Some Important Scientific Advancements

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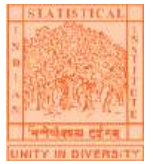
Advancements to be Discussed

- Fundamental primitive inventions.
  - Fire and wheel.
- Biological sciences.
  - Pharmacology and Human Anatomy.
  - Theory of evolution.
  - Genetics
- Physical sciences.
  - Atomic theory.
  - Periodic table.
  - Atomic structure.
  - Chaos.
  - Communication.



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Why?

- Brush up on general awareness.
- Interpret developments in terms of theories about science.
- View connections between subjects at a high level.
- Possibly obtain some insight into how scientific discoveries are made.
- Get inspired!

Disclaimers.

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Fundamental Primitive Inventions

- Fire.
  - Methods to *create* and *control* fire is the basic requirement of all further progress.
  - Prometheus: a titan from Greek mythology who gave fire to mortals.
- Wheel.
  - Movement of heavy objects.
  - Potter's wheel.
  - But, the Incas had not invented the wheel!



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Biological Sciences

- Pharmacology and Human Anatomy.
- Theory of evolution.
- Genetics



Pharmacology and Human Anatomy

- ‘De Materia Medica’ by Pedanius Dioscorides (circa 40-90 AD).
  - A 5-volume encyclopedia about herbal medicine and related medicinal substances.
  - Remained in use until about 1600 AD.
- ‘De humani corporis fabrica’ by Andreas Vesalius (1543).
  - Presents a careful examination of the organs and the complete structure of the human body.
  - A major error: blood flowing through veins is different from that through arteries.
- William Harvey (1578-1657).
  - Complete and detailed description of the systemic circulation and properties of blood being pumped to the body by the heart.



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Theory of Evolution

An explanation of how diversity arises in living organisms.

- Evolution: change over time in inherited traits of living organisms.
  - Traits: distinguishing features, such as anatomical, biochemical or behavioural features.
  - Evolution arises from variation (due to genetic causes) of traits in a population.

Causes of evolution.

- Natural selection and adaptive evolution: different chances of survival and/or reproduction of organisms that differ in one or more inherited traits.
- Genetic drift: differences in inherited traits arising from random genetic changes – neutral theory of evolution.



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  - Presented the theory of natural selection in details and provided supporting evidence.
  - In 1858, independent papers by Charles Darwin and Alfred Wallace had introduced similar ideas.
- Darwin was unable to explain the variations in traits for natural selection to work on.
  - Inheritence of acquired characteristics (Jean-Baptiste Lamarck): changes acquired during the life of an organism may be transmitted to offspring (Lamarckism).



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- Thomas Hunt Morgan (early 20th century): genes are carried on chromosomes and are the mechanical basis of heredity.
- Population genetics: combination of evolution by natural selection and Mendelian inheritance.
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Genetics

- Proteins are the main building blocks and functional molecules of cells (and life).
- Protein: sequence of amino acids.
- There are about 20 natural amino acids.
- A universal genetic code specifies these amino acids.
  - Codon: 3-letter ‘string’ over {A,T,C,G}.
  - 64 strings and 20 amino acids.
  - Different codons encode the same amino acid.
- Gene.
  - Unit of heredity.
  - Holds information to build and maintain an organism’s cells and pass genetic traits to offspring.
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Genetics/Genomics

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  - Totality of genes in an organism.
  - Stored on one or more chromosome.
  - A chromosome consists of a single DNA helix on which thousands of genes are located.
- Locus: specific location of a gene on a chromosome.
- Allele: a variant of a gene at a given locus.
  - Each gene can have different alleles.
  - Alleles determine gene expression: different alleles can have different or same trait.
- Genetic map: ordered list of loci for a particular genome.
- Gene mapping: process of determining the locus for a particular biological trait.



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History of DNA Research

- 1869: DNA was first isolated by the Swiss physician Friedrich Miescher.
  - Discovered a microscopic substance in the pus of discarded surgical bandages.
- 1919: Phoebus Levene identified the base, sugar and phosphate nucleotide unit.
- 1937: William Astbury – the first X-ray diffraction patterns.
  - Showed that DNA had a regular structure.
- 1928: Frederick Griffith discovered that traits of the "smooth" form of the Pneumococcus could be transferred to the "rough" form of the same bacteria.
  - First clear suggestion that DNA carries genetic information.
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- 1952: Hershey-Chase experiment.
  - DNA is the genetic material of the T2 phage.
  - DNA's role in heredity was confirmed.
- 1953: James D. Watson and Francis Crick suggested the double-helix model of DNA structure. The model was based on two things.
  - A single X-ray diffraction image taken by Rosalind Franklin and Raymond Gosling in May 1952.
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Genetic Engineering

- Direct human manipulation of an organism's genetic material in a way that does not occur under natural conditions.
  - Insertion of new genetic material at an unspecified location in the host genome.
  - Knocking out specific genes.
- Applications and potential.
  - Medicines such as insulin and human growth hormone are now produced in bacteria.
  - insect resistant and/or herbicide tolerant crops have been commercialized.
  - Potential for cheaper biotechnology drugs from genetically engineered plants and animals.



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Physical Sciences

- Atomic theory.
- Periodic table.
- Atomic structure.
- Chaos.
- Communication.



Atomic Theory

- Concept of an atom/parmanu (around 500 BC).
  - Maharishi Kanad (India), Leucippus, Democritus: a fundamental indivisible unit.
  - Pakudha Katyayama: particles normally exist in combined forms.
- John Dalton (1808): atomic theory.
  - All matter is made up of atoms which are neither created nor destroyed in a chemical reaction.
  - Atoms of a given element are identical in mass and properties.
  - Atoms of different elements have different masses and properties.
  - Atoms combine in ratio of small whole numbers to form compounds.
  - In a given compound, the relative number and kinds of atoms are constant.



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Periodic Table

- Classification of chemical elements.
- Invention is generally credited to Russian scientist Dmitri Mendeleev in 1869.
  - Previous versions exist.
  - Mendeleev intended the table to illustrate recurring (“periodic”) trends in the properties of the elements.
- The layout of the table has been refined and extended over time.
  - Discovery of new elements.
  - New theoretical models have been developed to explain chemical behavior.
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- Werner Heisenberg (1926): uncertainty principle.
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Sub-Atomic Particles

- Bosons (obeying Bose-Einstein statistics) and Fermions (obeying Fermi-Dirac statistics).
- Quarks: belong to Fermion group of particles; there are six types of quarks.
- Lepton: a basic constituent of matter of which the electron is an example.
- Gluons, gauge bosons, Higgs boson, graviton, ...



Chaos: A Twentieth-Century Theory

- Behaviour of certain kinds of dynamical systems.
  - Butterfly effect.
  - High sensitivity to initial conditions.
  - (Topological mixing: given open sets A and B, there is an n such that $f^n(A) \cap B \neq \emptyset$.)
- Observable even in some deterministic systems.
  - Being deterministic does not necessarily make the system predictable.
- Observation of chaotic behaviour.
  - Weather systems, population growth in ecology, molecular vibrations, electrical circuits and lasers, oscillating chemical reactions, fluid dynamics, mechanical devices, ...
- Some major contributors.
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Communication: Electric Telegraph

- Electricity: a long history.
- 1825: William Sturgeon invented the electromagnet.
  - Magnetism caused by passing of electric current.
- 1830: Joseph Henry sent current over one mile of wire to activate an electromagnet which caused a bell to strike.
- 1837: William Cooke and Charles Wheatstone patented the design of a telegraph based on the principle of electromagnetism.
- 1835: Samuel Morse proved that signals could be transmitted by wire.
  - Pulses of current were used to deflect an electromagnet.
  - This moved a marker to produce written codes on a strip of paper.
  - Led to the invention of Morse Code and the successful telegraph.
  - First public demonstration in 1838.
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Alexander Graham Bell and Thomas Watson.

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- Basic principle: showed that different tones vary the strength of an electric current in a wire.
- Transmitter: requires a membrane capable of varying electric currents.
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Communication: Wireless

- James Clerk Maxwell: mathematically predicted the existence of electromagnetic waves of different wavelengths.
- Heinrich Hertz (1888): showed experimentally the existence of electromagnetic waves in free space.
- Nikola Tesla (1893): demonstrated the first public radio communication.



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  - 1894: ignited gunpowder and rang a bell at a distance using millimetre range microwaves.
  - 1899: presented the “iron-mercury-iron coherer with telephone detector”; (coherer: Hertzian wave detector).
  - First to use a semiconductor junction to detect radio waves.
  - Invented various microwave components.
- Guglielmo Marconi:
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Communication Theory

‘A Mathematical Theory of Communication’: Claude Shannon (1948).

- Introduced the notion of information as a measure of randomness.
- Considered the problem of reliable communication over a noisy channel.
- Showed that reliable communication is possible if the rate of communication did not exceed the ‘channel capacity’.
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