A Brief History of Science
Part 10: The Revolution in Biology

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WHILE IDEAS IN PHYSICS and many other branches of science were undergoing great advancements in the 17th and 18th centuries following the advent of mechanical materialism and the ideas of causality and determinism, in biology the transition from observation to understanding happened much later. There were a few factors contributing to this, but the main factor was that, in the language of the eminent biologist Theodosius Dobzhansky, "nothing in biology makes sense except in the light of evolution." And the world was not yet ready to welcome the idea that biological species do evolve.

First, the belief that reigned supreme in the western world was that all the species on Earth were created by God and they have remained the same ever since. The belief was supported by the apparent empirical observation that biological species do not change. Cows give birth to cows, and horses give birth to horses and this goes on generation after generation. Even though some changes take place in each cow through the course of its life, nobody had seen the species changing. So the idea of fixity of species resulted from this empirical observation—the experience of people over generations. This is called the error of empiricism. And, one cannot advance much in biology with the idea of fixity of species.

Yet, the opening of the mind's eye in course of the Renaissance prompted people to look closer at the things around them, including living beings. Observation and study of nature started afresh. But since religious beliefs were still very strong in this period, people viewed the study of nature as an attempt to understand the mind of God in creating the different forms of living matter. For example, the English naturalist John Ray (1627-1705) was the first to introduce a classification of plants, but his discourses on the subject were titled "The wisdom of God manifested in the works of the creation". There were also discussions in the Church circles about the natural world, and aimed at integrating it with religious beliefs. Many books were written based on the idea of this "natural theology". Conceptually this did not advance biology much, but observational data started accumulating out of which biology would grow in the later years.

The philosophical foundation for any investigation was provided at that time by the Aristotelian system of formal logic, which, as we have seen in earlier issues, wanted to describe "things as they are", not things in the process of change and development. Therefore, naturalists of the period collected samples and described living beings "as they are". The philosophical basis of their study prevented them from noticing

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Carl von Linnaeus (1707-1778)

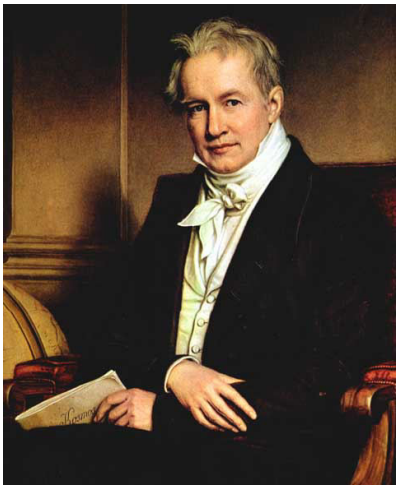
the clues that would later give rise to the idea of biological evolution.

But still, important works were done in this period. A case in point was the eminent Swedish biologist Carl von Linnaeus (1707-1778), who systematized the study of the biological world. He introduced a hierarchical system of classification consisting of seven levels (namely Kingdom, Phylum, Class, Order, Family, Genus and Species). He introduced a system of nomenclature based on similarity of the external morphology and behaviour of different forms of life. In this system the name of a species is preceded by the name of the genus (for example the scientific name of the wolf is *Canis lupus*—*Canis* is the genus and *lupus* is the species). We still follow this system of nomenclature. Yet, Linnaeus did not believe in evolution and was only studying the different species "as they are" and was categorizing them. This systematization itself contained hundreds of clues that pointed to the fact of evolution, but Linnaeus failed to see these because of his religious beliefs.

But evidence was accumulating. From much older times, people have been finding fossils of animal bodies, but dismissed them as the "unsuccessful creations of God". Fossils were also found at odd places—for example, fossils of marine animals on top of mountains, which demanded explanation. As explorers made voyages to distant lands, they found animals and plants that were not found in Europe. There was no mention of these life forms in any of the sacred books; no mention of how and when *these* were created. And when mining started on large scale, people started finding more and more fossils—and it became apparent that the number of different life forms found in fossils outnumbered the life forms that exist today. So "God's unsuccessful creations" theory came into question: If a creator makes more mistakes than correct ones, there is reason to doubt his wisdom. In any case, it was increasingly being felt that the genesis theory of the Bible was inadequate in explaining the multitude of life forms and fossils that were being found. But for a long time the age-old beliefs lingered and naturalists were reluctant to accept that species do change.

As an example, take the case of the eminent French naturalist Georges Buffon (1707-1788), head of the *Jardin du Roi* (Royal Gardens) in Paris. He was a person of great knowledge and wide-ranging interests. He wrote a 32-volume treatise on natural history which was immensely influential in shaping the thoughts of scientists for the next two generations. It was he who first conjectured how the solar system may have been created. It was he who pointed to the importance of comparative anatomy in understanding biology, and hinted at the possibility of transformation of one species into another with closely related anatomical features. But he saw these changes as "degeneration" from the original

Georges Cuvier (1769-1832)



Alexander von Humboldt (1769-1859)

forms created by God, and declared that he does not believe in evolution of species!

Another eminent naturalist, Georges Cuvier (1769-1832) followed up the idea of comparing the anatomy of different species to establish relations between them. For example, he studied the anatomy of the Indian elephant, the African elephant, mammoth fossils, and the fossil of an elephant-like animal found in America (now we know it as the mastodon). He showed that these are distinct but related species, the last two being extinct. He carefully studied fossils found in different strata of rocks and showed that many animals had lived in the past and became extinct after some time. But through this he did not conclude that species change. Rather, guided by his religious belief, he concluded that there have been many epochs of catastrophic floods, resulting in mass extinction of species and subsequent re-creation by God in multiple genesis events.

Yet scientific information was pouring in from all sides. The German explorer Alexander von Humboldt (1769-1859), travelled extensively in South as well as North America in the first decade of the 19th century and collected an immense volume of scientific information related to botany, geology and meteorology. He travelled through the Amazon and the Andes, documented the lives of several native tribes, discovered and studied many new species of animals (including the electric eel) and plants. His memoirs published over the next two decades contained very rich scientific information that enriched biological knowledge significantly.

Naturalists in this period were grappling with the question of being able to explain the immense variety of living organisms.

Philosophy opens the door

In this situation, philosophers took the first plunge. Immanuel Kant (1724-1804), whom we have met earlier in our discussion on causality, proposed that everything in the material world is in a state of "flux" (the word "evolution" had not been coined at that time). He even envisioned that the solar system itself had come into being through such an evolutionary process. He proposed a hypothesis that the solar system

originated from a primeval nebula. This, after a lot of modification and enrichment by subsequent generations of scientists like Laplace, is still the accepted theory today.

Picking on the idea that everything in nature is continuously undergoing changes, the German philosopher Georg Hegel (1770-1831) in his book "Science of Logic" pointed out that changes in nature do not proceed in linear progression, as uniformly gradual changes. Slow quantitative changes are in fact punctuated by qualitative changes; things proceed from "being" to "becoming". Water freezes to ice, seeds germinate to saplings, nitrogen and oxygen upon reacting give rise to substances with new properties—he cited these as examples of such qualitative changes. When such a qualitative transformation happens, the entity becomes a new entity, *negating* its earlier existence. According to Hegel, the Kantian "flux" or changes in nature need to be understood in terms of both the quantitative changes as well as the qualitative transformations. But in spite of providing this vital clue to understanding nature, he stood rooted on the concept of an "Absolute Idea"—the primary all-inclusive entity whose external representation is nature or material world—and fell prey to idealism.

However, with these developments in philosophy, the idea of evolution was, so to speak, in the air. It remained for the scientists to prove its reality with hard data, and to work out how it actually happens.

The backlash of natural theology

The believers of natural theology were keenly noticing the threat of the new idea. Various lines of argument trying to refute the idea of evolution were formulated in this period. But the most powerful attack came from the English clergyman William Palley (1743-1805). In the year 1802 he published a book titled "Natural Theology, or

Georg Hegel (1770-1831)

Evidences of the Existence and Attributes of the Deity collected from the Appearances of Nature". His argument was as follows.

Suppose you are walking along a forest path, and you come across a piece of rock. That would not raise any question in you, because there is nothing extraordinary about it. But if you come across a watch lying on the forest path, it will surely raise a question—because upon examination of the object you would notice the intricate mechanism. You would conclude that it is indeed extraordinary to find such an object on the forest floor, because, clearly, it is a product of conscious design.

Paley then took the argument forward by citing the extraordinary mechanisms that make a living body work, and argued that these must be the products of conscious design. He particularly cited the eye as an example of intelligent design. And, he said, if there is a design, there must be a designer. *That* designer of the natural world, according to Palley, is God.

It took the genius of Darwin to conclusively put an end to all these ideas in circulation with an alternative materialistic

James Hutton (1726-1797)

Charles Lyell (1797-1875)

explanation supported by testable evidence. But, as we'll see, even Darwin was influenced by natural theology in his early years.

Does the Earth change?

Kant's assertion about the ever-changing nature of the world encouraged the Scottish geologist James Hutton (1726-1797) to investigate if the Earth itself has undergone such changes. He found not only that the mountains, rivers and seas have changed over time, but also that the time taken for the changes to take place is much longer than what was supposed in the Biblical genesis belief. He explained the features of the Earth's crust by means of natural processes over geologic time scale. Through observation and carefully reasoned geological arguments, Hutton came to believe that the Earth's surface is perpetually being formed, and forwarded the crucial argument that the history of the Earth could be determined by understanding how processes such as erosion and sedimentation work in the present day. Hutton's work established geology as a proper science, and thus he is often referred to as the "Father of Modern Geology".

The English geologist Charles Lyell (1797-1875) worked further to unearth the history of the Earth, and published a 3-volume monograph titled "Principles of Geology", which was a compendium of the knowledge of geology in his time. It also popularized Hutton's idea that the Earth was shaped by the same processes still in operation today. It is this book that later proved crucial in the development of Darwin's theory of evolution [1].

Lamarck: A theory of evolution takes birth

The French naturalist Jean Baptiste Lamarck (1744-1829) first tried to propose a theory of biological evolution in the year 1809. According to Lamarck, the process of evolution is essentially the process of morphological change of the organs belonging to the members of a

[1] Darwin carried the first volume in his Beagle voyage, and acquired the other two volumes by post during the course of the journey.

Jean Baptiste Lamarck (1744-1829)

species, resulting in the transformation of a section of one species into another. Why do the organs evolve? Because of the influence of the environment on individual organisms. An organism may face a change in the environment to which it is adapted — which may happen on account of climatic change or migration to a different location. A change in the environment causes changes in the needs of organisms living in that environment, which in turn causes changes in their behaviour. Altered behaviour leads to greater or lesser use of a given structure or organ; a more frequent and continuous use of any organ gradually strengthens, develops and enlarges that organ, and gives it a power proportional to the length of time it has been so used; while the permanent disuse of any organ imperceptibly weakens and deteriorates it, and progressively diminishes its functional capacity, until it finally disappears. This rule—that use or disuse causes structures to change—Lamarck called the "First Law" in his book *Philosophie Zoologique*. Lamarck's "Second Law" stated that all such changes were heritable. The result of these laws was the continuous, gradual change of all organisms, as they became adapted to their environments.

Lamark's theory had great impact on his contemporaries. First, it stated that evolution of species is a fact. Second, it pointed to the course of evolution: According to Lamarck it proceeded from the simple to the complex, from the lower to the higher, and so it is a progressive process. Third, he proposed a plausible causal mechanism—evolution guided by "need to change" in response to the change in environment. Evolution, according to him, was an entirely natural process that does not require any divine intervention.

Darwin: The grand synthesis

This was the intellectual climate when Darwin was a young man. On the one hand, the philosophical ground for studying the biological world as a body of ever-changing living matter had been created; on the other hand the belief in a Biblical genesis was still very strong. However, the doubts about the genesis theory had been sown by the development in geology (which showed that the Earth was much older than supposed in the genesis stories), and the observational facts regarding the ever-changing nature of the world coming in from all quarters. The fact of evolution had also been forcefully propounded by Lamarck. But at the same time, the idea of a creation event had been further strengthened by the "intelligent design" argument, and most scientists studying the natural world were trying to strike a compromise between science and theology.

When Darwin boarded the HMS Beagle in 1831 for the arduous 5-year journey across the globe as a resident naturalist, he was a devout Christian and believed the Biblical genesis theory. His job was to study the flora and fauna of the places the ship visited—which he did remarkably

well. He collected thousands of specimens and dispatched them in crates to England for study and classification by professional biologists. He carefully took notes of what he observed. And by the time he returned to England in 1836, he had become doubtful about the idea of Biblical genesis.

He started carefully analyzing the data he collected, and by March 1837 he was convinced that transmutation of species was a reality. But as yet he had not found the mechanism of evolution. In his autobiography, he explained "It was evident ··· that species gradually become modified; and the subject haunted me. But it was equally evident that neither the action of the surrounding conditions, nor the will of the organisms (especially in case of plants), could account for the innumerable cases in which organisms of every kind are beautifully adapted to their habits of life." Thus, in his search for a mechanism of evolution, he was convinced, early on, that Lamarck's theory does not provide a satisfactory explanation.

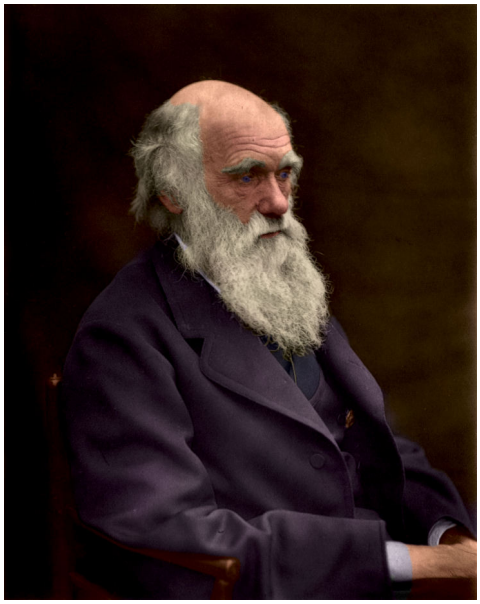
In 1838 he was able to formulate a plausible hypothesis that could be subjected to tests. Then, what he did was surprising: He did not think of publishing his idea; instead, he worked intently for no less than twenty years testing his hypothesis using the evidence from different areas of biology and geology. He prepared a preliminary 35-page sketch of his argument in 1842, and then expanded it to a 230-page "essay" in 1844. But he was not yet satisfied with his theory and was not ready for its publication (though he instructed his wife Emma to publish it in case of his death). In the meantime he continued accumulating facts and details in support of his theory.

This "silent" mode of working came to an abrupt end when he received a letter from a naturalist named Alfred Russel Wallace who, while working in the Malay Archipelago, had come to similar conclusions on the mechanism of evolution. Darwin showed the letter to his scientist friends Charles Lyell and J D Hooker. They suggested that extracts of Darwin's essay of 1844 and a letter addressed to Prof. Asa Gray of Boston, in October 1857 and Wallace's paper be read jointly at the Linnean Society meeting on July 1, 1858 — thus recording Wallace as a co-discoverer of the theory. After that, at the insistence of Lyell and Hooker, he wrote up the book '*On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life*'. When it was published in 1859, it went on to change the course of scientific history.

It is not possible to present a detailed account of Darwin's theory in the scope of this article. This has already been published in some earlier issues of Breakthrough, which are available in the archives of www.breakthrough-india.org (see, for example, "Darwin and the Theory of Evolution", Vol.12, No. 1, October 2006). Here we present a very brief outline of his argument.

Darwin noticed a few "clues" in his studies of the natural world. First, that within every species there are variations: no two organisms are the same. Second, that every organism exists in two types of struggle for existence: (a) the intra-species struggle for the limited resources like food, and (b) the inter-species struggle with the enemy (e.g., deer-tiger) or competing (e.g., tiger-leopard) species. Third, that in every species far more individuals are born than can survive in the struggle and can reach maturity. Only a handful of successful individuals can produce offspring.

On the basis of these clues he built his theory of natural selection: variation means different physical characteristics, and in a given natural environment some characteristic features may give survival



Charles Darwin (1809-1882)

advantage. These organisms are, therefore, better adapted to their environment. Out of the millions of individuals that are born in a given generation, the ones that carry the advantageous physical traits are "selected by nature" to produce the next generation. Thus the advantageous physical characteristics get transmitted and the disadvantageous ones get eliminated. This mechanism allows the average physical characteristics of a species to change over generations, and new species to emerge. True, the process was slow, but as Hutton and Lyell had shown, the Earth was old enough to account for the necessary time for this evolutionary mechanism to work.

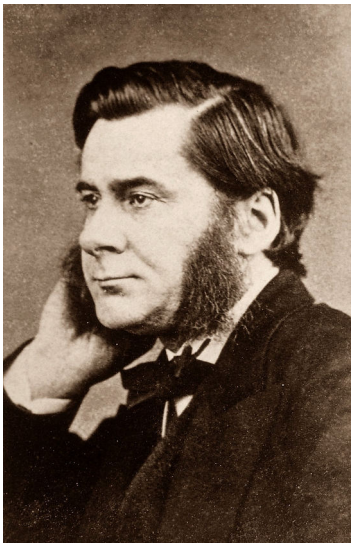
A few features of his theory are noticeable. First, it is a completely materialistic theory that calls for no divine hand or conscious design to produce the complicated organisms or body-parts that we see today. Second, it is a causal theory that clearly states the connection between the cause (environment) and the effect (change in organisms). Yet, unlike all causal theories science had seen so far, it, at base, is a probabilistic theory. The variations that take place are random, and from among all the variants natural selection chooses the form best adapted to the environment. A given physical characteristics gives an organism only a higher *probability* of survival, and only when viewed at the species level—with millions of individuals—does it become a causal mechanism governing the process of evolution.

Darwin himself threw light on his transition from a believer in "intelligent design" to a strict materialist. "The old argument of design in nature, as given by Paley, which formerly seemed to me so conclusive, fails, now that the law of natural selection has been discovered" Darwin wrote in his Autobiography. We can no longer argue that, for instance, the beautiful hinge of a bivalve shell must be made by an intelligent being, like the hinge of a door by man. There seems to be no more design in the variability of organic beings and in the action of natural selection, than in the course which the wind blows. Everything in nature is the result of fixed laws."

Convincing the world

Even though obtaining evidence for his theory was a two-decade long endeavour, convincing the world about the fact of evolution and its materialistic mechanism proved to be an uphill task. Given the dominance of religious sentiments in peoples' minds, it is understandable that *The Origin of Species* created quite a furore. Darwin had spared only a few sentences to simply state that all species, including man, was subject to natural laws, and the origin of the human race could be traced in a similar manner. The implication enraged the devout Christians who saw his theory as a blasphemous attempt to unseat God.

Darwin was a shy and reclusive man and did not want to take part in any debate. Fortunately, a few very competent professional biologists came forward to defend and to popularize his theory. A public debate was organized at the Oxford University Museum on 30 June 1860, in which Bishop Samuel Wilberforce took the side of the Church and Thomas Henry Huxley took the side of Darwin's theory of evolution. The debate is best remembered today for a heated exchange in which Wilberforce supposedly asked Huxley whether it was through his father's side or his mother's side that he claimed his descent from a monkey. Huxley is said to have replied that he would not be ashamed to have a monkey for his ancestor, but he would be ashamed to be connected with a man who used his great gifts to obscure the truth. Because of his staunch defence of Darwin's theory Huxley was popularly referred to as Darwin's "bull dog".



Thomas Henry Huxley (1825-1895)

With passage of time it became clearer that the theory fits all observations and provides a consistent rational explanation of the past and present variations in the organic world. Slowly people in larger numbers became convinced about the truth of the theory, and it found general acceptance. But the struggle between science and anti-science is far from being over (See Box-1).

It is notable that Darwin avoided any direct attack on religion, and differed from the approach of some science activists of his day. For example, Edward Aveling, a professor of biology and a serious campaigner in favour of Darwin's theory, used to mount frontal attack on religious beliefs to propagate atheistic views citing Darwin's theory. When he sought permission to dedicate his book "The Students' Darwin" to Darwin, the latter declined the offer. Darwin wrote, "though I am a strong advocate for free thought on all subjects, yet it appears to me (whether rightly or wrongly) that direct arguments against Christianity and theism produce hardly any effect on the public, and freedom of thought is best promoted by the gradual illumination of men's minds which follows from the advance of science. It has, therefore, been my object to avoid writing on religion, and I have confined myself to science." The science activists of today may also have something to learn from Darwin's views.

Darwin's method of investigation

What method did Darwin adopt in his investigations? In his time, two prominent methodological issues were in vogue: the inductive doctrine propounded by Bacon, and the deductive doctrine propounded by Descartes (see Part 5 of this series, published in January 2014). Most biologists in Darwin's time adopted the Baconian approach. Bacon had noted that in his time the minds of most investigators were obscured by religious beliefs, and the preconceived notions and prejudices prevented

Box-1: Evolution theory in school education

Even though Darwin's theory of evolution is now a scientifically accepted theory, and can be understood and appreciated by high school students, in many countries—even advanced ones—it is either not taught or is taught along with creationism. In the states of Georgia and Alabama of the United States, the biology textbooks must have a sticker that says "This textbook contains material on evolution. Evolution is a theory, not a fact, regarding the origin of living things. This material should be approached with an open mind, studied carefully, and critically considered." In the state of Kansas, there is no mention of evolution, the age of the Earth, etc., in the school curriculum so that evolutionary theory would not appear in state-wide standardized tests and it is left to the local school districts in Kansas whether or not to teach it. In the state of Pennsylvania, the Dover Area School Board voted in 2004 that a statement must be read to students of 9th grade biology mentioning intelligent design. And in the state of Texas, the Texas Education Agency (TEA) director of science curriculum Christine Comer was forced to resign in 2007 over an e-mail she had sent announcing a talk given by an anti-intelligent design author, because the TEA "must remain neutral" on the issue of evolution!

In the member states of the European Union, even though both creationism and the theory of evolution are taught in most schools, the Council of Europe has taken a firm stand. On October 4, 2007, it is to be appreciated that the Parliamentary Assembly of the Council of Europe (PACE) adopted its Resolution 1580 titled *The dangers of creationism in education*. The resolution observed that "The war on the theory of evolution and on its proponents most often originates in forms of religious extremism closely linked to extreme right-wing political movements," and urged member states to "firmly oppose the teaching of creationism as a scientific discipline on an equal footing with the theory of evolution and in general the presentation of creationist ideas in any discipline other than religion."

them from reaching correct conclusions about the working of nature. So he had recommended that one should collect information about various aspects of nature *without any prior idea in mind*, and should adopt inductive logic in deriving general conclusions about them. Even though Darwin said that he also adopted a similar approach, he actually didn't.

Instead, faced with a question, he would first look for the primary clues, would then form *hypothesis* on that basis, and then would meticulously plan *directed observations* that would prove the hypothesis to be either true or false. Thus, when he started methodical investigation after returning from the Beagle voyage, he always had a very clear idea about what he was looking for. So Darwin actually did not follow the Baconian recommendation that observations should not be guided by hypothesis.

Pointing out the problem of undirected observation, he wrote "A man might as well go into a gravel pit and count the pebbles and describe the colours. How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service." He underscored the importance of hypothesis in guiding empirical research by indicating what is worth observing and what evidence to seek. He says about his own method of research "I cannot avoid forming one hypothesis on every subject." Through his own work Darwin showed that, if the hypotheses are constructed on a scientific basis (and not on the basis of preconceived notions and

unfounded beliefs), these may become very powerful tools that guide systematic observation and help to reach correct conclusion. This is a very important point in the method of science, to which we shall return later.

The second point is that he never accepted something as true only because it appeared to him to be true. He always subjected his ideas to very strict tests. He would examine and re-examine his own database, and would explore all the possible alternative explanations. Only when it was evident that the other theories failed to offer satisfactory explanation of the question at hand, he would allow himself to conclude in favour of his hypothesis. Still he kept open the possibility that he might be proved wrong. This reflected a firm determination to guard against any kind of subjective bias.

Another aspect of his scientific personality is worth mentioning. Many scientists have a tendency to take note of only the arguments and facts favourable to his/her theory and disregard (or at least give less importance to) the ones that do not support the theory. But Darwin attached great importance to any contrary facts and objections that seemed to go against his theory. He made appropriate note of these and mentioned them in his book in full; and honestly expressed his inability to answer them with complete satisfaction. He did not try to ignore or bypass them.

For example, his theory vitally rested on the premise that there are variations within each species. His theory pointed to the way the variations unfavourable to adaptation in a given environment are eliminated by natural selection. One may thus conclude that variations would reduce with time, which is not supported by observation. He could not answer the question "How do new variations originate?" (it could be answered only after the development of genetics), but he clearly mentioned it in *The Origin of Species*.

"I had ··· followed a golden rule, namely that, whenever a published fact, a new observation or thought came across me, which was opposed to my general results, to make a memorandum of it without fail and at once; for I had found by experience that such facts and thoughts were far more apt to escape from memory than favourable ones" he wrote in his Autobiography. "Owing to this habit, very few objections were raised against my views which I had not at least noticed and attempted to answer."

After Darwin

Darwin's work opened a gate that had been closed for a long time: to understand the biological world in the light of evolution. Biology advanced in leaps and bounds in the century following the publication of *The Origin of Species*. Before Darwin, scientists had collected and recorded observations of lakhs of species, devised data bases to understand them, but the interaction, inter-relation, dependence on each other was poorly understood. Darwin interlinked the lakhs of species and uncovered the law governing the living world.

Yet, it is clear that Lamarck and Darwin proposed very different mechanisms of the evolutionary process. Who was right? Much of biology in the later years concerned resolution of this puzzle, which came only after we understood the molecular mechanisms of heredity and evolution. With the development of molecular biology and genetics, some improvisations, some factual additions and deletions, and further enrichment have taken place. But the basic theory of evolution as proposed by Darwin stands vindicated. We shall come to that chapter of the history of science in a later issue.

(To be continued)