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Biological Evolution: The Present Status of our Knowledge

Midway through the XIX century, Charles Darwin formulated the theory of biological evolution by natural selection. That theory has been decisively confirmed by modern science and is now supported by an enormous number of scientific observations, fossil finds, experimental results and formal theory. In a period in which groundless criticism of the science and teaching of evolution is on the rise, the biologists of the Accademia dei Lincei, along with other Academicians, have prepared a report reviewing the conceptual foundations of evolutionary biology, and describing the scientific evidence for the reality and mechanisms of evolutionary change. The present essay is a synthesis of that report.

From a scientific, Darwinian point of view, everything in nature, including the origin of life, is the result of natural processes and is ruled by natural laws. The fundamental axiom of Darwinism is that living organisms often generate more individuals than can survive. The principle of natural selection says that survival and reproduction is greater for those individuals which have more suitable, or “adaptive,” characteristics. If these characters are heritable, the underlying genes will spread in the population, while the less suitable or unfavourable characteristics will tend to decline in frequency, and may disappear or no longer be expressed. These changes in frequency – leading to the conservation of suitable characters and the elimination of unfavourable ones – is termed evolution by natural selection.

Biological evolution began on earth after the pre-biotic planet reached temperatures compatible with the formation of certain chemical compounds with characteristics favourable to the origin and persistence of life. A big step in the evolution of life occurred when photosynthetic and respiratory processes became established at cellular and intracellular levels. With the appearance of Cyanobacteria and the emergence of photosynthesis, oxygen began to spread

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in the atmosphere to the present levels, which represent an equilibrium between photosynthesis and respiration.

Darwin’s theory was quickly accepted by most of the scientific community in Darwin’s time because it was supported by the findings of comparative anatomy, embryology, and palaeontology. After Darwin biochemistry and molecular biology provided new evidence for evolution, especially by revealing the universality of the genetic code and the structural affinities of proteins, patterns that highlight the common evolutionary origin of the great organismic groups. A significant contribution has been made since the 1980s, by genomics, the science which studies the sequence of DNA in the genome of various organisms and its expression during development. In the last twenty years genomics has revolutionized understanding of the molecular mechanisms of biological processes (including those of disease), illuminating the nature of phenotypic variation at the molecular level and helping to explain the diversity of life. Genomics, in combination with the new discipline which studies the evolution of development, and modern phylogenetics (the study of the branching tree of life), have shown that many genes that are key regulators during the developmental “construction” of embryonic organisms are the same in species which are phylogenetically and evolutionarily quite distant from each other. Thus, animal life on planet Earth uses a collection of similar genes in different ways to produce very diverse organisms just by modulating and rearranging gene expression. For example, we now know that the gene complexes which regulate the development and the differentiation of the basal parts of fins in fishes are the same which regulate the development of the entire limb (with the exception of fingers) in amphibians and mammals. Thus, when and how a particular gene becomes active in the course of individual development importantly influences the diversity of organismic forms. Similarly, the fact that the same genes are involved in the formation of the brain of a fly, a mouse and of a man, despite the great phylogenetic distances between them, represents important evidence for the common origin of these animals. Comparative studies of protein structure also demonstrate that widely different organisms descend from a common ancestor via evolution that has established mutational modifications of the genes which control protein synthesis. Research of this kind can also contribute information of the speed of evolution of particular genes.

Species formation (“speciation”) was proposed by Darwin to be a process by which different populations initially of the same species gradually diverge until they reach the status of distinct species. Subsequent research on speciation has clarified how this process is favoured by geographical reproductive isolation between populations (allopatric speciation). Speciation without geographic isolation (sympatric speciation) can also occur, in sufficiently diversified environments, given special patterns of reproductive isolation such as assortative mating of males and females of similar phenotype and genotype.