived from different disciplines and showing that they have a common cause. Newtonian physics met this ideal because a single entity, gravity, could be shown to explain phenomena as diverse as the movement of planets around the sun, of the moon around the earth, ocean tides, or the fall of an apple from a tree.

To grasp the difference between Herschel and Whewell's philosophy, think of a murder. We find a body lying in a pool of blood with a murder weapon, a knife, lying beside it. After an investigation, someone is charged with the murder. Why? Did the investigation reveal a vera causa? A Herschelian would be satisfied only if the accused were seen killing the victim. A Whewellian would instead be satisfied with the establishment of a means, motive, and evidence that directly linked the accused with the crime, such as his fingerprints on the knife. Why should we need eyewitness testimony? Evidence alone can establish guilt.

We can see Darwin's dedication to Herschel's emphasis on vera causa in the opening chapter of the *Origin*, where he begins with a discussion of artificial selection. Darwin, who grew up in a rural district during the British industrial revolution, had seen artificial selection in action. Think for a moment about what industrialization entails. People leave the land and move to cities, and there is a general rise in population numbers. Hence, more people need to be fed with a smaller proportion of them being farmworkers. In other words, an industrial revolution demands also an agricultural revolution. Here, the key proved to be not machines but selective breeding. Bigger and fatter pigs, cows that produce more milk, shaggier sheep. Perhaps most important of all was the development of quality root crops like turnips. Darwin, coming from rural Britain—his uncle Josiah was a gentleman farmer trying to upgrade sheep production—knew all about breeding. So, early in his quest for a mechanism, Darwin sensed that selection, which meant breeding from the good forms and rejecting the inadequate, was the key to organic change.

The practicality of artificial selection and its ability to cause change was only part of the battle. Darwin then had to address a more challenging theoretical issue. At Cambridge, Darwin was introduced to Archdeacon Paley's major work *Natural Theology*, dealing with the side of religious belief that focuses on reason and evidence for the deity. In particular, Darwin was saturated with the favorite argument of the British for the existence of God, namely the argument from design. Inviting his readers to consider the eye, Paley argued that it resembles a telescope in both structure and func-

tion. But telescopes have telescope designers and makers. Hence, eyes must have a designer and maker as well, better known as the god of Christianity. At this point in his life, the late 1830s, Darwin was not inclined to reject a Designer, although already he wanted Him to be someone who worked at a distance through law rather than individual acts. What Darwin did get from Paley was the premise that he accepted to the end of his life, namely that the organic world is as if designed. The hand, the eye, the nose, and all the other "contrivances" (a favorite word of Darwin's) or, as we call them today, the adaptations that organisms have for living and reproducing, have a design-like nature. Organisms are not just thrown together in a random way. They work, they are organized, they function, they exist as if an intelligence sat down and planned them. Random, blind forces lead to messes—remember Murphy's Law, that if things can go wrong they will. Organisms are not messes. They are the very antithesis of a mess. Hence, for Darwin, a mechanism of change had to be capable of creating design-like features. Darwin realized that selection can do all these things. The whole point of the breeders' art was to produce the features that were desired—more fat on pigs, more milk from cows, more fleece on sheep. By introducing artificial selection and then arguing to natural selection, he was providing a Herschel-type vera causa. He was arguing from a force we know, a force we cause ourselves, to a force of nature. The first chapter of the *Origin* is deceptively friendly, all about things people know about. But, at the same time, it is establishing proof for the mechanism that underlies his theory. Organisms can be changed in permanent ways through the process of selection.

The big problem now facing Darwin was how to get a natural equivalent of the breeders' artificial selection. What could make a force so strong and persistent that selection could operate efficiently in the wild?

At the end of September 1838, Charles Darwin read a late edition of Thomas Robert Malthus's *Essay on the Principle of Population*, where Malthus observed that human populations can increase in size faster than does their ability to produce food, causing a struggle for existence. At once Darwin seized on this struggle, generalizing it to animals and plants. Darwin put exponential population growth together with artificial selection, and he had his mechanism. His notebooks of 1838 show that he had arrived by then at natural selection as the mechanism that causes evolution.

Darwin was as sensitive to Whewell's concept of a consilience of inductions as he was to Herschel's concept of vera causa. After the mechanism of selection is introduced, and after some other matters are attended to—for

instance, the introduction of the secondary mechanism of sexual selection, the principle of divergence, some rather unsatisfactory speculations about the causes of heredity—the *Origin* turns precisely to such a survey of biology, showing the big problems and showing how selection speaks to them. In fact, the bulk of the *Origin* is devoted to this consilience of inductions.

Darwin worked systematically through instinct and behavior, paleontology and the fossil record, biogeography and the distributions of organisms, morphology, systematics, and embryology. Again and again, Darwin argued that selection speaks to the issues and conversely the issues justify a belief in natural selection.

The Long Wait

Darwin first articulated his theory in a 35-page "Sketch" in 1842 and then a full 250-page "Essay" in 1844, neither of which was published during his lifetime. We wonder why Darwin waited fifteen more years to publish the *Origin*.

One interpretation is that the delay was just part of the fabric of his life. On a personal level, at the beginning of 1839 he got married, and he and his wife were soon plunged into the joys and cares of a family. They moved from London to a village in Kent, where eventually they had ten children, seven of whom grew to adulthood. Darwin was a devoted father, but also a persistent tinkerer, constantly doing experiments and making natural history observations. It was also around this time that Darwin started to fall sick—from being a vibrant young man who had lived rough on the Argentinean pampas with the gauchos, he now became an invalid. He had headaches, stomach cramps, insomnia, boils, bad breath, and a host of other ailments.

Despite medical attention and frequent visits to spas and other rest resorts, Darwin never again enjoyed good health. The nature of his illness is one of those great Victorian mysteries. Some think Darwin's troubles were physical; perhaps he got Chagas' disease from insect bites he suffered while traveling in South America. Others think they were psychological, caused by the anxiety he felt about his theory, its likely stormy reception, or its effects on Victorian society. Either way, Darwin really did suffer, and this slowed him down; however, he learned to use his illness to his advantage. He interacted with society only when it suited him, and fixed his life so that his work came first and last, with due exceptions made for his fam-

ily and visitors in between. Health problems or not, Darwin continued to write and publish. He published his diary of the voyage in 1839 as the third of a three-volume series about the voyage, then revised it for publication by itself under the title *The Voyage of the* Beagle (1839, second edition in 1845). He edited multiple volumes of the zoology of the voyage (1838–1843) and published his three monographs on geology (1842, 1844, 1846). All this activity belies bad health alone as the cause of his waiting so long after articulating his theory in the "Essay" before publishing it in the *Origin*.

An alternative explanation is that Darwin spent the intervening fifteen years improving his status and knowledge as a biologist. After finishing his geological work in the mid-1840s, he turned to what grew into a massive study of barnacle classification that took more than seven years to complete. There is no doubt that this work solidified Darwin's standing as a scientist. In 1853, he was awarded the Royal Medal for Natural Science for his barnacle monographs. His barnacle years also gave him hands-on experience in comparative anatomy, embryology, paleontology, and systematics. All these fields were central to the argument presented in his essay of 1844. It was during this interval that he experimented with pigeon breeding to better understand selection and inheritance, performed experiments to characterize how organisms disperse across oceans, and tinkered endlessly with other problems suggested by his theory. We can see clear imprints of all of these activities in the *Origin*. So, even though he had worked out his theory by 1844, by 1859 he was able to combine it with a wealth of personal experience. In 1844 he wrote as one who had gained much of his knowledge from reading. In 1859 he wrote with the insights of a practicing scientist, and as a scientist who was widely recognized for his achievements.

Another reason for Darwin's delay was likely the publication in 1844 of the anonymously authored *Vestiges of the Natural History of Creation*, a book written for a general audience that promoted the idea of species transmutation, or evolution. Its proposal of evolution, and many other features of its popular science, caused a huge row. Although there were circles where its ideas were welcomed, all Darwin's mentors took up arms against the book. *Vestiges*, judged as a work of science, is not a great masterpiece, and Darwin certainly felt no threat from the contents. But he did not want to engage in battle, certainly not at a time when he was feeling really unwell; and so we suspect he shelved any publication plans that he had at that time.

Darwin instead settled into a comfortable regime of research. At the same time, however, realizing that a successful theory needs friends, he in-

troduced his scientific companions to his theory. Apart from Charles Lyell, his confidants were men of a new generation, including Joseph Hooker, who would become the director of the Royal Botanical Gardens, and Thomas Huxley, who rivaled and overmastered Richard Owen as an anatomist, plus others, not all of whom were converted to his ideas. He cultivated a team of future advocates but also benefited from their arguments, which became part of the *Origin* and helped Darwin anticipate the arguments that would arise after the *Origin* was published. Darwin must have felt a need to present his ideas to a critical world in more complete form, so exhaustively documented that even the skeptics who lashed the *Vestiges* might be convinced. By 1858, he was well along in writing his "big book" about evolution, which would have run to well over one thousand pages if it had ever been published.

Meanwhile, word of Darwin's reputation as a naturalist got out, so it was not pure coincidence that in 1858 a young naturalist-collector out on the Malay Archipelago sent him an essay in which he presented his own theory for the origin of species. Receiving it in the early summer, Darwin read this essay by Alfred Russel Wallace and realized that the younger man had made exactly the same discovery he himself had made some twenty years before and was just now readying for public display in his "big book." Joseph Hooker and Charles Lyell arranged for the immediate publication of Wallace's essay alongside some extracts of Darwin's earlier writings that documented Darwin's priority in discovering natural selection. Then, for fifteen months, Darwin wrote furiously. *On the Origin of Species* was published in the late fall of 1859, the same year that Oregon was admitted as the thirty-third state of the Union, John Brown raided Harper's Ferry, and Charles Dickens wrote *A Tale of Two Cities*. Darwin always thought of the *Origin*, which ran to nearly five hundred pages, as just an abstract of the "big book," which was never published. The *Origin* had none of the citations or data that characterized his other writings.

On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life, was first published in London by John Murray on November 24, 1859. Twelve hundred and fifty copies were printed and bound. Five went to official organizations, the author got 12 free copies, and Darwin purchased another 90 to be distributed to friends, family, and prominent scientists throughout the world. He also sent copies to all his Cambridge mentors. Of the remaining 1,100 copies, 500 were purchased by Mudie's Subscription library, which guaranteed

Darwin a wider readership, and the remainder were purchased by book dealers, all on the day of publication. Murray at once asked Darwin to prepare a second edition.

Aftermath

In all, there were six editions, the final one appearing in 1872. Darwin listened to all the objections that were raised to his theory, so by the sixth edition the work was very much changed, with additions, subtractions, and rewritings on every page. A few more slight corrections were made in 1876, although the reprinting done in that year was not considered a new edition. It was this version that Murray reprinted again and again until the copyright expired in 1901. By then, approximately 40,000 copies had been sold in Britain and the empire. Foreign translations appeared immediately after the first edition. The *Origin* has now appeared in over forty languages, most recently in Tibetan. It is also available in braille. Traditionally, in both English and foreign languages it was the sixth edition that was printed, since this seemed to be the definitive edition and final statement by Darwin on the subject. However, in the past thirty or forty years, with the rise of the history of science as a freestanding academic discipline, there has been an increasing tendency to reprint the first edition. It is felt that this is the work that shook the world and moreover the work in its cleanest form, before Darwin started to tinker with it, often for reasons that seem less compelling today than in the 1860s.

The *Origin* caused an immediate uproar in Victorian society. In 1860, at the annual meeting of the British Association for the Advancement of Science in Oxford, Samuel Wilberforce, the bishop of Oxford, debated the *Origin* with Thomas Huxley. Although it may be apocryphal, legend has it that Wilberforce asked Huxley if he was descended from monkeys on his grandfather's or his grandmother's side. Huxley replied that he would rather be descended from a monkey than from a bishop of the Church of England. True or false, the Wilberforce-Huxley story captures one dimension of the reaction to the *Origin*. What is not apocryphal is that, at that meeting, Darwin's old captain, FitzRoy of the *Beagle*, who earlier had probably had the same liberal religious ideas as Darwin but who had by now become a bit of a religious fanatic, went around the room brandishing the Bible and condemning his old shipmate!

What is less well known is just how widespread acceptance of evolutionary ideas became in the years immediately after the *Origin*. Few were prepared to go along with natural selection, at least as a comprehensive and adequate explanation of the evolutionary process, but the idea of "descent with modification," as Darwin called it, was almost universally accepted. This was true even of practicing Christians, as we can tell from religious publications, letters, sermons, and other sources of information. John Henry Newman, the great theologian who started life as an evangelical Christian, then became the leader of the High Church faction of the Church of England, and finally converted to Rome and ended up as a cardinal, can stand for many. He had long rejected the argument from design as a major stumbling block to science. In 1870, about his seminal philosophical work, *A Grammar of Assent*, Newman wrote: "I have not insisted on the argument from *design*, because I am writing for the 19th century, by which, as represented by its philosophers, design is not admitted as proved. And to tell the truth, though I should not wish to preach on the subject, for 40 years I have been unable to see the logical force of the argument myself. I believe in design because I believe in God; not in a God because I see design" (Newman 1973, p. 97). He continued: "Design teaches me power, skill and goodness—not sanctity, not mercy, not a future judgment, which three are of the essence of religion."

When he was asked about whether Darwin should be awarded an honorary degree from the University of Oxford, Newman replied: "Is this [Darwin's theory] against the distinct teaching of the inspired text? If it is, then he advocates an Antichristian theory. For myself, speaking under correction, I don't see that it does—contradict it" (letter of June 5, 1870, in Newman 1973, p. 137). Certainly Newman, like many others, would have liked more direction to the evolutionary process than Darwin would have allowed, and when it came to human souls he would have been adamant that here there was need of miraculous intervention, but overall he like many other fellow believers wanted to let science get on with its business. When he was setting up a Catholic university in Dublin in the 1850s, Newman insisted on the need to keep scientific inquiry unfettered by religious dogma (Newman 1873, pp. 428–32). In his view, science and religion deal with different spheres and thus, properly understood, do not interact and cannot conflict. Of the natural and supernatural worlds, he said that "it will be found that, on the whole, the two worlds and the two kinds of knowledge respectively are separated off from each other; and that, therefore, as being separate, they cannot on the whole contradict each other" (p. 389).

With the *Origin* published and with the world turning toward evolution, what of Charles Darwin? He was to live another twenty-three years, and somewhat expectedly all else was a bit of an anticlimax. He kept up a punishing schedule of work. His original intention had been to publish his "big book" on evolution, but his publisher persuaded him not to. The *Origin* was making its mark and selling well. The "big book" would just cut into those sales. Darwin instead planned to write separate books that detailed various parts of the *Origin*, which he continued to think of as an abstract. For the first decade or so, this ambition was dampened by the need to keep up with the publication of new editions of the *Origin*, some of which involved extensive revisions. Partly for this reason, the grand plan got sidetracked, and in the end Darwin finished only *The Variation of Animals and Plants Under Domestication*—published in two volumes in 1868—from this intended series. Before *Variation*, and in the midst of the controversies and battles spawned by the *Origin*, Darwin published *On the Various Contrivances By Which British and Foreign Orchids Are Fertilized By Insects, and On the Good Effects of Intercrossing* (1862), which was the first of six books on plants. Darwin saw orchids as objects of beauty, but also as presenting great problems to be solved because of their complex structure and their intricate mechanisms of pollination. Orchids were a wonderful distraction from the *Origin* controversies. In the end, he also saw the orchid book as "a flank movement on the enemy" (Browne 2002, p. 174) because orchids provided such a good counterpoint to natural theology. While Bishop Paley argued that such intricate beauty was a product of design, Darwin showed that it was instead a product of natural selection that provided a mechanism to attract insect pollinators, efficiently transmit pollen to other flowers, and thus reproduce.

Darwin also produced two major works on our species and its evolution—*The Descent of Man and Selection in Relation to Sex* (2 vols., 1871) and *The Expression of Emotions in Man and Animals* (1872). These books are where Darwin argued that humans are part of the animal kingdom, which was a fight that he avoided in the *Origin*. Darwin also wrote a brief autobiography, intended for private reading by his family. It, like virtually every letter and notebook attributable to Darwin, has since been published.

For the rest, Darwin rather dabbled as his fancy took him, but these projects also often provided forums for him to expand on ideas presented in the *Origin*. His five other books on plants include one on the effects of cross- and self-fertilization, which expands on his preoccupation with the dark

side of inbreeding—a personal concern of his since he had married his first cousin and worried about the health problems of some of his children. His finale, published the year before his death, is on earthworms and their role in the formation of vegetable mold. It seems particularly whimsical, but it represents a different form of his interest in how seemingly small, everyday processes can cause great change if they persist over long intervals of time.

Throughout his life, Darwin kept up a huge correspondence, and later he watched as his supporters—Huxley particularly—spread the gospel of evolution far and wide. In his last decade, Darwin's health improved somewhat, and he was able to enjoy both his large family and his fame. Finally, at the age of seventy-three, his heart gave out and he died—no real surprise, for like everyone else of his generation he was a heavy smoker. By now, what is also not surprising is the outpouring of national recognition and respect. Darwin was not just famous; he was a man to make the country proud. He was a brilliant scientist who labored on despite years of ill health; he was a beloved travel writer; he was rich but did not flaunt his money, nor did he squander it; he was a model family man (wife, children, faithful servants, not a hint of scandal); he may not have had formal religious beliefs, but he was modest in his doubts, and they never stopped him from bonding with believers including his close friend the local vicar. He was in short the archetypical Victorian gentleman in addition to being the Newton of the life sciences. There could be only one burial place for him, and there, for all eternity, he lies in Westminster Abbey, next to that other great English scientist, Isaac Newton.

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