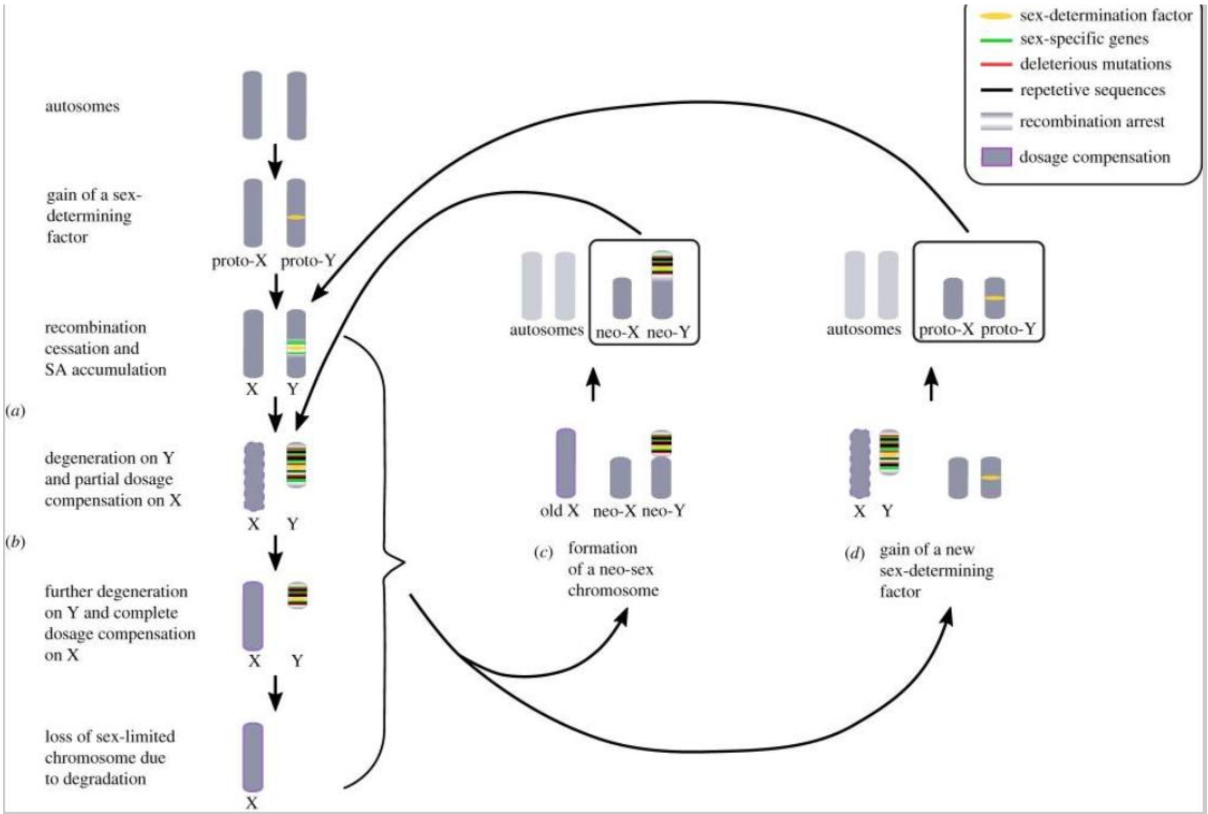
Evolution of sex chromosomes

Many separate-sexed organisms have sex chromosomes controlling sex determination. Sex chromosomes often have reduced recombination, specialized (frequently sex-specific) gene content, dosage compensation and heteromorphic size.

(a) Genetic sex determination and recombination suppression

The accepted theory of the evolution of heteromorphic sex chromosomes starts with a pair of homologous autosomes that gain a major sex-determining function through one or several genes. This can happen in a system that already has a sex chromosome pair and in that case it results in a so-called turnover or in a hermaphrodite ancestor. Two mutations are needed in order for separate sexes to evolve from hermaphroditism—one suppressing male fertility and the other suppressing female fertility, usually at different loci—otherwise a mixed mating system results (e.g. gynodioecy with females and hermaphrodites, which is the most common mixed system in plants). In case of a turnover, the new sex-determining gene needs to cause a fitness increase compared to the old sex-determining gene in order to invade.



Explanation of figure:

Overview of the dynamic evolution of sex chromosomes, illustrated in a male heterogametic system. Top left corner: an autosome pair in a hermaphrodite gains a sex-determining factor that evolves to become a highly heteromorphic pair of sex chromosomes, via cessation of recombination, degeneration (a) and evolution of dosage compensation (b). This progression can however be perturbed by a turnover event, such as the formation of a neo-sex chromosome (c) or a gain of a new sex-determining factor (d). In (c), the moderately degenerated Y chromosome fuses with an existing autosome, forming a new sex chromosome pair with an old sex-determining factor. In (d), an *autosomal pair gains a new sex-determining factor, creating a completely new sex chromosome pair. The old Y is lost. In both (c) and (d), the old X may eventually gain diploidy through non-disjunction and subsequently lose dosage compensation, becoming an ordinary autosome pair. Note that although (c) and (d) are shown as leading to chromosome turnovers, this progression is not inevitable. {SA, sexually antagonistic allele}*

Next, sex-specific genes become linked to the sex-determining region, and suppression of recombination evolves in the heterozygous sex since it is advantageous for these genes to be inherited together. Recombination between the proto-X and proto-Y sex chromosomes (proto-Z and -W in female heterogametic systems) can be hindered either through gradual reduction with genetic modifiers or large inversions. The recombination suppression region of the proto-sex chromosomes can expand further via the accumulation of sexually antagonistic genes (i.e. genes that are beneficial for one sex but detrimental for the other), near the sex-determining region.

(b) Degeneration and dosage compensation

The increase of the non-recombining region results in strongly differentiated sex chromosomes, as genes decay via accumulation of deleterious mutations on the sex-limited Y chromosome. Following Y degeneration, the homogametic sex (XX females) will have two copies of X-linked genes compared to the heterogametic sex's (XY males) one, resulting in unequal expression between the sexes. The solution is dosage compensation, which can be achieved in multiple ways (e.g. X chromosome inactivation in female mammals, or X hyper expression in male Drosophila. Dosage compensation is a common phenomenon taxonomically, but varies in its extent; it is almost complete in mammals, but is partial in birds and some snakes.

(c) Sex chromosome turnovers

Though some organisms have lost the Y chromosome completely (e.g. crickets and dragonflies), not all sex chromosomes end up highly differentiated. There are two main hypotheses: occasional recombination between X and Y due to sex-reversals and frequent turnover events. Sex chromosomes in sex-reversed female frogs (i.e. with an XY genotype) recombine as much as in XX-females, introducing new genetic variance on the Y. However, this only works for species with relatively undifferentiated sex chromosomes—strongly differentiated sex chromosomes cannot recombine successfully. Sex chromosome turnovers are very common in fishes and may result from the evolution of a new sex-determining gene on an autosome or transposition of a sex-determining locus to an autosome, or fusions between autosomes and existing sex chromosomes (formation of a neo-sex chromosome).

THEORIES OF ORIGIN OF LIFE

How life originated on earth has been a mystery for mankind. While common man generally believes that God created life, scientists believe that life could have been created by natural means. In the following discussion, we shall be assessing some of these theories.

Theory of special creation

Religions preach that life was created by God whether it is Hinduism, Islam or Christianity. Religions teach that all species of plants and animals were individually created by God for specific purpose and that they do not have any relationships among them. According to Hindu mythology, life was the creation of Brahma, Islam says Allah created living beings and Christianity says that God created all life in 6 days. However, science cannot accept theories that have no concrete evidence.

Cosmozoic theory (=Panspermia)

Micro-organisms from space have been coming on earth along with meteorites and comets for a long time and then perhaps evolved into higher organisms in water. Pieces of Martian rocks have been recovered from Antarctica which contained bacteria-like organisms on them. This can be given as evidence that life could have come to earth from some other planet. Francis Crick and Laslie Orgel found *molybdenum* in the bodies of plants and animals which in plants is required in nitrogen metabolism. But molybdenum is a rare on earth and could not have been used by organisms.

Another theory postulates that some planet with primitive life must have collided with earth and life got transferred on to earth. Some workers such as Richter (1865), Helmholtz (1884) and Arrhenius (1908) and explorers like Eric von Daniken and Zecharia Sitchin propose that the universe may have several planets with intelligent life. If such intelligent beings achieved capability of space travel and if they landed on earth in the past, they could have then brought life on earth.

Spontaneous generation theory (=Abiogenesis)

Thales, Anaximander and Aristotle believed that life originated from the non-living things and still continues to evolve by this method. For example, worms and frogs can appear spontaneously from mud and fly larvae can appear in rotten meat. Francisco Redi (1690) was the first scientist to refute this theory by experimentally demonstrating that if you cook fish and meat then no organisms appear in it in a sealed container. But people still believed that microorganisms developed by spontaneous generation.

Another scientist, Spallanzani (1780) boiled and sealed broth and found that no micro-organisms appeared spontaneously. Later, Louis Pasteur (1860) conducted a more sophisticated experiment in which flasks whose neck was drawn like swan's neck were used to trap micro-organisms and dust. The boiled broth was kept in these flasks did not rot, suggesting that micro-organisms did not appear spontaneously.

Biogenesis

Redi, Richter, Spallanzini and Louis Pasteur rejected the theory of abiogenesis and proposed a new theory called Biogenesis. The theory postulates that life can emerge only from a form of life such as spores, eggs or hibernating animals and not from inorganic substances. But still this theory does not explain how life originated in the beginning.

Biochemical origin of life

This theory is also called **biopoiesis**. It was proposed by A.I.Oparin (1923) and J.B.S.Haldane (1928). Oparin (1936) published a book titled, *The Origin of Life* in which the theory was explained in detail. This theory says that life evolved in the primitive atmosphere of earth by reactions in chemicals present at that time. Organic compounds, such as carbohydrates, fats and proteins could have been formed easily by chemical reactions of elements, namely, oxygen, hydrogen, nitrogen and carbon which combined with one another to form larger molecules such as carbon dioxide, carbon monoxide, water, ammonia, methane, hydrogen, acetylene etc.

As the water was formed its vapours along with different gases formed atmosphere as the temperature dropped down. Condensation of the water vapours and the gases brought down heavy rains. The rain water collected in low lying areas and created oceans. The water reacted with hot metals on earth's surface producing acetylene gas that filled the atmosphere of primitive earth. Simple amino acids like Glycine were formed by reaction of ammonia with other compounds. Carbohydrates and fatty acids are also chains of carbon, hydrogen and oxygen and could have been formed by similar method.

Amino acids possess natural tendency to form polypeptide chains by amide bonding and these chains can easily form proteins in suitable atmosphere that was available in the primitive atmosphere of earth. The larger protein globules formed protein aggregates or Microspheres, Coacervates or Protobionts. These large protein spheres could grow in size by absorbing protein molecules from the surrounding water and then divide by fission, a primitive method of reproduction.

Coacervates got surrounded by a fatty layer that formed a cell membrane like structure. Such organisms were called **Eubionts**, which could reproduce by fission. Later, enzymes and genetic material also evolved to make reproduction easier. RNAs could have been formed in high energy environment which can also act as enzymes. Earliest genes were probably minerals associated with proteins and capable of replication.

Nucleic acids are more efficient coding materials and probably evolved later. RNA was perhaps the first genetic material evolved as proposed by Crick, 1968 and Watson et al., 1986. RNA molecules have also been known to act as enzymes. DNA is a complex molecule and might have been formed much later may be by RNA by some of kind of reaction as created by reverse transcriptase.

This kind of primitive organisms can be called **Progenotes,** which could be the ancestors of all life. They must have fed on the organic molecules present in water and could synthesize organic substances required by the cell. **Prokaryotes**, such as bacteria must have evolved in the next step. We have fossils of **cyanobacteria** in 3,500 million year old rocks suggesting that they were the first living organisms to evolve on primitive earth. Prokaryotes gave rise to **Eukaryotes**, when DNA got enclosed in a nuclear membrane about 1600 million years ago.

Evidences supporting biochemical origin of Life

Many scientists believed that if life could evolve by chemical reactions naturally in oceans then it should be possible to produce it in laboratory. S.L. Miller (1953) designed an experiment in which conditions of primitive earth could be recreated. He boiled water in a flask to produce steam which was directed into a large chamber in which methane, ammonia, hydrogen and water vapour could be subjected to electric sparks. The resultant material was cooled to obtain liquid material.

Amino acids like glycine, alanine and aspartic acid were formed in cooled liquid. Several other workers repeated this experiment and obtained almost all amino acids. Bahadur (1954) in his experiments obtained all amino acids by mixing paraformaldehyde, ammonia and ferric chloride together and exposing it to sunlight. Lowe, Rees & Markham (1963) heated liquid hydrogen cyanide and aqueous ammonia and obtained amino acids. Abelson (1966) mixed carbon dioxide, nitrogen and hydrogen together and exposed the mixture to ultraviolet radiation. Amino acids glycine, alanine, serine, aspartic acid and glutamic acid were obtained in this experiment.

Protein-first hypothesis

It is now generally accepted that amino acids were formed in the oceans but could these amino acids also polymerise to form microspheres. This could have happened in three possible conditions: 1) If amino acids are dehydrated and heated, 2) If amino acids are absorbed in clay, or 3) If amino acids reacted with cyanide or phosphate compounds. Fox (1957) after heating a mixture of 20 amino acids could produce polypeptides.

The spheres of polypeptides were similar to coacervates, which were called **protenoids.** Microspheres exhibit some properties of cells. They can divide by fission. They are covered by a double layer of non-fatty membrane and they can produce ATP to obtain energy. Steinman & Moser (1967) conducted experiments and found that formation of peptides could be stimulated by other peptides that acted as enzymes.

Gene-first hypothesis

Nucleotides could not have been formed in the natural conditions as existed on primitive earth as nucleotides require a series of enzymes to bind together the nucleoproteins, sugars and phosphates. But several scientists have opined that this could have happened on young earth. Ponnamperuma (1965) produced ribose and deoxyribose by subjecting a mixture of methane, ammonia and water to radiation. Even formaldehyde solution under specialized conditions formed sugars.

Experiments conducted by Schramm (1965) revealed that polynucleotides could be formed in the presence of phosphorus-containing compounds. Horowitz (1959) gave the theory that life began in the form of "naked genes" without a cell and cell membrane and that these had the capabilities of self-duplication. They also had the ability to influence environment to ensure supply of materials for the cell. Although sufficient evidence is not available to prove this theory but Muller (1965) and Sagan (1965) believed that some polynucleotide chains could act as enzymes.

Possibility of Life in outer space

Life is a complex of chemicals that has achieved extreme specialization and capacity to produce its own kinds. The universe has countless number of galaxies scattered all over. Our own galaxy called Milky Way contains about 100 billion stars, each one them having solar systems of their own. The number of earth-like planets capable of supporting life is estimated to be more than 100,000 within our own galaxy. Millions of galaxies lie within our range of telescope. So earth-like planets is not a rarity in the universe.

In spite of strong possibility of life in the universe, the distances are astronomical. Even communication to such long distances can take years and travel to such planets will not be possible within the lifetime of an individual. Although life may exist in several places in the universe, it is scattered, separated by long distances.

EVOLUTION OF ELEPHANTS

Elephants belong to the Order Proboscidea, the name coined by Carl D. Illiger (1811), because of the long proboscis or trunk formed by the elongation of nose and upper lip. Only two genera exist today, *Elephas* in Asia and *Loxodonta* in Africa. Their nearest relatives are sea-cows and manatees (Sirenia). The following characteristic features make elephants subjects of curiosity and awe.

- Huge body size, 10-13 feet tall, bulky body, weighing 6-7 tons.
- Pillar-like legs, with five toes encased in a huge cushiony mass and plantigrade locomotion. Ulna is the dominant bone of fore leg.
- Skull is large, height being more than the length and having air cavities (diploe). Neck is shortened to support large head.
- Proboscis or trunk is formed by the elongation of nose and upper lip and is used for handling objects, more or less like human hand.
- Elephants possess pharyngeal pouches for storing water.

- Dentition is lophodont, adapted for grinding rough fodder. Second pair of upper incisors is modified to form tusks which grow throughout life and each one may attain a length of 9 feet, weighing 200 pounds. Male tusks are larger.
- All molars do not grow at the same time but new ones appear on the posterior side and the older and worn out ones are shed on the anterior side by horizontal displacement.
- Stomach is simple and liver 2-lobed, without a gall bladder.
- Brain is small in comparison to the body and fore brain does not cover the hind brain. However, temporal lobes are well developed, which provide elephants with better sense of touch, smell, hearing and extraordinary memory.
- They produce high frequency infrasonic sounds for communication.

Changes during evolution of elephant

Ancestors of elephants were swamp dwelling small pig-like animals, which had no proboscis and enlarged tusks. During evolution as the swamps shrunk, they had to get adapted to browsing or grazing habit on land and underwent changes accordingly.

- Height increased to 10-13 feet and weight 6-7 tons. Large size provided protection against predators. Modern elephants have no natural predators.
- Rectigrade locomotion: Limbs became long and pillar-like to support heavy weight of body and for the same reason feet developed huge cushion-like pads and tion.
- To make the skull light air cavities called *diploe* were formed in the whole of skull.
- As the neck became short to support heavy skull, upper lip and nose got elongated and highly muscular to form proboscis which functioned like hand for handling objects.
- As the animal fed on rough and highly abrasive diet, its teeth became lophodont with silica deposited in the depressions. Teeth replaced by conveyer belt system.
- Second incisors in the upper jaw attained hypertrophy to form tusks for digging roots and for removing barks from trees which elephants relish.
- Elephants developed infrasonic sounds for communication over long distances.
- As an adaptation to survive in arid climate they developed pharyngeal pouches for storing water.
- Elephants show **mosaic evolution** in the development of body organs.

Moeritherium: This is the earliest and best known ancestor of elephants from Eocene Epoch. It was a heavily built animal, the size of a pig or tapir, about 3 feet tall. Proboscis was absent but snout was slightly elongated. One pair of upper as well as the lower incisors was slightly enlarged. Legs were stout and terminated in broad feet. Diastema was present and molars were low-crowned.

Phiomia: Fossils of *Phiomia* were unearthed from Oligocene deposits near the Egyptian Lake Moeris and also from Shivalik Hills in India. It was twice the size of *Moeritherium*. Skull was large with air cavities and nasal openings lay just in front of orbits. Jaws were elongated having one pair of incisors each, modified to form downwardly curved tusks.

Palaeomastodon: Lived almost at the same time as *Phiomia*. Fossil records are not very well documented. Height was about 6 feet. Molars were less complex than in *Phiomia.*

Dinotherium: This genus lived in Miocene and Pliocene epochs. Fossils have been found in Europe and India. There were no tusks in the upper jaw but lower jaw had tusks that curved downward and backward, suggesting that they were used for digging roots of plants. A small proboscis was present in the upper jaw. It was probably a swamp dweller digging and feeding on the roots of plants.

Trilophodon (=Gomphotherium): Fossils have been discovered from Miocene rocks in Europe, Africa and America. They were great migrants and widely distributed animals. Body size was nearly as large as the Asiatic elephant. Upper tusks were downwardly curved and lower jaw was enormously long also having a pair of tusks.

Tetralophodon: Fossils of this species were discovered in Italy, India and North America. Molars were high crowned with four crossing cusps. Upper tusks were long and straight while lower tusks were small. Upper jaw formed long proboscis while the lower jaw was short.

Dibelodon: Fossils of this species were recovered from the Pliocene deposits in North America. They were probably the first elephants to reach South America. They are characterised by shortening of the jaw and loss of the lower tusks.

Mastodons: Several species existed during Oligocene to Pleistocene in Africa, Eurasia and America. They had simple bilophodont molars (*mastos* = small cusps). True mastodons had lower jaw without tusks and molars were low crowned, indicating that they were foliage feeders.

Stegodon: Their fossils have been found in South and Southeast Asia only. They probably appeared in Pliocene and survived up to Pleistocene. They had short head, long proboscis and short tuskless lower jaw. Molars had more roof-like ridges as compared to mastodons. Teeth were adapted to browse on tough vegetation containing silica. Modern elephants are presumed to have evolved from *Stegodon.*

Mammonteus: *Mammonteus (=Mammuthus) primigenius,* commonly known as woolly mammoth is the best known elephant. It was abundant in arctic region up to Spain and Italy in Europe and also in North America. Frozen specimens were found in Siberian tundra in Lena delta. Recently more complete specimens have been recovered and preserved in frozen caves in Siberia. The animal was well adapted to withstand cold climate by having a coat of coarse long black hairs and with a thick coat of brown wool beneath. Tusks were long and curved. They attained a height of about 9.5 feet.

EVOLUTION OF HORSE

Evolution of horse dates back to Eocene epoch, about 60 million years ago. Primary centre of evolution were Great Plains of North America, from where species migrated to Europe and Asia from time to time. For some reasons horses became extinct in North America by the end of Pleistocene epoch but their offshoots in Europe and Asia flourished.

Evolution of horse was triggered by a change in the climate and vegetation during lower Cenozoic period, when grasslands in most parts of the world replaced forests. The main modifications in the body of horses from small forest-dwelling animals to large, grazing and fast-running animals can be outlined as follows: ·

- Increase in the size and height of the body from a small, rabbit-like animal to 6 feet tall grassland animal.

- Gradual enlargement and better development of the third digit (median digit) and reduction of the other lateral digits.
- Lengthening of the limbs and perfection of the hoof for fast running in open grasslands.
- Reduction of ulna bone in the fore leg and fibula in the hind leg and strengthening of radius and tibia.
- Change from digitigrade to unguligrade locomotion for fast running.
- Elongation of the pre-orbital or facial region of the skull and migration of eyes to the top of head.
- Modification of teeth from brachydont (low-crowned) to hypsodont (high crowned) to withstand tougher food (grass).
- Increase in the size and complexity of the brain for superior intelligence.
- Reduction in pectoral girdle and disappearance of the weak clavicle.
- Body became streamlined, muscles tight, without loose fat, for long and sustained running.
- Nostrils became wide to allow more air into strong lungs and stamina increased.

Eocene horses

Hyracotherium* or *Eohippus: Fossils of *Hyracotherium* were found in Europe and those of *Eohippus* in North America (Wyoming and New Mexico). Height was about 12 inches. Facial region was short and eye-orbits located about in the middle of the length of the skull. Dentition was brachydont (low-crowned) and bunodont (low cusps) to feed on soft vegetation. Premolars were simpler than molars. Ulna in the foreleg and fibula in the hind leg were complete. Fore foot had 4 digits and hind foot had 3 digits, all touching the ground.

Orohippus and ***Epihippus:*** Both are related genera and do not differ much from the preceding species. There were four digits in front foot and three in the hind foot. Median digit became larger and lateral ones shorter but all touched ground and carried the body weight.

Oligocene horses

Mesohippus and ***Miohippus:*** There is enlargement in size to about 24 inches. Three functional digits in fore as well as hind foot, all touching the ground but the median toe was much stronger than the others. Ulna and fibula became thin and slender. All premolars became molariform, as a pre-adaptation to harsh diet.

Miocene horses

Parahippus and ***Merychippus:*** There were three digits in each foot but the middle one was larger and stronger and the lateral digits did not reach the ground. Pre-orbital region of the face became elongated. All premolars became molariform and dentition became hypsodont but the milk teeth were still low-crowned. Central toe ended in a large convex hoof.

Anchitherium: It was found in Europe and Asia where it came from North America. It was larger than *Miohippus*. It had 3 toes and digitigrade locomotion. Teeth were low-crowned and molars were simple.

Pliocene horses

Pliohippus: Lateral digits reduced to vestiges. Skull had elongated. Crown of teeth was similar to modern horses but they were curved and pattern of ridges was not so advanced. Facial fossae were deep. It had acquired unguligrade gait of swift locomotion.

Dinohippus: Lived about 12 million years ago in North America. Its fossils have been discovered recently and it showed remarkable similarities with modern horse, much more than *Pliohippus* does. It had straighter teeth and reduced skull fossae. It is believed to have given rise to modern horses.

Hypohippus: Fossils were recorded from North America and China. Size was 40 inches, similar to pony. It was a 3-toed browsing horse, with well-developed lateral hooves and vestiges of the first and 5th digits still present in the fore leg.

Hipparion: Size about 40 inches. There were three toes in each foot but lateral digits were small. They migrated from North America to Old World through Alaska and Siberia.

Protohippus: It was a 3-toed grazing horse that had low crowned teeth.

Hippidion: It had short and stout feet having only one toe. Head was large with long and slender nasal bones.

Pleistocene horses:

Because of the harsh climate of the Pliocene and glaciations of Pleistocene epoch, horses became extinct in North America. Only one genus, ***Equus,*** survived in northern Africa, Asia and Europe. It soon spread to different parts of Asia, Africa and Europe and diversified into 5 distinct species namely, *Equus caballus, E. zebra, E. hemionus, E. assinus* and *E. przevalskii.*

EVOLUTION OF MAN

Origin of man is one of the most puzzling phenomena of nature. While the fossil records in the case of other animals doubtlessly reveal their ancestry, human fossil records are scanty and full of gaps. There is no written account of our ancestry other than the religious theories that unanimously indicate that Gods descended from heaven and created man in their own image. Man appears to have evolved through natural selection from ape-like creatures that migrated from forests to grasslands and lived as group hunters.

Factors that influenced human evolution

Both Miocene and Pliocene were dry periods of great stress, when sea level went down by about 200 meters and northern and southern hemispheres had huge ice caps. There are indications that fragmentation of dense tropical forests in east Africa initiated the evolution of bipedal hominids from the arboreal apes. The dry period of a few million years put a lot of pressure on the animals living in the shrinking forests and forced them to migrate and adapt to the open grasslands. The evolution of horse, camel, giraffe, and elephant was also triggered by the same factors.

Some groups of apes that were omnivorous and semi-terrestrial, faced with intense competition in the forests, started migrating to grasslands. Community living evolved to defend themselves in groups and also to hunt large animals in groups. As the hands were engaged in handling arms and food, they had to walk and run on two legs, giving rise to bipedalism, resulting in the elongation and strengthening of legs. Standing upright in the tropical savannas could also have given them the advantage of scanning horizons for predators as well as potential prey, exposed less of body surface to the perpendicular sun rays and more to the horizontal cooling winds, and freed the hands for carrying stones, sticks, food or infants.

Manipulation of objects by hand put a lot of pressure on brain, leading to its enlargement and increased intelligence. As these migrants continued to live in grasslands and perfected their bipedal locomotion and use of hand for more complex jobs, their brain increased in size and capacity. Later, they started living in caves for protection and probably developed a language for communication. *Australopithecus* was such a creature, which lived socially in caves, made stone tools and hunted animals. Eating cooked food led to the reduction of canines, shortening of jaw and simplification of teeth. Human evolution is an example of specialization in brain's ability, achieved due to manipulative skills of hands, strategic group hunting and communication in social groups.

Fossil Records of human phylogeny

Explosive primate radiation took place in the early part of Coenozoic era, in Palaeocene and Eocene epochs. Primitive monkeys and primitive anthropoid apes made their appearance in the Oligocene epoch, about 35 million years ago, thus setting the stage for further hominid evolution. However, fossil records depicting human evolution are incomplete and fragmented and do not give a clear linear picture of human phylogeny.

Oligocene primates

Parapithecus was a primitive primate ancestral to man, apes and monkeys. It was very small squirrel-like earliest primitive monkey having tarsier-like appearance. The jaw was conical, the two halves converging at an angle of 33 degrees. These creatures were probably adapted for arboreal mode of life and had opposable thumb, forwardly directed eyes and reduced snout.

Propliopithecus fossils were discovered from Fayum deposits in Egypt that comprised of a lower jaw with teeth. The jaw is smaller and more pointed than that of a gibbon, prognathous and deep. Canines were smaller and bunodont grinders had 5 bulbous cusps as in apes and man.

Limnopithecus first discovered by Hopwood in 1933 from Kenya is represented by several fragments of mandibles, teeth and limb bones. The dentition is gibbon-like but limb bones are unspecialized and a combination of monkeys and gibbons.

Miocene apes

Pliopithecus is represented by several well preserved fossils from Egypt and Europe. It shows affinity with pongids but the mandibular symphysis is longer and more prosimian type. A shallow simian gap is present. Body is gibbon-like in the morphology of pelvis, vertebrae and sternum. Limb bones are surprisingly primitive, resembling those of prosimians while the general body proportions are like those of monkeys.

Dryopithecus (=Sivapithecus) (=Proconsul) was ancestral to Orangutan, chimpanzee and gorilla and resembled gibbon in stature. Most of the fossils are represented by jaw fragments and teeth, with few exceptions such as a humerus and an ulna from France and a femur from Germany. The three genera, *Dryopithecus, Sivapithecus* and *Proconsul* have been placed in the subfamily Dryopithecinae. Arms and legs were of same length and posture was semi-erect. Skull lacked the well-developed crests and massive ridges characteristic of modern apes. Dental arch was parabolic and dentition more man-like but canines were larger and lower premolar is sectorial. It was a brachiator, swinging with arms on tree branches.

Sivapithecus is believed to be the direct ancestor of *Ramapithecus,* whose fossils have been recovered from the same deposits in the Siwalik Hills and date from 17 to 8 million years old.

Sugrivapithecus fossils were discovered from Siwalik Hill by Lewis in 1934 and are represented by fragments of jaw and teeth. The small size of teeth and canines and simplified molars suggest a transitional stage to hominid type of dentition.

Gigantopithecus remains have been recovered from Siwalik Hills. Reduction of front teeth and canines shows hominid tendencies but the jaw was massive and premolars and molars were large. Jaw allowed grinding sideways motion. It was larger than gorilla, a terrestrial herbivore and lived in open grasslands.

Lufengpithecus fossils recovered from China reveal a highly sexually dimorphic hominoid, having distinctly smaller females and considerably larger male of the size of a chimpanzee.

Sahelanthropus tchadensis. A cranium, jaw fragments and several teeth were discovered from Chad in Africa by Michel Brunet et al. (2002). The 6-7 million year old skull resembles that of a chimpanzee from the posterior side but on the front side is Australopithecine in character.

Ramapithecus (=Kenyapithecus)(=Bramapithecus) fossils of fragments of an upper jaw and teeth were found in 1932 from Haritalaya Nagar in Himachal Pradesh in Siwalik Hills in India by G. Edward Lewis. In Kenya L.S.B. Leakey (1955) discovered a few teeth and jaw fragments of the same species. Canines were small and grinders had low cusps but coated with thick layer of enamel. *Brahmapithecus* is represented by lower jaw only. Face was short and jaw allowed sideway motion. Dentition was human and palate arched. Incisors and canines were small, permitting lateral chewing. Grinding teeth were large and broad with thick enamel coating, suggesting herbivore diet of grass, seeds, roots and perhaps raw meat.

Ramapithecus fossils show advancement in morphology over *Sivapithecus* that brings it closer to *Australopithecus.* They probably originated in Africa and later migrated to Eurasia.

Pliocene hominids

After *Ramapithecus* no fossils are available for almost 10 million years, which is a big gap in phylogeny of man.

Oreopithecus fossils were discovered from lignite mines in Italy. One nearly complete skeleton of the abominable Coal Man was unearthed from Italy and later about 200 fossils were collected from Europe and East Africa. Dentition was human, canines were small and face short but premolars and molars were ape-like. Pelvic girdle was broad, indicating erect posture. It was an herbivore living in swampy areas.

Australopithecus africanus, "the southern ape" is the most primitive of Australopithecines that existed between 5.5 and 2 million years ago. Fossil of a 5-year old boy (Taung baby) was discovered from South Africa by Prof. Raymond A. Dart in 1924.

It was 5 feet tall and walked erect. Vertebral column had a lumbar curve and pelvis was broad. Foramen magnum was placed under the skull. Teeth human and dental arch smoothly rounded. Palate seems to be shallow anteriorly and deep posteriorly.

Canines were small and simian gap absent. Premolars and molars greatly enlarged relative to incisors and canines. Cranial capacity was 450-700 cc. Face was prognathous with long palate but less prominent eyebrow ridges and without chin. Orbits were large and rounded. Nasal bones were flat, giving the short face a dish-shaped appearance.

Australopithecus occurred in two forms: a small **gracile** and a larger **robust** form spread in Tanzania, Kenya and Ethiopia and South Africa. Many scientists are now using the generic name *Paranthropus,* which was originally given to the species *robustus,* to refer to the **robust** forms of *Australopithecus,* which includes *robustus, boisei* and *aethiopicus.*

Australopithecus afarensis was a gracile form and probably a descendant of *A. africanus.* One almost complete skeleton of a female named **"Lucy"** was discovered from Afar (Ethiopia) by Donald Johanson in 1973. It was dated at 3.5 million years. It was about 5 feet tall and walked erect and had an arched foot to support the bipedal gait. Cranial capacity was 400-500 cc. Canines were small with thick layer of enamel and molars were designed to grind tough material.

Australopithecus garhi. A fragmentary skull was excavated in 1997 by Asfaw and White from Bouri village in the middle Awash region in Ethiopia and dated at 2.5 million years. The fossil was found near antelope bones which were butchered by it using specialized stone tools that were carried with it from other places where the raw material for it was available. The stone hammers, axes and blades enabled this species to exploit a broader range of habitats and prey to obtain energy rich food that was necessary for the enlargement of energy consuming brain.

Australopithecus anamensis fossils, discovered near Anam lake at Kanapoi and Allia Bay in Kenya by Meave G. Leakey, were dated to about 4 million years. Skull fragments and teeth were similar to those of earlier species but arms and leg bones were more advanced and indicative of bipedal gait.

Ardipithecus ramidus is represented by 21 specimens found near Lake Turkana and from Aramis in the Awash Valley in 1995. Dated back to 4.4 million years, it perhaps walked erect. It is believed to be a sister species of *anamensis.*

The following three species were **robust** forms of *Australopithecus,* sometimes identified by the separate generic name, *Paranthropus, as* they seem to have descended from a common ancestor.

Australopithecus robustus (=Paranthropus robustus) was first discovered by Robert Broom in 1939 from South Africa and dated to 1.5-2.0 million years. It is characterized by heavily built skull having rounded appearance, higher vertex and a bony keel on the top for the attachment of large jaw muscles. Forehead was slanting and eyebrow ridges massive. Foramen magnum and occipital condyles were anteriorly placed. Dental arch was rounded and massive without diastema and simian shelf. Incisors and canines were small and spatulate, while premolars and molars were very large.

Zinjanthropus boisei, the "Nutcracker Man" was discovered by L.S.B.Leakey in 1959 from Tanganyika in East Africa and at Olduvai gorge in Tanzania, along with stone tools, and was dated to about 1.7 million years. It had massive jaws and teeth, with small incisors and large canines. There is cerebral enlargement with a cranial capacity of 600 cc. Face was protruding and forehead high, having prominent eyebrow ridges. Nasal spine was elevated.

Australopithecus aethiopicus was discovered by Allan C.Walker from Lake Turkana in Kenya and is represented by a 2.5 million years old blackish skull. It is related to *A. robustus* and *boisei* and may be their ancestor.

<u>Pleistocene hominids</u>

Homo habilis, called the "Able Man" lived 1.85-2.6 million years ago and walked erect. Fossils were discovered by Louis Leakey in 1959 from Olduvai Gorge in Tanzania, where later several teeth, jaw and skull fragments were discovered. Its premolars and molars were smaller and anterior teeth larger. It was 140 cm tall, with cranial capacity of 700 cc and human teeth. It was a habitual bipedal and probably ancestral to all *Homo.* It hunted small animals and was a scavenger of large carcasses. Face was less prognathous and nasal bones convex. It was closely related to *A. africanus* but was more advanced in features and occupied similar ecological niche.

Homo erectus fossil remains dating from 1.9 million years to about 250,000 years discovered from Java, China and later Europe and Africa are collectively known as *Homo erectus,* the archaic man that had larger brain and used stone hand axes. Supraorbital ridges are prominent, with an indented area behind them.

It had massive face that projected below and heavily built mandibles, without a chin that were moved by strong masseter muscles. Teeth are similar to man but incisors are slightly larger and shovel-shaped having enlarged pulp cavity, an adaptation for hard chewing. They knew the controlled use of fire to cook food and keep them warm. The use of fire was perhaps necessary to occupy caves that were inhabited by large carnivores. The mean cranial capacity was 1020 cc, which was approximately twice the size of australopithecines but only three-fourth of *Homo sapiens.*

Homo ergaster, considered the African counterpart of *Homo erectus,* was discovered from Koobi Fora in Kenya and dated to 1.6 million years. In 1954 hominid remains from Algeria and Morocco showed affinities with the Chinese form of *Homo erectus.* After 1970, Richard Leakey unearthed fossils from the eastern shores of Lake Turkana and one complete skull from Koobi Fora that is believed to be the earliest *Homo erectus* fossil in Africa.

Pithecanthropus erectus (Java Man) was discovered by a Dutch army officer, Eugene Dubois in 1891. Skull cap, few teeth and a femur are known. Forehead was low and supraorbital ridge. Cranial capacity was 775-900 cc. Height was about 5 feet and it walked erect efficiently. Bones of the skull were extraordinarily thick. Face was prognathous, chinless and skull flat on the top and projected behind.

Sinanthropus pekinensis (Peking Man) was first reported by a Canadian Professor, Davidson Black in 1927, who found only one skull. It was similar to Java man but skulls were small and cranial capacity 850-1200 cc. Eyebrow ridges were stout. Stone tools of varied designs were also found along with bones of large animals and pieces of charred wood and bones. It walked erect.

Homo heidelbergensis is represented by a single jaw recovered from a sandpit near Heidelberg in Germany in 1907. Lower jaw was massive and chinless but teeth were stout and human. The anatomical features were more advanced than those of the African and Asian forms of *Homo erectus*. They were low-browed hominids having thick bones and robust skeletons and perhaps represented earlier stage of *Homo sapiens.*

Steinham Man is represented by a complete skull found in 1933 from a gravel pit at Steinham site in Germany. Its age is estimated to be same as for Swanscombe man, from the second interglacial period. Cranial capacity was 1070 to 1175 cc. Fore head was high but eyebrow ridges were heavy and the nasal opening broad as in Neanderthals.

Ehringsdorf Man is also known from Germany with a cranial capacity of 1350 cc. It lived up to 120,000 years ago. Forehead was well developed, eyebrow ridges heavy and chin reduced.

Swanscombe Man is known by two pieces of the skull roof consisting of one occipital and two parietal bones that are unusually thick. Skull is broad at the back but the occipital region is not projected behind as in Neanderthals. Cranial capacity was 1300 cc. Some stone tools were also discovered from the same site.

Fontechivade Man fossils are from France. Skull bones were thick and cranial capacity about 1400 cc. Supraorbital ridges were not prominent.

Solo Man is known by partial skull and 2 femur bones discovered from Solo river in Java in 1933. Forehead was low and eyebrow ridges heavy. Cranial capacity was 1300 cc.

Rhodesian man was discovered in Rhodesia (= Zimbabwe) in 1921. Cranial capacity was 1300 cc. Eyebrow ridges were heavy and jaw was projecting forward, although the dental arch was parabolic. The Rhodesian man was about 6 feet tall, neanderthaloid in appearance and is now regarded as a subspecies of *Homo sapiens.*

Neanderthal Man *(Homo neanderthalensis)* is known originally from Neander Valley in Germany. Later, fossils of about 200 individuals were unearthed from 70 sites in Austria, China, France, England, Germany, Greece, Italy, Iraq, Israel, Java, Russia and Yugoslavia.

The species lived between 200,000 and 30,000 years ago. The average cranial capacity was 1450 cc, which is greater than in modern man, but the brain was large posteriorly and ventrally. They were stout and powerfully built people, weighing over 80 kg and having an average height of 5’6”. Long bones were thick, slightly curved and had large areas for muscle attachment. Forehead was low and slanting, eyebrow ridges were heavy and cheek bones were large. Nose was broad and chin was absent. Stature was robust and completely upright. Teeth were large.

They were cave dwellers living in the most adverse environmental conditions and used fire, made stone tools and crude carvings and practiced burial. There is strong evidence of ritualistic practices, religious beliefs and ceremonious burials. The classic Neanderthals come from fourth interglacial period in Europe and had stocky and rugged stature, broad nose, stout mandible, projecting occipital region and no chin.

Causes of extinction of Neanderthals are not clear. The most plausible explanation is that a more advanced species, Cro-Magnon man evolved in Africa and migrated to Europe about 40,000 year ago and exterminated the Neanderthals. However, recent findings indicate that extinction of Neanderthals was not so fast and that it coexisted with Cro-Magnon for about 10,000 years and perhaps produced viable hybrids.

That leads to another possibility that they must have interbred with the new and more advanced populations immigrating from Africa, producing the modern man. But a study of mitochondrial DNA sequences recovered from the skeleton of a Neanderthal suggests that modern humans are closely related to each other than to Neanderthals.

Cro-Magnon Man *(Homo sapiens fossilis)* was a contemporary of Neanderthal man and lived in Europe during the upper Paleolithic period (about 40,000-10,000 years ago). Large number of fossils was found from a cave in Cro-Magnon in France. Male was 6 feet and female 5 feet 6 inches tall. Skull was like modern man, with a distinct chin, flat eyebrow ridges and orthognathous face. Teeth and jaw were distinctly like modern man. Cranial capacity was about 1500 cc., same as that of modern man.

They showed technological advancement in using bones, antlers, stones etc. to make tools and spears and also specialized tools such as needles, harpoons, engraving tools, blades, soft hammers and heat-treated flints. They used ornaments for the first time and performed rituals. Coloured pictures of animals in the deepest parts of the caves and also carvings of wood, ivory and stones point to their advanced skills. They apparently knew the use of fire but did not practice agriculture or domestication of animals. They also buried their dead with some rituals.

Both Cro-Magnon and Neanderthal man lived during the glacial period, when their main occupation was hunting wild animals for food, which they cooked on fire in caves. Cro-Magnon had better intelligence and advanced tools and arms and hence perhaps exterminated Neanderthal.

Towards the end of glaciations, they probably migrated to warmer parts of the world and settled down in colonies along the rivers to practice agriculture and domestication of animals, which gave them sure and constant supply of food. Evolution of man after that was very fast as compared to the earlier slow pace of evolution during Pleistocene epoch.

Homo floresiensis. Also named as *Homo hobbit,* the discovery of the little man from limestone cave at Liang Bua on the Indonesian island of Flores by the Australian archaeologists surprised everyone. The 18,000 year old fossils were only a meter tall and had cranial capacity of only 380 cc. These tiny people lived in isolation in the far-flung Indonesian island where giant rats, tiny elephants, Komodo dragons and other large lizards were abundant. The isolation forced the species to remain small-sized and live in holes in the ground to escape giant predatory lizards and hunt giant rats for food.

The molecular evidence. Mitochondrial DNA is inherited maternally through the cytoplasm of the egg which contains about 100,000 mitochondria (sperm contains insignificant amount of mtDNA, only about 50), and is not subjected to the same selection pressure as the nuclear DNA.

The rate of mutation in mtDNA is ten times faster than nuclear DNA and is constant and hence can be measured to reveal a relationship between two species that emerged from common ancestor. Cann et al. (1987) analyzed 144 mtDNA samples from human groups of different origin and estimated the age of common ancestor as 150,000-290,000 years. Linda Vigilant et al. (1991) studied mitochondrial DNA of 189 people from different regions. Their direct maternal ancestry was found to converge to a single female in Africa called **"mitochondrial Eve"** that lived between 1,66,000 and 2,49,000 years ago.

Data on amino acid residues indicates that chimpanzee and gorilla are genealogically closer to man than to other apes. The fusion of acrocentric chromosomes, which is called Robertsonian translocation, has perhaps taken place, which reduced the number of chromosomes from 48 in apes to 46 in man. Such chromosomal rearrangements and also pericentric and paracentric inversions alter the metabolic pathways and thus produce reproductive isolation.

Single origin versus multiple origin of man

Molecular evidence seems to support the African origin of humans and then their migration to other continents to develop racial differences. All non-African mitochondrial DNA sequences are only variants of the African sequence, and African populations possess the maximum mtDNA variability suggesting their ancient character. A study by Hammer and co-workers of Y-chromosome of more than 1500 individuals from all continents also points to the African origin of man. Human populations all over the world are basically similar in anatomy and genetic composition and hence must have had a single origin in Africa.

Multiple origin hypothesis or multiregional proposal, on the other hand, suggests that all human populations in different continents evolved in parallel over long periods from *Homo erectus.* Hominids migrated out of Africa much earlier than the subsequent origin of modern man about 100,000 years ago in different geographic regions of the world. Fossils from the Chinese and Australian regions show continuous and independent progression from the *Homo erectus* stage to the present. Human ancestors were highly mobile creatures and hence constantly exchanged genes between populations to break the reproductive isolation and keep genetic variability to the minimum.

Cultural and social evolution of man

Modern humans, being highly social, learn from their experiences, share these experiences with the others and modify their behaviour based on constant learning. Unlike other animals, they are also capable of modifying their environment to suit their needs and keep considerable control over it.

An important difference between the genetic exchanges and cultural exchanges is that the former can take place between parents and offspring while the latter can take place among the unrelated individuals. Therefore, while the biological traits are transmitted *vertically* within the lineages, cultural traits are transmitted both *vertically* and *horizontally* within lineages or among the unrelated individuals.

Cultural evolution is therefore much faster than the genetic evolution. While the cultural evolution follows Lamarckian mode of inheritance, the biological evolution is driven by natural selection in which information is transmitted through DNA and the mechanisms of heredity. Cultural evolution is independent of genetic system and can take place without making any change in the genes.

EVIDENCES OF EVOLUTION

Fossils are the only direct evidences to suggest that evolution has actually taken place and that the species are not fixed but ever changing entities. Unfortunately fossil history of almost every species is incomplete; thereby the evidence of fossils cannot be entirely relied upon in evolutionary studies. Therefore, other evidences, albeit circumstantial, have to be taken into consideration while studying evolution. Some of such evidences are outlined below.

MORPHOLOGICAL AND ANATOMICAL EVIDENCES

While comparing different organs of animal body of various groups, some interesting facts emerge that can be used to demonstrate that gradual change has actually taken place in species.

Homologous organs: When organs of similar origin and ancestry are found to perform different functions they are called homologous organs. For example, limbs of all tetrapods have evolved from the same basic structure found in amphibians but they have modified to perform varied functions in different groups, such as fore limb of man, horse, frog, bat's and bird's wing, flipper of dolphin and fossorial leg of mole, all have the same basic arrangement of bones.

They all have humerus, radius and ulna, carpals, metacarpals and phalanges in the fore leg and femur, tibia and fibula, tarsals, metatarsals and phalanges in the hind leg. Only their shape and size has modified to suit the specific need of the animal. Serial homology in the limbs of different groups of arthropods from the basic crustacean plan is another striking example of evolutionary modifications.

Analogous organs: Analogous organs are those which perform the same function but have not evolved from the identical ancestral form but have independent origin. For example, wings of insects, bats and birds are used for flight but have evolved independently and thus structurally different. Insect wing is made of chitinous venation and membrane, wing of bat is made of skin called patagium stretched between fingers while bird wing is made of feathers but they are all used for flying. Bones that support the wing of bat and bird are homologous but the patagium and feathers are not.

Adaptations: Environment and ecological conditions change continuously, more so over a long period of time. This puts pressure on the animals and plants to either change accordingly or perish. We, therefore, find animals belonging to the same group, living in different environmental conditions and undergoing different modifications not only in their morphology but also in habits. This may lead to convergent, divergent or parallel evolution in species.

Convergent evolution: Whales and dolphins having lived in aquatic situations for such a long time have changed into fish-like form because the environmental conditions demanded it but they still continue to carry mammalian features such as suckling the young and breathing air. This is called *convergent evolution* in which unrelated organisms start resembling each other due to environmental influence. Pectoral fins of fish and flipper-like fore limbs in dolphin, sea turtle and penguins demonstrate similarity due to convergence.

Parallel evolution: Sometimes related animals evolve side by side and resemble each other due to evolving in the similar environmental conditions, e.g. ungulates: deer, antelopes, goats, sheep, cow, bison etc. offer identical adaptations for grazing and fast running. All carnivores belonging to cat and dog family show parallel evolution in modifications that help in hunting down the prey. In Australia, marsupials exhibit parallel evolution to the placentals of the world because they occupy identical ecological niches.

Adaptive radiation: Populations of widely distributed species often encounter various types of environmental conditions to which they must adapt gradually. Such populations diverge from each other and in the long run become different species or genera. This phenomenon is called *adaptive radiation* and was noticed by Charles Darwin in different species of finches found in Galapagos Islands. All these finches had evolved from a single population that was accidentally blown off the coast of South America and upon finding all ecological niches vacant, adapted to feeding on different kinds of food.

Coevolution: An interesting case of evolution can be seen in coevolution, in which two or more species depend so heavily on each other for their survival and propagation that they constantly evolve together. Predator-prey, host-parasite and symbiotic species offer such reciprocal adaptations. While the prey constantly looks for new methods of escaping from predation, the predator manages to acquire equally efficient techniques to catch the prey and the coevolution goes on. The most remarkable coevolution is often seen in flowering plants and their insect pollinators. The nectaries of flowers are often so concealed as to be found only by a particular species of insect pollinator.

Mimicry: Mimicry is a phenomenon in which two different animals resemble each other for gaining protection from the predators. In Batesian mimicry the model is protected and the mimic gets protection by resembling morphologically with the model. So the predators are confused and let the mimic go too. For example, the poisonous *Danaus* butterfly is mimicked by *Hypolimnas* female and is avoided by the birds.

In Mullerian mimicry both the model as well as the mimic are protected but still resemble each other so that damage done to the population by the learning predators is shared by the two species. Several tailed amphibians having poisonous glands resemble each other and so do the wasps and unpalatable moths.

Vestigial organs: They are those organs which were functional in the ancestors but have lost their significance due to changing circumstances. When organs lose their utility they start to atrophy and eventually become rudimentary. In man 180 such organs are present, e.g. vermiform appendix, ear muscles, plica semilunaris in the eye which is a rudiment of nictitating membrane, rudimentary tail vertebrae called coccyx, small canines, third molar, body hairs etc.

These organs were in use in prehistoric man who lived in caves and fed on raw diet but lost their utility when he started to cook food and live in protected situations. Similarly, ostriches and other flightless birds have functionless wings, which lost their value when these birds started depending on their running speed to escape from predators.

EMBRYOLOGICAL EVIDENCES

Ernst Haeckel (1866) studied embryos of various groups of animals and was struck by the resemblances of early embryos of all chordates. It is only at the later stage that they start looking different and show characteristics of the group. He postulated the famous phrase; *Ontogeny recapitulates phylogeny,* which means that the evolutionary history of an animal is repeated in the embryological development of the animal concerned. Thus, all animals start their life cycle as a unicellular zygote, and then become multicellular morula, hollow blastula and finally the triploblastic animal. Early embryos of all vertebrates possess typical chordate characters and resemble each other.

PALAEONTOLOGICAL EVIDENCES

Paleontology is the science that deals with the study of fossils of animals and plants in order to draw inferences in support of evolution. Fossil can be anything that can give an indication of the existence of prehistoric organisms. Majority of them are bones buried deep in the soil, which in the course of time turns into rock. Very old bones get petrified and no organic matter is left in them.

Often, impressions, footprints or molds and casts give a fairly clear idea of the animals to which they belonged. Most of the bird fossils, including that of *Archaeopteryx,* are impressions on the rocks as their bones are too fragile to be fossilized. Fossil footprints of dinosaurs found in America, Australia and also in India, give an idea of not only their size but also the way they walked. Rarely though, we are sometimes lucky to find complete animal preserved including its skin and hairs intact. Discovery of a frozen woolly mammoth in Siberia was such a lucky event but complete insect fossils preserved in amber are not a rarity for entomologists.

TAXONOMIC EVIDENCES

Taxonomy is the science of classifying organisms. The whole exercise of classification takes into account not only the morphological similarities and differences but also evolutionary relationships among different groups. The classification therefore reflects evolution.

The Swedish naturalist, Carl von Linne (1758) proposed the natural system of classification in his book, *Systema Naturae* and advocated that animals placed in the same group evolved from the common ancestor. For example, snakes and lizards belonging to order Ophidia have evolved from a common ancestral group; and monkeys, apes and man, which have been placed in order Primates, also have common ancestry.

CONNECTING LINKS AS EVIDENCES

While classifying animals we encounter certain animals, mostly living fossils, which fall between two groups as they exhibit intermediate characters. Such connecting links prove that major animal groups have not evolved suddenly and independently but have modified gradually through intermediate stages.

Viruses are capable of living in both non-living (crystallized) and living phases when they use host cell's machinery to multiply, suggesting that biochemical molecules must have combined to produce the most primitive life in the early atmosphere of earth. Connecting links are found between all major groups. For example, *Proterospongia* falls between Protozoa and Porifera, since many collared and amoeboid cells live in a common matrix as in sponges. *Neopilina,* which was caught from 3500 meter depth off the Pacific coast of South America has a single dome-shaped molluscan shell and a foot but is segmented and possesses nephridia as in Annelida.

Peripatus connects Annelida with Arthropoda by having characters of both the groups. It has annelidan pseudosegmented body, nephridia and simple eyes but also has arthropod clawed segmented legs, antenna and tracheal respiration. The egg-laying mammals, Monotremes, are so primitive that they still carry reptilian characters. The famous fossil of *Archaeopteryx* has long been considered a connecting link (fossil connecting links are sometimes called *missing links)* between reptiles and birds.

ZOOGEOGRAPHICAL EVIDENCES

It is generally believed that animals live and propagate in areas of suitable climate and abundance of food. But this contention does not get support from the actual distribution of animals in different continents and islands. Why animals are different in continents where climate is similar, such as in South America, Africa and Australia. Elephants, lions, giraffes, zebras, rhinoceros, apes, hippopotamus etc. that are so common in Africa are absent in South America and Australia.

Why bird fauna of South America is so different and new world monkeys are different from those found elsewhere. But South American tapirs and alligators also occur as far away as in Malaysia and eastern China respectively. On the other hand we come across endemism in monotremes and marsupials of Australia, which are not found anywhere else in spite of the similarity in climate in many places. Sclater (1857) was the first one to address these questions and based on his studies he divided the continental masses into six realms.

Later, A.R. Wallace (1876) carried out detailed studies on the subject and is aptly called father of zoogeography. The peculiarity of distribution of animals can be explained by the fact that animals have a tendency to disperse in all directions in areas of suitable environmental conditions but are restricted by the barriers and hostile environment. Camels and tapirs occur in Asia and South America, two widely separated continents. Similarly, alligators are found in America and China. Apparently these animals have distributed to these areas through land bridges whenever they appeared during the process of continental drift.

Zoogeographical studies reveal how evolution can proceed in different ways in different environmental conditions. Uneven distribution of animals over different continents clearly demonstrates that evolution is the direct result of adaptations of animals to mosaic environment.

PHYSIOLOGICAL AND BIOCHEMICAL EVIDENCES

The composition of protoplasm and nuclear material is similar in all animals. The biochemical reactions and the hormones and enzymes involved in them are also similar. For instance, all animals have glycolysis, Kreb's cycle, electron transport chain, urea cycle etc. that shows their relationships. Physiology of digestion, respiration, excretion, heart beat and endocrine system is similar with minor differences. This shows that all animals have evolved from the common primitive ancestral animals and developed complex physiological processes as they progressed through evolution.

George Nottal developed Precipitin Test to find out physiological relationship between different groups of animals. In this test blood of man (or any other animal) is injected into a rabbit to produce antibodies against it. Then serum of rabbit is taken and mixed with the blood of other animals to find out relationship. Coagulation of blood after mixing indicates close relationship, as in the case of chimpanzee. There will be no precipitation with the blood of a cat or dog. The precipitin test indicates physiological relationship between animals that has been produced by evolution.

CYTOLOGICAL EVIDENCES

Fundamental structure of cell remains the same in all animals whether lower or higher, suggesting that all animals have evolved from the primitive unicellular animals. Cell organelles, namely, mitochondria, golgi body, lysosomes, ribosomes, nucleus, nucleolus and chromatin are strikingly similar in all animals.

Also the process of mitosis and meiosis are identical, suggesting that all animals have a common origin and therefore inherited the same processes. RNA and ribosomes take part in protein synthesis in all animals and composition of DNA from adenine, guanine, cytosine and thymine in double helix is also the same. Had there been no evolution, animals should have developed different types of cellular compositions independently. Similarity in chromosomal bands in chimpanzee and man shows their close evolutionary relationship.

On the other hand plant cells are slightly different from animal cells by having cell wall made of cellulose and having chlorophyll but within plant kingdom, there is cytological similarity.

GENETIC EVIDENCES

Principles of heredity were discovered my Mendel by experimenting on plants but the same principles apply to animals as well. The mechanisms of mutation, chromosomal aberration, aneuploidy, polyploidy and hybridization are similar in all organisms. Composition and expression of genes is also similar, showing relationship among all animals.

New species are produced by gradual accumulation of genetic changes over long periods and finally producing reproductive isolation between two populations. Mutations can produce sudden changes and evolution of new types. In micro-organisms, such as bacteria and viruses, evolution can actually be seen happening as they mutate quickly and evolve new strains.

Closely related species are known to be genetically compatible and can produce hybrids, e.g. male donkey and female horse can produce mule, which is sterile. But in some species of insects fertile hybrids are known, which can give rise to new species almost instantly. Evolution can actually be demonstrated through cross-breeding experiments in animals.

EXPERIMENTAL EVIDENCES

Best argument in favour of evolution would be to experimentally demonstrate evolution happening. Since evolution takes a long time, sometimes millions of years, it is not possible to show species evolving, particularly in the case of higher animals such as vertebrates. But micro-organisms that have a short life cycle and therefore can complete hundreds of generations in short time, can be used in experiments to demonstrate evolution.

Lederberg's Replica plating experiment

Lederberg (1952) designed experiment in which he grew bacterium, *Escherichia coli,* under optimum conditions on a broth and could isolate any streptomycin resistant strain from the culture by growing the colony on sterile nutrient agar plate for easy identification. The colony growing on the agar plate could be transferred to another streptomycin containing plate by imprinting it on velvet and by pressing another plate against it.

The experiment demonstrated that mutations appeared spontaneously but were not selected in a streptomycin free environment. But when the culture was exposed to streptomycin, natural selection operated and the culture transformed gradually into a resistant one. Bacteria and viruses evolve so quickly that the process of evolution can actually be demonstrated.

Experiment by Luria and Dulbruk

Salvador Luria and Max Delbruck (1943) designed a Fluctuation Test Experiment in which they grew populations of *Escherichia coli* in flasks containing viruses and then checked the growth of colonies on nutrient agar plates. The experiment demonstrated that the bacteria can change from virus sensitive to virus resistant forms when exposed to virus containing cultures.

Melanic moth

The industrial melanic moth *(Biston betularia)* occurred in light grey form in England before the industrial revolution, because the light colour of its wings provided it with selective advantage to camouflage against the lichen-covered tree trunks. After the industries came up in 1848 and smoke coming out of them killed lichens, baring the dark tree trunks against which light coloured moths could no longer camouflage, the mutant dark coloured forms appeared and replaced the light coloured ones within a span of 50 years. This shows how species can change along with the changing environment.

NATURAL SELECTION

Darwin's observations during the voyage of the Beagle made him think differently and changed his views permanently. He started believing that species change gradually due to the force of natural selection and started writing his ideas. In 1859, Darwin published his famous book, "Origin of species" that gave details of the theory and made Darwin a celebrity. Ever since, the theory is known as Darwinism or Darwin's theory of Natural Selection.

In his theory, Darwin gave details of his observations in different parts of the world during the voyage of the Beagle, from which he made two deductions and in the end concludes that natural selection takes place.

Observations

1. Overproduction: Darwin said that all organisms, without any exception, reproduce at a much higher rate than required. For example, fishes lay millions of eggs during spawning. Each oyster can lay 60-80 million eggs. Darwin calculated that if a pair of houseflies lays all its eggs and if all off-springs survive and reproduce to their full potential, then in one season (March to October) it will leave a progeny of 191,000,000,000,000,000,000 individuals.

Elephant is considered to be the slowest breeder. Its reproductive age is 30-100 years, during which it produces only 6 youngs. Darwin says even this is overproduction because if all off-springs and their off-springs survive and reproduce, then one pair will give rise to 19 million off-springs in 750 years.

2. Number is constant: In spite of overproduction by all organisms, their number in a given area remains more or less constant. All ecosystems have a limited capacity to support a particular species of organisms, e.g. a pond can support a fixed number of fish and a forest can support a fixed number of tigers or deer.

3. Variations: No two individuals are alike, even within a species, race or cohort. There are variations among individuals in appearance, physiology and capacity to starve, run and tide over cold or heat and many other traits. Darwin believed that all variations are heritable and he gave some weightage to Lamarckism because he did not know mechanism of heredity.

Deductions

4. Struggle for existence: From the first two points, that is, overproduction is going on in nature everywhere but the number of organisms that can be supported by any ecosystem has to be constant, Darwin deduced that large number of off-springs produced will have to struggle among themselves to survive. Large number of individuals will perish in this struggle and few will be able to reach adulthood. Darwin believed that the struggle among the animals is always in the form of physical combat.

5. Survival of the fittest: As the struggle for existence is fierce, according to Darwin only the fittest individuals survive it and reach adulthood to reproduce and leave offspring. As Darwin gave a lot of importance to physical strength in the struggle, he believed that fittest is the individual which is physically strong and is able to fight for food, space, mates and can also escape predators and survive to reproduce to become parent of the next generation.

Conclusion

Natural selection: When animals overproduce, nature has a large number of individuals to choose from. Variations and struggle for existence give it the variety from which it selects the fittest individuals that become the parents of the next generation. Therefore, nature selects the cream from generation to generation and unfit and weaker individuals die out. Natural selection is a refining process, which brings improvement in a species from generation after generation, making the species fittest to live in a specific environment. Thus the species constantly changes and evolution goes on forever.

Criticisms of Darwinism

1. Darwinism mentions about survival of the fittest but does not explain about 'Arrival of the fittest', which means a character needs a long time to develop before it can become useful or fittest. For example, bird's wings or electric organs of fish must have taken millions of years to develop fully and during this period of growth they were not useful organs and therefore should have been eliminated by natural selection.

2. Darwin believed that all variations are heritable, which is not true. Only genetic variations are heritable and not the somatic ones. During Darwin's time mechanisms of heredity were not known and hence he tried to explain the inheritance by his theory of **pangenesis.**

3. Many useless and non-adaptive characters also persist in many animals and are not eliminated. For example, small tails in giraffe or pig and ear muscles and appendix in man have no selective value.

4. Darwinism does not explain over-specialization, which ultimately led to the extinction of the species. For example, dinosaurs became extinct due to overspecialization in body size. Sabre tooth tiger *(Smilodon)* had oversized canines, which led to its extinction in Africa. Similarly Iris deer *(Megaloceros)* grew such huge antlers that they interfered in its movement through the forest and ensured its extinction.

5. Struggle for existence is not a physical one as Darwin suggests. Most of the time it is passive as for example many species of insects and other animals camouflaging against the predators do not actually fight physically.

6. Most of the mutations that produce new characters are harmful and cause diseases and therefore not useful in natural selection. Darwin did not know about mutations and explained sudden appearance of characters due to "Spots" or "Sports".

7. Natural selection does not operate on one character as Darwin thought.

8. Darwin believed in blending inheritance, according to which characters of both parents blend in the offspring. But now according to the Mendel's laws of heredity, it is known that characters segregate in the second generation.

Neo-Darwinism - Synthetic theory of natural selection

Modern theory of evolution

Darwin's theory lacked an input of modern concepts of genetics and the mechanisms how characters appear and persist in a population. Darwinism, although basically sound, now needed improvements in several aspects of the theory. Neo-Darwinism is originally associated with Weismann (1834-1914), who tried to explain inheritance of characters by his theory of germplasm.

He divided body into two parts: somatoplasm and germplasm and explained that only those characters that are in germplasm are heritable. Synthetic theory emerged by the synthesis of the original idea given by Charles Darwin and addition of new knowledge of genetics, population dynamics, statistics, and heredity to the theory. This is the most modern theory of evolution and has been constantly improved during 20thcentury by the contribution of the following scientists: R.A. Fischer, J.B.S. Haldane, Ernst Mayr, Julian Huxley, G.G. Simpson contributed with their studies on population dynamics. T. Dobzhansky, H.J. Muller, H. DeVries, G.L. Stebbins added information on genetics and mutation. G.H. Hardy, W. Weinberg, Sewall Wright did extensive work on population genetics and statistics, which helped to understand the mechanism of heredity.

The modern synthetic theory in its present improved form can be outlined as follows:

1. Overproduction: This point of Darwinism that says that organisms have a tendency to reproduce at much higher rate than required is retained in this theory without any change.

2. Limited space and food: Earth as well as all its ecosystems has limited space, which cannot be stretched to accommodate unlimited number of animals. Similarly food supply that any ecosystem can provide is also limited.

3. High death rate: All offspring produced do not reach maturity but only a small number of them manage to gain adulthood and reproduce. A large number die due to limitations of space and food, which imposes struggle for existence among them.

4. Variations: Variations are differences among the closely related individuals. According to the new theory, only heritable variations are important in evolution, which are caused by haphazard mutations, chromosomal aberrations, aneuploidy, polyploidy, hybridization etc. Somatic variations are short-lived and therefore have no value in natural selection. For details see chapter on Variations.

5. Net reproductive differential: Reproductive differential is the ability of a species to leave more progeny than the others in the next generation. It is different from reproductive capacity, which simply means producing more offspring. In reproductive differential, the offspring must also survive, grow and produce the next generation.

Therefore, leaving more individuals in the next generation is more important for the competing species. All beneficial characters help in reproductive differential, which may be physical, behavioral, physiological or morphological.

Dice's experiment with mice explains this phenomenon more clearly. He placed equal number of white and brown mice in a large cage that had natural terrain, with bushes rocks etc. There was plenty of food and their reproductive rate was almost same. Dice released a pair of owls in the cage and allowed the mice to breed for several generations. There were no limiting factors in the cage except that the brown mice could camouflage against rocks and bushes whereas white mice were prominent and could be easily spotted by the owls. Dice found that white mice died out gradually, while brown mice survived and flourished.

6. Speciation due to isolation: Speciation is the origin of one to several species from the ancestral ones, due to isolation. When species are split into two populations due to geographical isolation, they separately accumulate several inversions, translocations and mutations and become reproductively isolated in due course. Isolation is the primary requirement for the formation of species. For details see chapters on Isolation and Speciation.

Examples of natural selection

1. The industrial melanic moth: *Biston betularia,* the industrial melanic moth, is a gray colored moth that perfectly camouflages on tree trunks covered with lichen in England and escapes predation by birds. With industrial revolution in England in the middle of 19^{th} century, lichens on tree trunks got killed due to smoke belching out of factories. Tree trunks were now bare and dark and made the light gray moth prominent to the predatory birds. Now natural selection favoured dark coloured moths, which could camouflage on bare tree trunks. Since the moth has only one generation in a year, in less than 50 generations, the natural selection replaced gray population with black population.

2. Resistance in mosquitoes and houseflies: DDT was used extensively, sometimes by airplanes over large areas. Initially it killed 99% of mosquito population but at the same time put a lot of pressure on the surviving individuals to mutate. Mutant resistant strains survived DDT application and became the parents of the next generation. Natural selection preserved the resistant populations and eliminated the susceptible ones. This can be called an artificial selection by man, due to which today not only mosquito and housefly but also many agricultural pests have become resistant to most of the available insecticides.

3. Liederberg's replica plating experiment: Liederberg (1952) conducted experiment on *Escherichia coli* by exposing the susceptible strains to penicillin repeatedly. As the generation time of the bacterium is 20-30 minutes only, hundreds of generations could be cultured and exposed to penicillin within a short time. He found that mutations for resistance appeared instantly and quickly replaced the susceptible populations by natural selection.

4. Fluctuation test experiment: Salvador Luria & Max Delbruck (1943) cultured a population of *E. coli* in one flask along with bacteriophage viruses. He then cultured samples from the flask on agar plates and found similar growth on all agar plates. He found that in some flasks instant mutations had appeared for resistance against viruses while in others susceptible strains died out. This experiment proved that in populations exposed to environmental extremes, either the mutants appear or hidden recessive mutations express and get exposed to natural selection and save the population from the possible extinction.

Natural selection is a phenomenon that forces the species to keep improving generation after generation so that they remain in the fittest state to survive in a particular environment. Random genetic changes provide raw material that causes variations and gives natural selection a chance to operate.