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1 CHAPTER BIOTECHNOLOGY

➔ BASICS: DNA, RNA, CHROMOSOME, GENOME

1. WHAT IS DNA?

DNA (deoxyribonucleic acid) can be looked at in two ways:

- As code of life
- As vehicle of heredity

2. DNA AS CODE OF LIFE

- DNA carries the genetic information in the form of genes, which encode a complete set of instructions for building and maintaining an organism.
- The code is present in the nucleus of every cell of every living organism (with few exceptions like RBC, certain viruses etc.)
- The code is read by a host of machineries in the cell to build proteins which are the building blocks of life. (Proteins constitute 55% of the dry mass of the cell. Everything from the cell's structure to enzymes are made of proteins.)

3. WHAT IS CHROMOSOME?

- Chromosomes are thread-like structures found in the nucleus of cells that carry genetic information. They are composed of DNA (deoxyribonucleic acid) and proteins.
- Normally, each cell in the human body has 23 pairs of chromosomes (46 total chromosomes). This includes 22 pairs of autosomes plus one pair of sex chromosomes. Females have two X chromosomes (XX), while males have one X and one Y chromosome (XY).

4. WHAT IS GENOME?

A genome is an organism's complete set of DNA or genetic material. It is a collection of all the genes and the regions between the genes contained in our 23 pairs of chromosomes.

BUILDING BLOCKS OF DNA

- The building blocks of DNA are called nucleotides. Each nucleotide is made up of three main components:

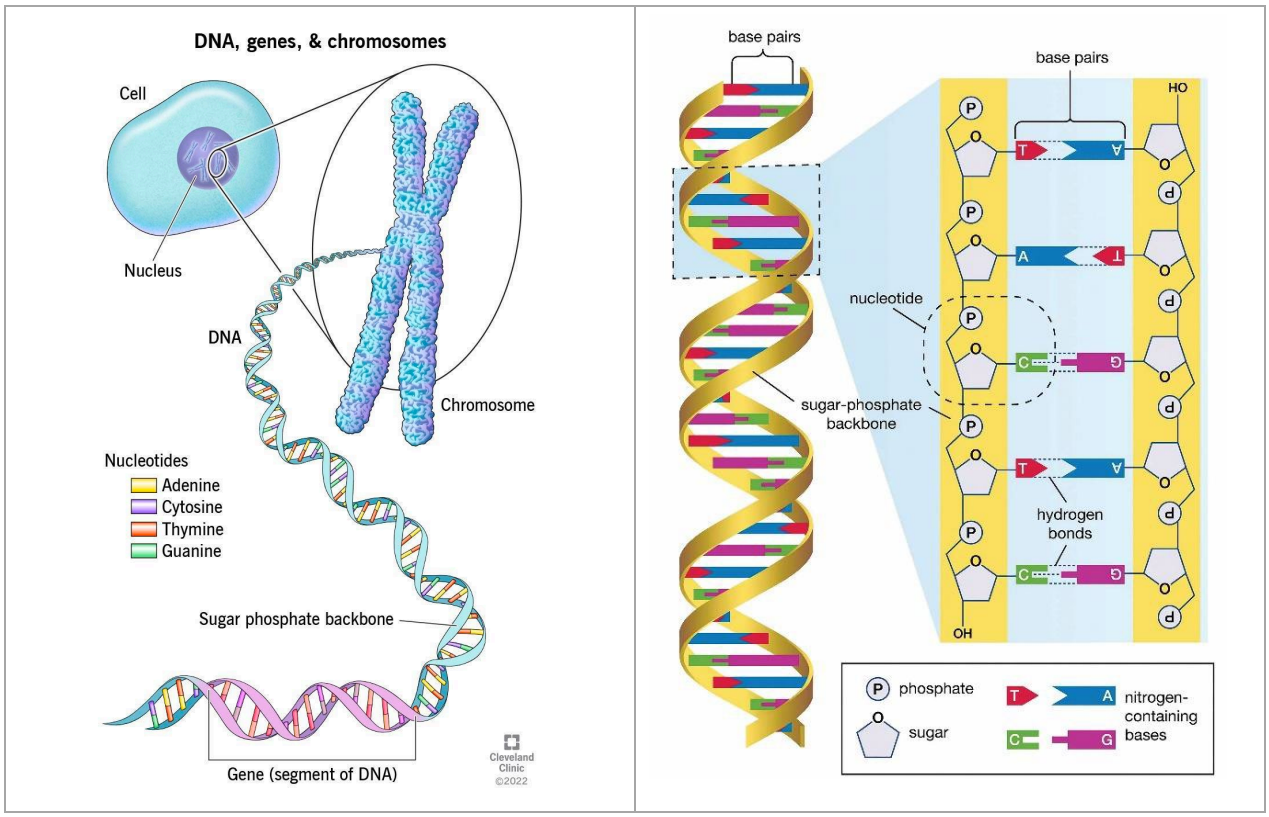
(i) **Sugar molecule**: A five-carbon sugar molecule, called deoxyribose, provides structural support to the DNA molecule.

(ii) **Phosphate group** attached to the deoxyribose sugar molecule. The phosphate groups contribute to the overall negative charge of the DNA molecule and play a role in linking nucleotides together to form the sugar-phosphate backbone of the DNA strand.

(iii) **Nitrogenous base (4 bases):** Adenine (A), Guanine (G), Cytosine (C) and Thymine (T).

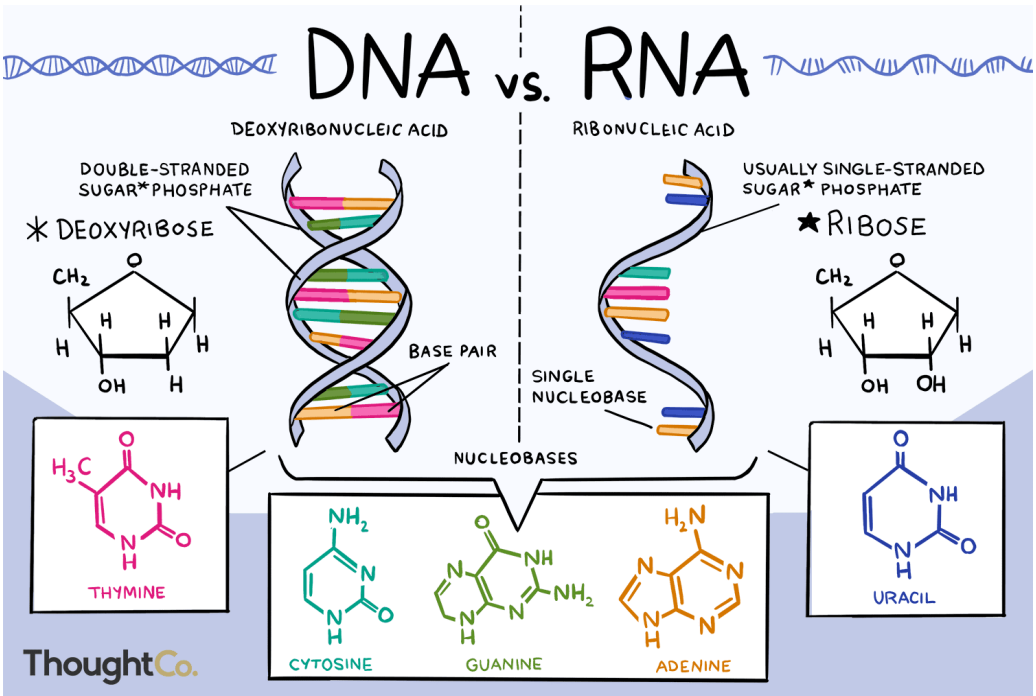
Specific sequence of these four nitrogenous bases determines the genetic code. These bases pair up specifically (A-T and C-G) forming the "rungs" of the double helical structure of DNA. (So if you know one strand you know what is on the other)

Note: While in nature only 4 lettered-DNA is found, scientists have recently created a synthetic DNA with 8 letters. The human genome is made of 3 billion base pairs. (So total 6 billion bases)



5. MITOCHONDRIAL DNA

- In addition to the nucleus, some DNA is also present in the mitochondria (mtDNA). Mitochondria are cellular organelles found in the cytoplasm, aka powerhouse of the cell as they generate most of the cell's energy currency- ATP (adenosine triphosphate).
- mtDNA codes for a small number of genes, essential for the proper functioning of mitochondria. In humans, mtDNA is circular and much smaller (consists of about 16,500 base pairs), compared to nuclear DNA.
- **Inheritance:** Unlike nuclear DNA which come from both parents, mtDNA is inherited almost exclusively from the mother. This is because mitochondria are primarily contributed by the egg cell during fertilisation. While sperm cells do contain mitochondria, these mitochondria are typically not incorporated into the developing embryo.



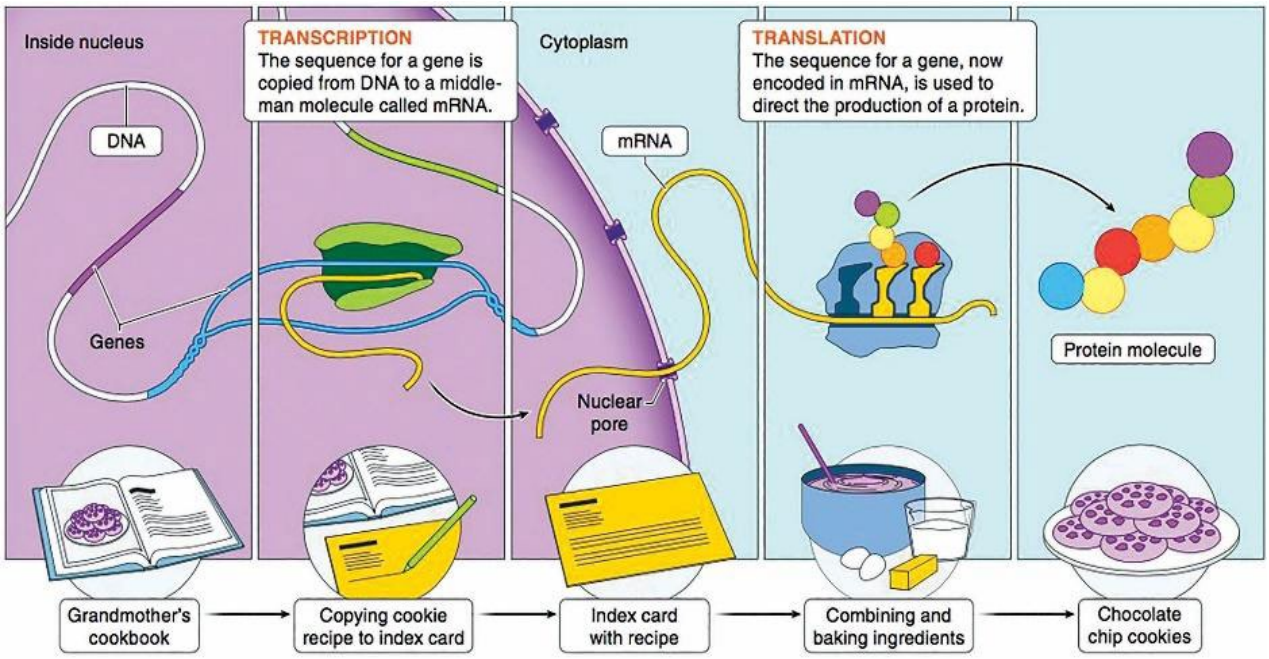
6. WHAT IS RNA?

- RNA (Ribonucleic acid) in a single-stranded molecule/ nucleic acid found in most living organisms and viruses. It is made up of nucleotides, which are ribose sugars attached to nitrogenous bases and phosphate groups.
- The nitrogenous bases include adenine (A), guanine (G), uracil (U) and cytosine (C).
- **Major types of RNA:**
  - **mRNA:** messenger RNA molecules copies the genetic information/ instruction from DNA and carries it to ribosomes, where protein synthesis occurs. In order to transcribe, mRNA uses an enzyme called RNA polymerase.
  - **tRNA:** transfer RNA assists in translation of mRNA into proteins by bringing amino acids to the ribosome. t-RNA brings amino acids that are lying in the cell after reading 3 letters of mRNA at a time (3 letters or codon translate into one amino acid).
  - **rRNA:** ribosomal RNA molecules are structural components of ribosomes (cellular structures where protein synthesis takes place).
- RNA is generally less stable than DNA due to the presence of an extra hydroxyl (OH) group on the ribose sugar in RNA. This makes RNA more prone to degradation by enzymes called ribonucleases. DNA, with its deoxyribose sugar lacking the extra OH group, is more stable and less susceptible to enzymatic degradation.

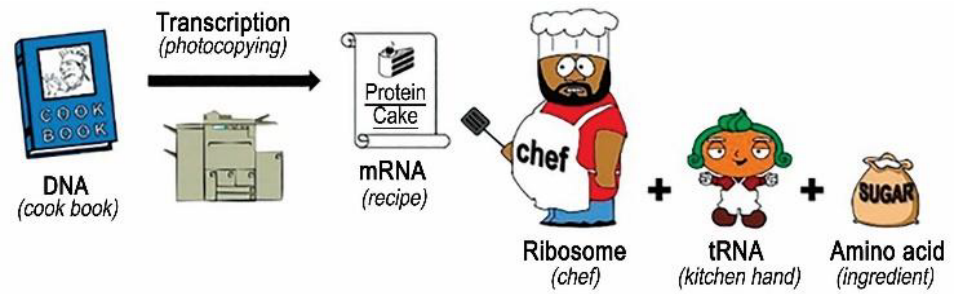
CENTRAL DOGMA

Central dogma of molecular biology explains how genetic information flows from DNA to RNA to proteins.

- **Gene expression** is the process our cells use to convert instructions in DNA into proteins. This happens in two-stages called transcription (occurs in the nucleus, in eukaryotic organisms) and translation (occurs in cytoplasm).
  - **Transcription**: mRNA copies the sequence of a gene from DNA, and then leaves the nucleus and travels to cytoplasm.
  - **Translation**: Using the template encoded by mRNA, translation is carried out by ribosomes, i.e., the information in the mRNA is used to synthesise proteins (building blocks of life).



CENTRAL DOGMA (COOKBOOK ANALOGY)



- Consider DNA to be a cookbook of recipes for making proteins. Transcription is the process of photocopying the recipe (done by mRNA inside the nucleus).
- Once copied the recipe mRNA goes outside the nucleus to the chef (ribosome). There is also a translator, tRNA who translates mRNA recipe to rRNA of the ribosome which then makes Amino acids (the building blocks of proteins).
- A block of 3 letters in the mRNA corresponds to 'cooking' of 1 Amino acid. Each 3-letter base in mRNA that is read by tRNA that corresponds to one amino acid is called 'codon'.
- Many Amino acids come together to form the primary structure of protein. The primary structure is twisted and folded to make a 3-D structure of protein.

GENE

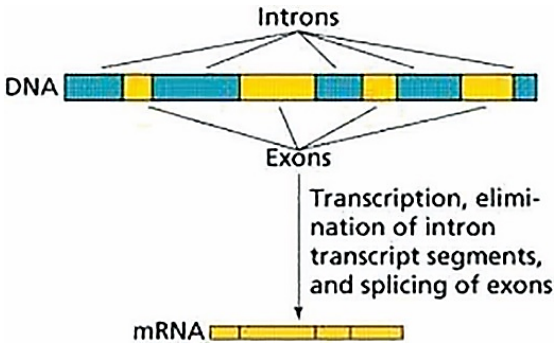
- The **Human Genome Project** (completed in 2003) found that only 1.5% of the total human genome (3 billion base pairs) codes for proteins. (The coding parts of protein are called **genes**)
- It also found that humans have about 20,000–25,000 genes. Remaining 98.5% of the genome is non-coding, meaning it does not provide instructions for making proteins.

EPIGENETICS: IT'S ALL ABOUT GENE EXPRESSION

- For a long time, non-coding regions of the genome (98.5%) were thought to be 'dark area' or 'Junk DNA', because they did not appear to have any specific purpose.
- However, new studies suggest that they play a huge role in gene expression which has become an important area of study in recent times called epigenetics.
- **Epigenetics** deals with the processes that control how the genes are expressed.
  - We know that all the cells in our body have the same genome. Average human body contains approximately 37.2 trillion cells and about 220 different cell types.
  - If the same code (genome) exists in the nucleus of all these cells, how 220 odd cell types make up for 4 different tissue types and 78 different organ types, all working in unison to make human life possible?
- The answer lies in **gene expression**. Different genes are expressed in different cells that perform different functions that look differently. (like your heart cell and your kidney cell)

INTRONS, EXONS AND RNA SPLICING

- As we have seen, mRNA is a copy of only the coding part of DNA (gene).
- The coding part does not occur on chromosomes in one single sequence as one whole. It is spread out on a chromosome in parts. Each part is separated by a non-coding part of the genome.
- In fact, 25% of all the non-coding parts occur in between genes.



- The non-coding parts between genes are called **introns** and the coding parts that mRNA is interested in are called **exons.**

Click here for INDEX

- So, mRNA must copy only exons and cut out all the introns. This cutting of introns to join only exons is called **RNA splicing.**
- The final mRNA after splicing of introns is called **exome** (which represents only 1.5% of the genome). It is this final mRNA after splicing that is important for coding for protein.

MUSCULAR DYSTROPHY

- One type of muscular dystrophy, a genetic disease, is a result of defect in RNA splicing while copying X-chromosome.
- Since it is associated with the X-chromosome it is more prevalent in males as they have only one X-chromosome.

7. GENOME SEQUENCING: READING THE CODE OF LIFE

Genome sequencing in simple words is reading the entire book of genome letter by letter (base by base). It is a procedure for determining the precise order of the four nucleotide bases (A,T,C,G) in DNA.

Sequencing Technologies:

- **Short-read**: Earlier approach to sequencing, where the genome was chopped into small fragments which could be reassembled like a jig-saw puzzle. In this approach we read 150 bases at a time. Reading short segments of the genome was time-consuming and labour intensive.
- **Next-Generation sequencing:** Use of computers to read multiple fragments at the same time in an automated process which makes whole-genome sequencing relatively faster, accurate, automated and cheap. (dominant method)
- **Nanopore sequencing:** Use of nanotechnology enabled reading longer sequences of the genome (2.3 million base long sequences at once). The technique is also suitable for identifying pathogens in food, disease control and diagnosis of infection.

Applications of Genome Sequencing:

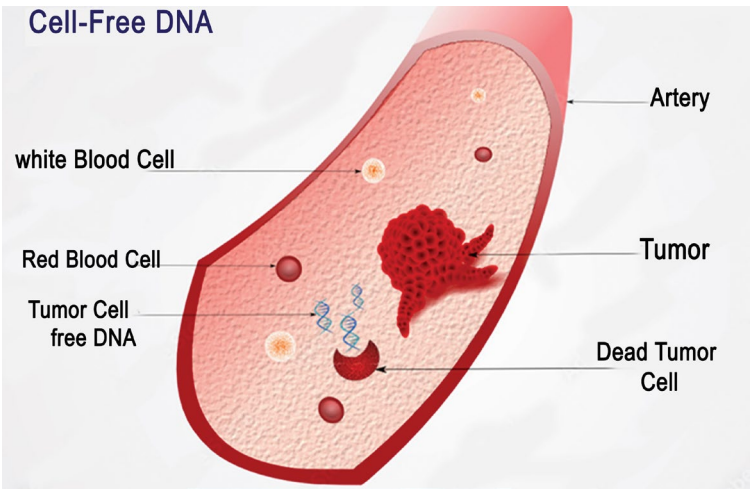
- **Disease diagnosis and Personalised drug development**: Identify genetic mutations and variations, evaluate rare disorders and even cancer from genetical viewpoint. **E.g.,** Mutation in MYBPC3 (Cardiac Myosin binding protein) leads to cardiac arrest at young age (found in 4.5% of Indian population but is rare globally).
- **Agriculture:** Help identify genes that contribute to desirable traits in plants and animals, allowing for selective breeding of crops and livestock.
- **Tool for prenatal screening** to investigate whether a foetus has genetic disorders/anomalies.
- **Identify suspects in criminal investigations** and establish paternity in cases of disputed parentage.
- **Help trace the evolutionary history** of species and understand the mechanisms underlying evolution.

Important Genome Sequencing Initiatives:

NAME	SIGNIFICANCE
Human Genome Project (1990-2003)	Led to the decoding of the entire human genome for the first time, giving the ability to read nature's complete genetic blueprint.
IndiGen (completed 2019)	Initiated by Council of Scientific and Industrial Research (CSIR) from April 2019 to October 2019. **Aim:** To sequence whole genomes of 1029 individuals from diverse ethnic groups across India.
Genome India Project (2020-2023)	To create a comprehensive reference database of genetic variations and subsequent data analysis of 10,000 individuals representing India's diverse population. Entire dataset will be stored at **Indian Biological Data Centre** (India's only data bank for life-sciences) and made available as a digital public good or research.

Genomic in Indian agriculture	Wheat Genome Sequencing Programme Rice Functional Genomics National Plant Gene Repository programme Next Generation Challenge Programme on Chickpea Genomics INDIGAU: Genomics of cow
National Genomic Grid	**Aim:** To collect cancer cells and tissues to facilitate cancer research in India. Uses genome sequencing of cancer cells to study genomic factors influencing cancer in the Indian population.
Earth Bio-genome Project	International effort to sequence and digitise the genomes of every eukaryotic biodiversity on Earth over a period of 10 years. It is an open-source DNA database. **Application:** Planning environmental conservation initiatives.
Human Microbiome Project	To study genes of microbes in the human body including gut, skin, oral cavity and vagina to study their role in human health and diseases. **Note:** Human body contains 10 times as many microbes as human cells.
DeepVariant: AI in genomics	Google's AI system that converts sequencing data from high-throughput sequencing into an accurate picture of the entire genome.
AlphaFold	Google's AI system that is capable of predicting protein modelling. Important to understand diseases and corresponding drug development.

8. CELL-FREE DNA



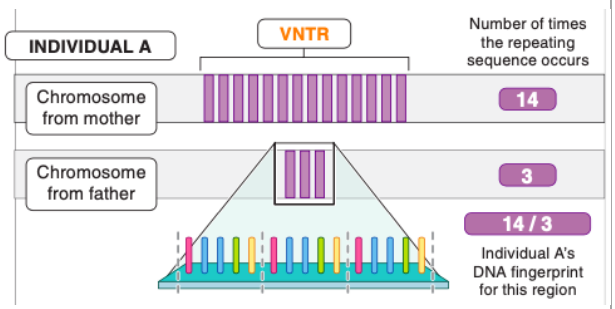
- Cell-free DNA (cfDNA) refers to fragments of DNA found in bodily fluids such as blood, urine, saliva, and cerebrospinal fluid.
- They are released into the bloodstream by cells that underwent programmed cell death or an unplanned cell death due to any injury or disease.
- These degraded (non-functional) fragments of nucleic acids do not possess the ability to replicate or carry out cellular processes.
- However, cfDNA can carry genetic information from the cells they originated from, making them a valuable source for various applications.

Important applications of cfDNA:

- Non-invasive prenatal testing to screen for chromosomal abnormalities in a developing foetus like Down syndrome, Edwards syndrome etc.
- Can provide information about genetic mutations and alterations present in tumour cells and early cancer detection.
- Aid in diagnosis of infectious diseases and in forensics.
- Used as a biomarker for neurological disorders like Alzheimer's disease etc.
- Provide an early indication of graft rejection in patients who underwent organ transplants.

9. VARIATIONS IN THE GENOME: IDENTITY MARKERS

- Humans are 99.9% identical in genome to one another. But given the size of the human genome (3-billion base pairs), even a small (0.1%) proportion of variation is huge.
- The variation in the base pairs is called polymorphism. They are very important to decide the complete make-up of an individual including one's eye colour, susceptibility to disease, one's parentage and even ancestry etc.
- Further variations can be of many types, like single base variation, large sequence variation, variations in the way sequences are structured etc.
- Study of variations has interesting applications. (see table)

DNA Fingerprinting / DNA profiling	• There are some sequences in our genome (15 to 100 bases) that keep repeating over and over again. Say, like a word 'green' keeps on repeating in a book. • It so happens that the number of times this repetitive sequence occurs on a chromosome differs. These are called VNTR (variable number of tandem repeats) • By counting the number of times the repetitive sequence occurs on chromosomes (both mother's and father's versions), we can **establish the identity of an individual.** This is the DNA fingerprint of that individual.  **Applications:** • Forensics • Establishing parentage
Single Nucleotide Polymorphism and Population genetics (related Nobel Prize 2022)	• Single letter changes in DNA is called Single Nucleotide Polymorphism. • They occur throughout a person's DNA, one in every 300 letters on an average. • It could occur due to mutation during DNA replication (cell division) or may be inherited. **Applications:** • Can act as biological markers to locate a gene associated with disease. Could help in dealing with future pandemics. • Some SNPs which are inherited act as markers to indicate ancestry. (very important in studying population genetics). SNPs keep changing as they flow from one generation to another. Tracing gene flow by observing SNPs is one way of establishing ancestral links. **Nobel Prize for 2022 (paleogenetics):** • The scientist who won the Nobel prize in 2022 had studied the gene flow from hominins to homo sapiens after the migration out of Africa, 70000 years ago. • He studied the gene flow of Neanderthals and Denisovan (both extinct hominin species) to Homo sapiens. • Some genes inherited from these ancient relatives might influence how our immune system reacts to infections.
1000 Genome Project	It is an effort to study different variations in DNA including SNPs and also larger organisational variations in the genome.

→ STEM CELLS

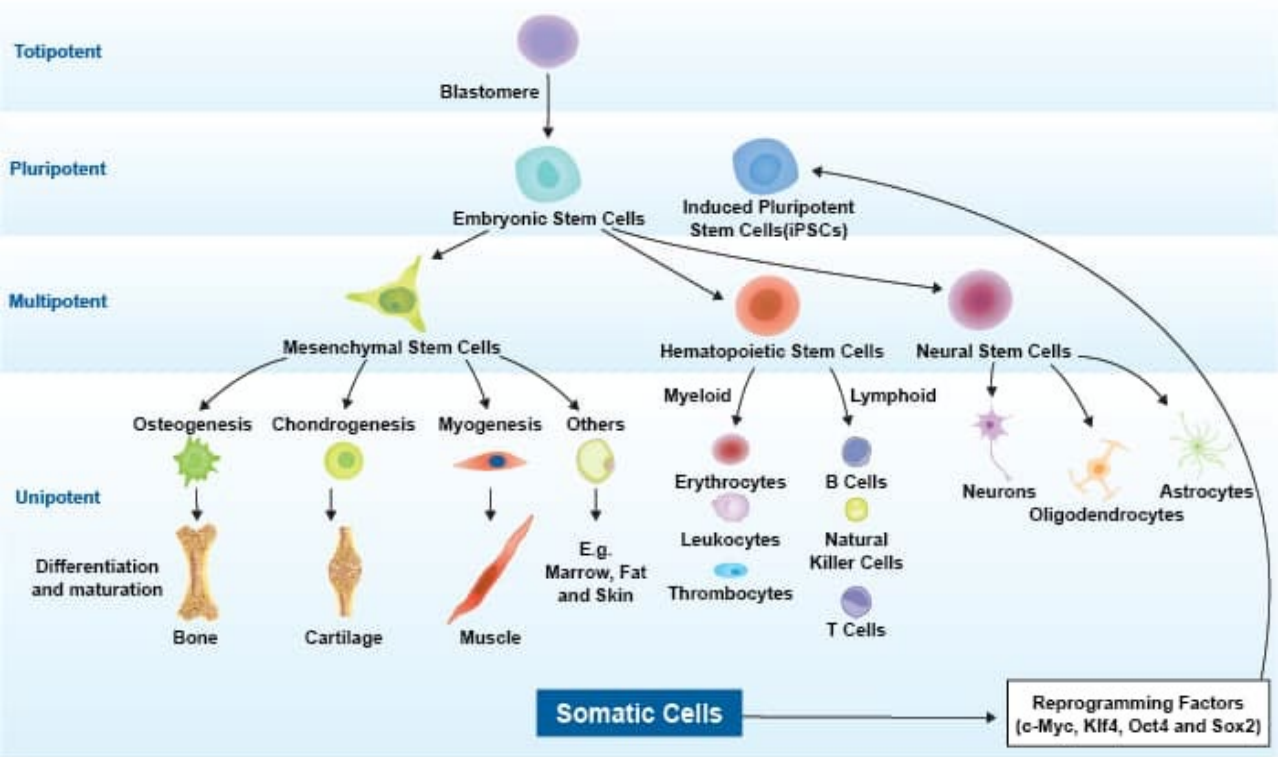
Stem cells: Undifferentiated cells with the potential to develop into specialised cell types in the body.

Types of Stem cells:

- **Totipotent**: Most versatile with potential to differentiate into all different cell types of an organism and extraembryonic cells (including placenta and umbilical cord). Only found in fertilised egg (zygote).

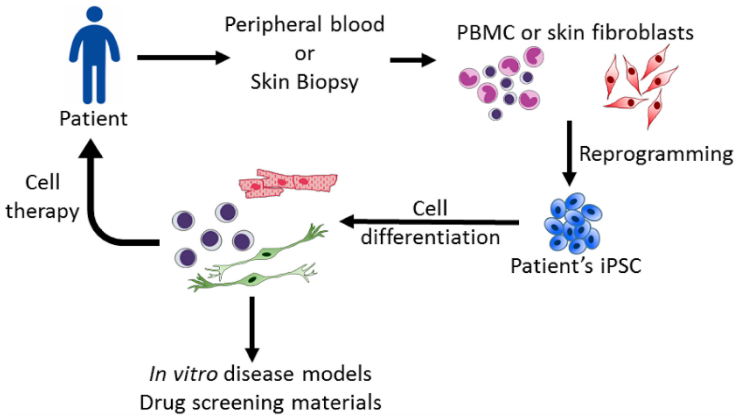
- **Pluripotent**: Derived from inner cell mass of a blastocyst (an early-stage embryo). Can differentiate into all three primary germ layers (endoderm, mesoderm, and ectoderm), which give rise to all different cell types in the body (except extraembryonic cells). **E.g.,** Embryonic stem cells and induced pluripotent stem cells (reprogrammed from adult cells).
- **Multipotent**: More specialised than pluripotent stem cells and can differentiate into limited range of cell types within a specific tissue or organ. **E.g.,** Hematopoietic stem cells (give rise to various blood cell types), mesenchymal stem cells (can differentiate into bone, cartilage, fat cell etc.)

Unipotent: Most specialised type of stem cells, can only renew themselves and differentiate into one specific cell type. **E.g.,** Stem cells in skin that can only differentiate into another skin cell.



10. INDUCED-PLURIPOTENT STEM CELLS: IPSCs

- iPSCs are a type of pluripotent stem cell that can be generated directly from a somatic cell.
  - If one can reprogram specialised cells (somatic cells) to tweak the transcriptional factors, it can reverse into embryonic stem cells.
  - Reprogramming adult cells to become pluripotent is done by introduction of four specific genes, collectively known as Yamanaka factors. It was awarded the Nobel prize in 2012.

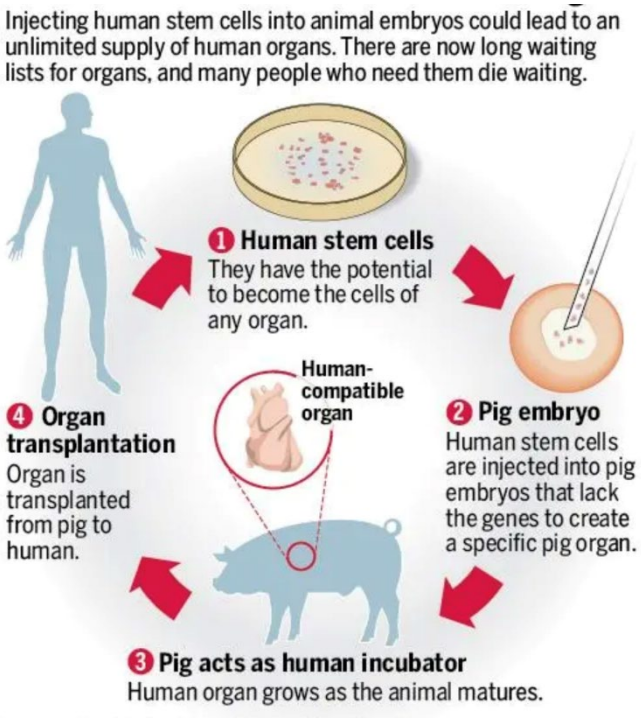


- **Advantage:** Since iPSCs can be derived directly from a patient's own cells, it eliminates the need for embryonic cells and avoids issues related to immune rejection.
- iPS cells hold promise in both regenerative medicine (tissue engineering/organ transplantation) and drug development, and allow researchers to study diseases at cellular level.

11. STEM CELL THERAPY

Stem cell therapy: Use of stem cells to grow healthy adult cells in the lab to replace damaged, defective, or degraded adult cells in the body.

- It is particularly useful when:
  - cells are degraded as in case of neurological disorder with degeneration of neurons (Alzheimer's, Parkinson's etc.) as neurons do not multiply.
  - damage of organs due to accidents, old age etc.
  - the body produces defective cells as in case of blood related disorders like sickle cell anaemia, beta thalassemia where regular blood transfusion is needed. In this case there are 3 ways:
    i. Stem cell transplantation of a healthy donor
    ii. Make iPS cells and grow healthy adult cells
    iii. Gene-edited stem cells from one's own body

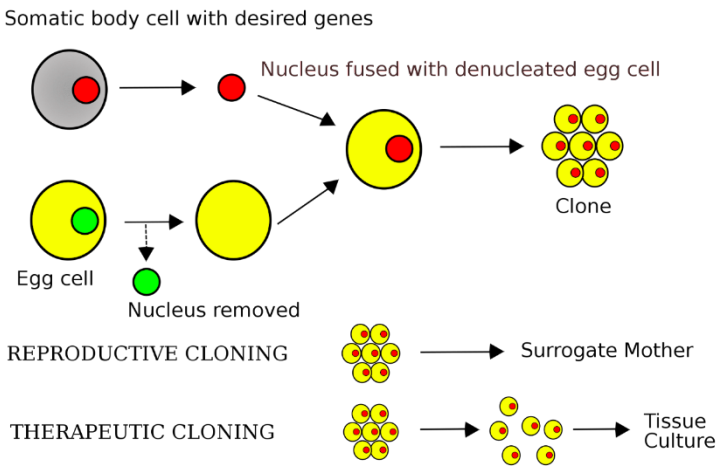


- As per the **National Guidelines for Stem Cell Research** (NGSCR) 2017, only bone marrow transplant or hematopoietic stem cell transplantation for blood disorders (including blood cancers and thalassemia) is permitted in India.

Note: Stem cells from humans can be introduced in pigs to grow organs in them as they have a faster life cycle.

12. SOMATIC CELL NUCLEAR TRANSFER (SCNT) OR REPRODUCTIVE CLONING

- SCNT technology, also known as "cloning by nuclear transfer," is a technique used in the field of reproductive cloning.
- **Cloning involves 3 steps:**
  1. Take any adult cell (skin, hair, nail etc) and suck out its nucleus.
  2. Take an egg cell from a donor and remove the nucleus from the egg/oocyte. (enucleated)
  3. Inject the nucleus of the adult cell in the enucleated egg. You have an oocyte with somatic cell nucleus.



- Oocyte cytoplasm reprograms the nucleus of the somatic cell and it makes an embryonic stem cell.
- The embryonic stem cell can then be grown into an organism identical to the person from whom the adult cell was taken. (since it is the nuclear DNA that codes for proteins) This is how Dolly the sheep was cloned.
- **Applications:** Help preserve endangered species, replicate highly valuable animals, and advance scientific research in areas such as regenerative medicine and genetic engineering.

- **Disadvantage:** Reproductive cloning is very inefficient as the nucleus from somatic cells resists reprogramming.

13. TISSUE ENGINEERING/ REGENERATIVE MEDICINE/ ORGAN TRANSPLANTATION

- One major challenge of organ transplantation or stem cell transplantation is finding suitable donors, as matching of HLA (human leukocyte antigen) plays a crucial role in the success of these procedures.
- HLA genes encode proteins essential for the immune system to distinguish between self and non-self cells and respond to foreign substances (pathogens or transplanted tissues).
- When the HLA match is absent the immune system rejects organ transplants. HLA matches are best among same-sex siblings. Even between parents and offspring, there is no suitable HLA match.

Note: To find healthy donors for stem cell transplantation, a database called **National Stem Cell Registry** is maintained in India.

14. AUTOLOGOUS, ALLOGENIC AND XENOGENIC TRANSPLANTS

- In the context of organ or stem cell transplantation, depending on its source, donor cells plantation can be classified as:
  1. **Autologous:** Cells from one's own body (including stem cell therapy, iPS cells etc).
  2. **Allogenic:** Cells from another's body but of the same species.
  3. **Xenogenic:** Cells from another species.
- With advancements in gene editing techniques, gene therapies and Xenotransplantation are seen as the potential alternatives to supply organs for transplantation. However, the major challenge is immune reaction from the human recipient.

15. XENOTRANSPLANTATION

Scientists Successfully Transplant Two Kidneys From a Genetically Modified Pig Into Human Recipient

TOPICS: Kidney Organ Transplant Popular Surgery University Of Alabama

By UNIVERSITY OF ALABAMA AT BIRMINGHAM JANUARY 20, 2022

SCIENCE

U.S. man who got first pig heart transplant dies two months after surgery

AP

MARCH 09, 2022 21:00 IST

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- Organ transplantation from one species to another is called xenotransplantation.

Need for Xenotransplantation:

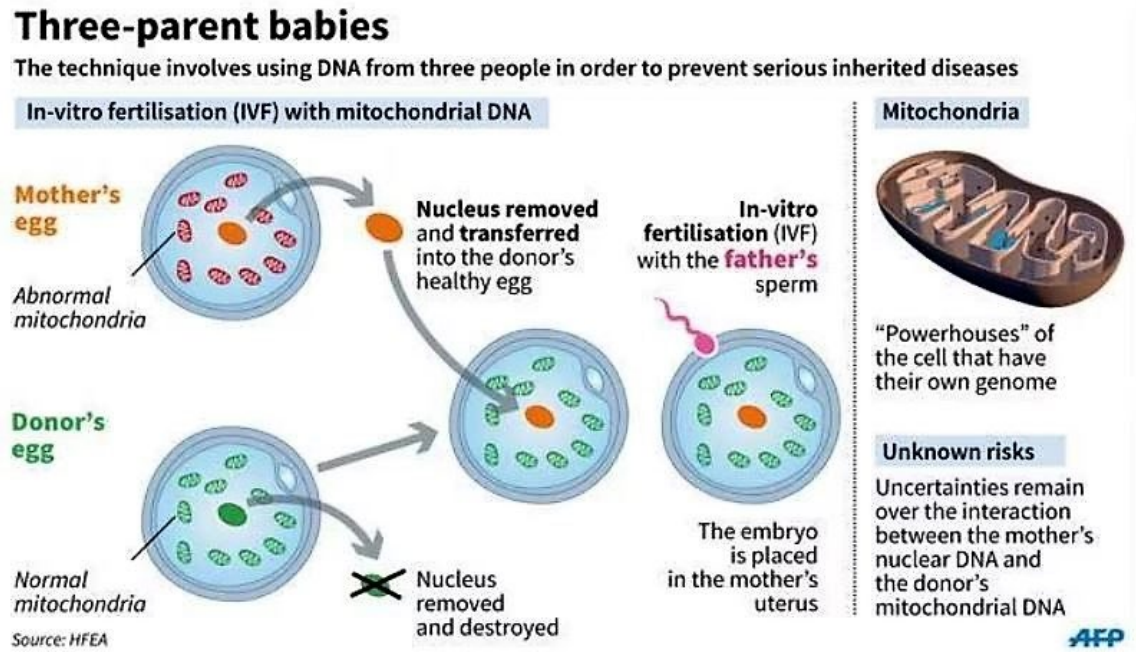
- While Autologous is the best method (as there won't be immune rejection), making iPS cells takes a lot of time. Allogenic is good when there are suitable donors.
- Given the shortage of donors with HLA match, scientists have been increasingly working on Xenotransplantation as animals like pigs with lower lifespan can be bred to grow human organs.
- Gene editing in pigs to reduce immune rejection has made organ transplants from pigs to humans possible, which could offer help to thousands of people who face organ failure, disease, or injury.
- Natural lifespan of a pig is 30 years, they are easily bred and can have organs of similar size to humans.

16. MITOCHONDRIAL DNA TREATMENT

- Mitochondrial DNA is more prone to mutations compared to nuclear DNA. This is because mitochondria are exposed to free radicals generated during energy production, which can damage DNA.
- When mitochondria are impaired they do not produce sufficient energy, which affects how organs function and cause inherited conditions like heart problems, liver failure, brain disorders, blindness and muscular dystrophy. There is no cure for mitochondrial DNA diseases at present.

Mitochondrial Donation Treatment (three parent baby):

- Mitochondrial donation involves replacing unhealthy mitochondria in the mother with healthy mitochondria from a donor through in-vitro fertilisation (IVF). This would avoid passing faulty mitochondria to the child.
- **The Process:**
  - Mother's egg with faulty mitochondria is collected in the laboratory.
  - Egg's from the donor (female) with healthy mitochondria are collected, and its nucleus is removed.
  - Nucleus carrying the mother's DNA is inserted into the donor's enucleated egg.
  - The 'reconstructed egg' is fertilised with the father's sperm via IVF.
  - The final product — 'resulting embryo' — having genetic material (DNA) from parents, and healthy mitochondria from the donor, is implanted into the mother's uterus. The baby thus produced has three genetic parents.



➔ RECOMBINANT DNA TECHNOLOGY: BIRTH OF GENETIC ENGINEERING

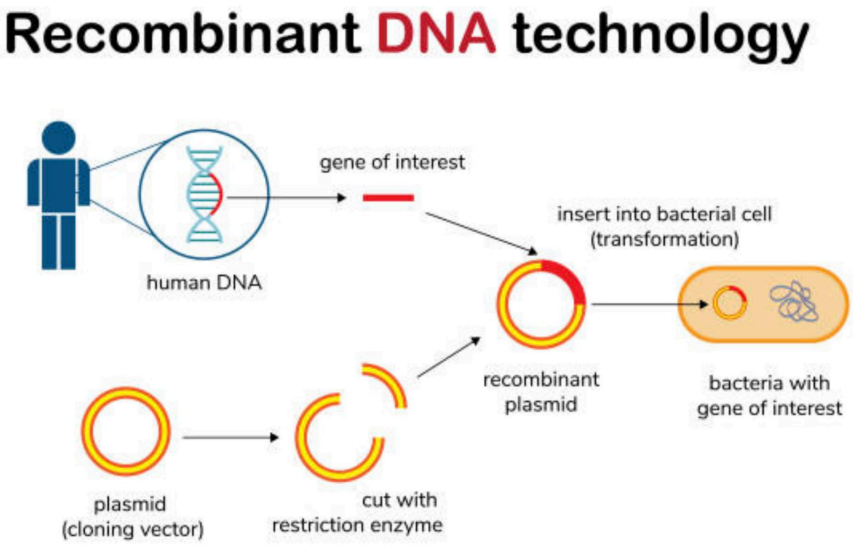
17. R-DNA TECHNOLOGY: MANIPULATING THE CODE OF LIFE

- Recombinant DNA technology or genetic engineering involves manipulation of the genetic code or DNA of living organisms.
- **Basic principle:** Isolating a specific gene or DNA sequence of interest from one organism and inserting it into the genome of another organism. The inserted gene can be from the same species or from a different species.

KEY STEPS IN R-DNA TECHNOLOGY

- **Isolation** of the gene or DNA sequence of interest from the source organism.

- **Fragmenting** this DNA using 'molecular scissors' (Restriction endonuclease Enzymes).
- **Screening** the fragments for a 'desired gene'.
- **Inserting** the fragments with the desired gene into a 'vector' (plasmids, bacteriophage, cosmid) to develop a recombinant DNA. (done using an enzyme called DNA ligase which acts like molecular glue)
- **Introducing** the recombinant vector into the target organism or host cell. The vector integrates into the host's genome and the gene of interest is expressed.
- **Expression:** The target organism produces the protein encoded by the inserted gene.



18. APPLICATIONS OF R-DNA TECHNOLOGY

- Creation of Genetically modified (GM) crops with desirable traits (resistance to pests, diseases, or herbicides).
- Production of therapeutic proteins such as insulin, interferon and human growth hormone (Human insulin was the 1st therapeutic protein to be genetically cloned in E.coli using R-DNA technology)
- Creation of Mono-clonal antibodies.
- Production of vaccines against Hepatitis B.
- Backbone of Hepatitis and HIV diagnostic tests.
- Produce clotting factors for treating Haemophilia.
- Create genetically engineered microorganisms for bioremediation and cleaning up environmental pollutants.

19. CONCERNS OF R-DNA TECHNOLOGY

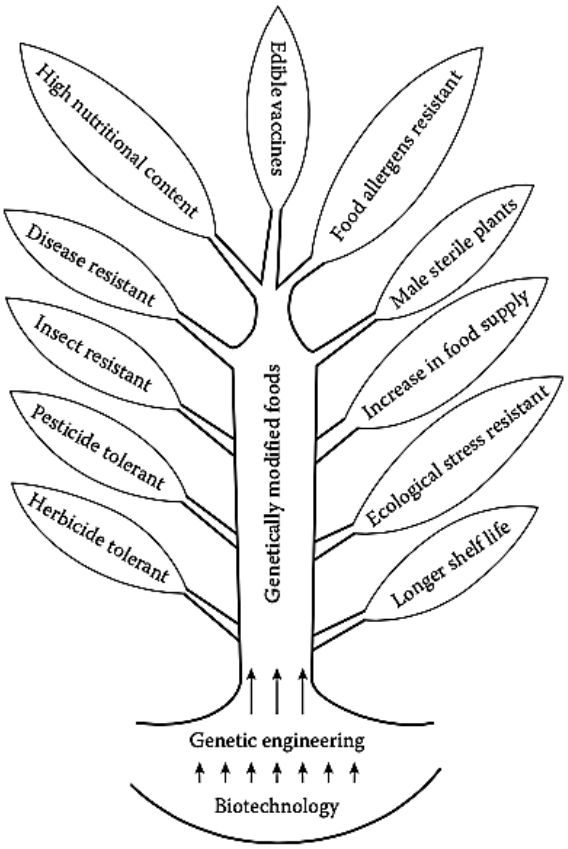
- Environmental release of GMOs may have unintended consequences. **E.g.,** Herbicide-resistant crops could lead to evolution of superweeds resistant to herbicides.
- Horizontal gene transfer from GMOs to other organisms could lead to spread of unwanted traits, such as antibiotic resistance.
- Allows germline editing or genetic changes to human germline which would be passed onto future generations.
- Accidental release of GMOs/superbugs from laboratories may cause future pandemic and environmental damage.

20. GM CROPS

- Transgenic plants are those that have been genetically modified using recombinant DNA technology.
- Genetic modification is done to confer a particular trait to the plant with one of the following properties:
  - Increased yield of a crop

- Increased nutritional content of a crop
- Developing resistance to:
  - Abiotic stresses like temperature, salinity or herbicide-resistant
  - Biotic stresses like insect-resistant crops.

- BT cotton is the only genetically modified crop that is commercially allowed in India from 2002.



REGULATION OF GM CROPS IN INDIA

- Genetically Modified Organisms (GMOs) and the products thereof are regulated under the "Rules for the Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms/Genetically Engineered Organisms or Cells, 1989" under the Environment (Protection) Act, 1986.
- The rules include within its purview all molecular genetics techniques including R-DNA, gene editing techniques, gene drive etc. The rules are enforced by the MOEFCC, DBT and State Governments.
- Genetic Engineering Appraisal Committee (GEAC), a statutory body under MoEFCC, is the final approval authority for allowing field trials and commercial cultivation of GM crops. GEAC is also responsible for certification of GMOs.
- Food has been moved out of Regulation of Genome Engineering Technologies recently. Accordingly, the Food Safety and Standards Authority of India (FSSAI) regulates manufacture, storage, distribution, sale and import of GM food in India.

21. GM CROPS: RECENT DEVELOPMENTS

Bt Crops: Importance of Bacillus thuringiensis	• Soil-dwelling bacteria Bacillus thuringiensis produce spores containing crystals that are poisonous to the insect's digestive system (its gut) but harmless to crop plants and to people. • Thus, all Bt crops involve inserting a gene from soil bacteria to the plant to make it express a crystal that kills the insect by attacking its digestive tract.
Bt cotton	• Resistance to bollworm pest • Only GM crop allowed in India
Bt brinjal	• Bt brinjal is genetically engineered by inserting a gene from the soil bacterium Bacillus thuringiensis for its insecticidal property. • Since 2010 there has been an indefinite moratorium on commercial cultivation of Bt Brinjal in India.
HTBT Cotton	• Short for Herbicide Resistant Bt Cotton • The cotton seed is inserted with a gene from a soil bacterium. • This produces a modified protein glyphosate which makes it herbicide resistant. **Problem with Glyphosate:**

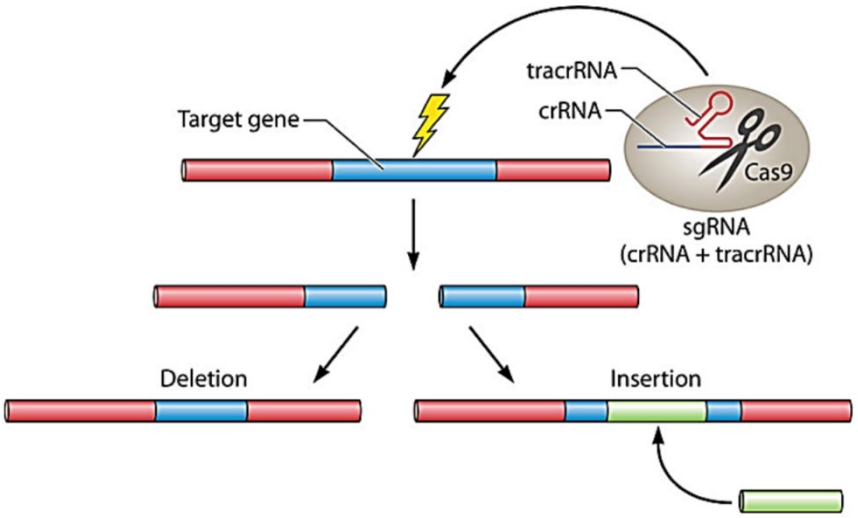
	• Glyphosate is a herbicide used in cotton fields which is known to be harmful to soil and also classified as 'probable human carcinogen' by WHO. • Besides glyphosate also impacts honeybee gut microbiome thereby affecting pollination.
GM Mustard(DMH-11) **Dhara Mustard Hybrid**	Recently, GEAC approved GM mustard for commercial use, the first genetically modified crop in the country to get approval in two decades. **About GM Mustard** • Transgenic hybrid variety. • Under normal conditions mustard plants do not cross across varieties as they are self-pollinating in nature. • As a result we do not have hybrid varieties of mustard due to which plant-breeders are not able to induce desired traits in mustard plants. • Genetic modification is done to alter the genes of 2 mustard varieties including Varuna and Heera. • Genetic modification is done with the help of soil bacteria barnase and barstar which help create hybrid varieties of mustard. **Benefits:** • Increase in yield up to 20-30% • Seeks to attain self-sufficiency in edible oil seeds production **Issues:** • Transgenic hybrid variety becomes tolerant to a herbicide called glufosinate-ammonium upon genetic modification. • Herbicides are extensively used in field trials including glyphosate, endosulfan. • These may harm honey bees (the biggest pollinators of mustard fields).
Golden Rice	Vitamin A (2 genes from daffodil and 1 from bacteria)
Soybean Sugarbeet Sugarcane	Herbicide tolerant (glyphosate, glufosinate)
Edible vaccines	A new approach for delivering vaccine is transgenic food crops **E.g.,** A rice-based mucosal vaccine for cholera. Plant-based mRNA vaccines using transgenic lettuce are developed.
GM Rubber	World's 1st planted in Assam. To make it more tolerant to colder climates as rubber is native to warm humid Amazon forests.
GM Soymeal	India will import GM soymeal for the 1st time to be used as livestock-feed particularly in poultry.
Protato	Protein packed GM potato that contains 60% more protein than a wild-type potato.
GM bacteria for nitrogen fixation	Genetically modified bacteria are made that copy the action of Rhizobium to induce the ability of nitrogen fixation in the roots of crops other than legumes.

➔ GENE EDITING: CRISPR-CAS9: REVOLUTION IN GENETIC ENGINEERING

22. CRISPR-BASED GENE EDITING

- CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) and Cas9 (CRISPR-associated protein 9) are components of the bacterial immune system that have been repurposed for gene editing.

Working of CRISPR:



- In CRISPR-based genome editing, the first step is identification of the targeted DNA sequence.
- Once identified, a guide RNA molecule brings Cas9 protein to the specific spot in the DNA.
- Cas9 protein acts like a pair of molecular scissors and cuts the DNA at that specific spot.
- Once the RNA-guided Cas9 enzyme cuts the DNA at a specific site, we could make the following changes to the DNA:
  - Inserting a new sequence (gene insertion)
  - Deleting the sequence (gene removal)
  - Modifying the sequence (gene editing)
- If the existing (native) genome is altered, the end product would be genetically modified (GM) and if a foreign genome is inserted then the end product would be transgenic.

Advantages of CRISPR:

- CRISPR offers much greater precision in modifying DNA and targets specific locations with much greater accuracy compared to R-DNA technology.
- Further, CRISPR can be used for a wider range of applications than R-DNA. This is because CRISPR is not just limited to introducing new genes but can also be used to make precise edits within existing genes.

Concerns:

- Potential to make irreversible changes to the human genome and Risk of passing erroneous CRISPR-induced changes to successive generations.
- Special traits in offspring/designer-babies can be created through CRISPR posing ethical concerns.
- Eliminating dangerous species of pests by gene-editing or recreating extinct species may disrupt the food web/ecological cycle.
- Potential weapon of mass destruction by creating harmful biological agents or products.

Limitations:

- In CRISPR-based editing, mutations are corrected by cutting the double strand of the DNA. As a result, it can cut only large portions of the genome and not single letter changes.
- Additionally, it can induce unintended off-the-target mutations or incomplete edits in some places.

➔ ADVANCEMENTS IN GENE EDITING SYSTEMS

23. BASE EDITING

- Advanced form of CRISPR, which is suitable for single letter editing.
- While Cas9 cuts double stranded DNA targets, base editing uses an enzyme to rearrange some atoms in the base molecule of the DNA, thereby altering it.
- It involves rewriting the DNA instead of cutting the target sequence and adding new base molecules. This makes it suitable for single-letter mutations.

24. PRIME EDITING

- Another advanced form of CRISPR, but unlike CRISPR which chops DNA in half, prime editing nicks it (small nick instead of complete cut) and writes a new section of DNA in the specified region similar to base editing.
- Though it is similar to base editing, it includes an additional enzyme, a reverse transcriptase, to copy and paste new DNA sequences into the genome.
- Thus, it is suitable for precise insertions, deletions, and augmentation of the genome.
- While base-editing is suitable for single-letter modifications, prime editing is suitable for more extensive large edits.

REGULATION OF GENE EDITING IN AGRICULTURE IN INDIA: (SDN1 AND SDN2)

- "Rules for the Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms/Genetically Engineered Organisms or Cells, 1989" notified under the **Environment Protection Act, 1986,** regulate genetically modified organisms.
- There is no explicit mention of the term gene editing. Recently an amendment was introduced to the aforesaid regulation in order to encourage gene editing in agriculture.
- Gene editing techniques using native genome are allowed in India. However, gene editing techniques using foreign genomes are not allowed.
- The gene editing techniques called **SDN 1 and 2** (Site-Directed Nuclease) use native genome and hence, are allowed under the Rules under EPA, 1986.
- However, gene editing techniques using foreign genomes like **SDN 3, 4 and 6** are placed under GMO regulation and therefore not allowed in India.

SCOPE AND APPLICATIONS

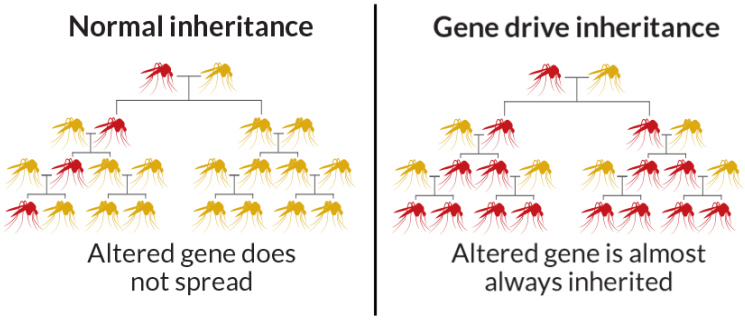
Following are some landmark achievements of the CRISPR system.

GENETIC ENGINEERING: RECENT ADVANCEMENTS	
What can all CRISPR systems do?	**GENE EDITING: DNA AND RNA BOTH** • Both coding and non-coding parts including RNAs (gene expression) • Initially only DNA was the target, recently RNA is also being modified using the CRISPR system. • Conventionally could change a section of DNA (large cuts) • Now with base editing suitable for single-letter mutations. **APPLICATION** Gene therapies can not only repair faulty genes but also regulate healthy genes, either by silencing certain genes or activating silent/non-expressive genes.

	MOLECULAR DIAGNOSIS In addition to editing, CRISPR can be used to detect single target DNA or RNA molecule (CRISPR-Cas13). This makes it a sensitive diagnostic tool to detect mutations. **SHERLOCK** A biological detective that uses CRISPR-Cas13 to detect RNA sequences associated with diseases like **Zika virus and Dengue virus.**
CRISPR in Gene therapy	• Scientists have demonstrated administration of CRISPR-based gene therapy both in-vivo (directly in the human body) and ex-vivo (from lab culture to human body). • CRISPR-based gene therapy is most suitable in **mono-genetic diseases** in which we can identify a single gene responsible for the disease trait. Examples of such diseases: ○ Blood-related disorders: Sickle-cell anaemia, beta thalassemia, Haemophilia etc. ○ Corneal diseases and skin diseases ○ Degenerative neurological diseases ○ Immunological diseases like HIV, bubble boy syndrome etc. ○ Immune-therapy for cancer (CAR T-cell therapy) • Scientists have demonstrated how CRISPR-CAS9 can be used to eliminate HIV in infected mice. • Gene editing is tried in mice to correct genes involved in muscular dystrophy. • Gene editing has been carried out inside the human body for the 1st time to treat Hunter's syndrome. • The US has approved CAR-T cell therapy which involves modifying immune cells to attack cancer cells in case Leukaemia. In 2021 Department of Biotechnology supported 1st CAR-T cell therapy was conducted in India. • 1st in-vivo administration of gene therapy to modify photoreceptor cells in the eye to treat blindness was done in 2020.
CRISPR in tissue engineering and organ transplantation	**CRISPR AND CELL THERAPY** CRISPR is increasingly being used in tissue engineering to genetically modify pig cells to make them suitable for growing human organs in them. Stem cells from humans can be introduced in pigs to grow organs in them as they have a faster life cycle. The challenge was that a section of the pig genome was known to cause cancer which acted as a major hurdle in organ transplantation from pigs to humans. These cancer-causing genes are edited using CRISPR to silence them.
CRISPR in agriculture: GM Crops	• Engineer crops to increase their nutritional value, pest-resistance, drought-tolerance. • ICAR is using SDN 1 and 2 to produce rice varieties which are drought-resistant, salinity-resistant and high-yielding. **CRISPR IN CLIMATE-SMART AGRICULTURE** CRISPR is used in plants to increase their photosynthetic efficiency by up to 25%. E.g., tobacco plants. **CRISPR AND CCUS TECHNOLOGIES** The CRISPR system is being used to increase the carbon fixing property in algae by increasing its photosynthetic efficiency. **CRISPR AND BIOFUELS**

	• CRISPR is used to genetically modify microbes like yeast to improve its efficiency of fermentation and producing ethanol at a faster rate. • CRISPR is used to genetically modify methanogens (microbes) to improve their performance in biogas production.
GM food	**LAB-GROWN MEAT** • Cell-based meat produced by culturing cells in a lab does not have a suitable texture and flavour. CRISPR systems are used to genetically modify cells to produce proteins responsible for texture and flavour. **CLEAN MEAT PROJECT: INDIA** • The Clean Meat project will be taken up by CCMB and the National Research Centre on Meat of ICAR. Gene edited lab-cultured meat to augment its nutritional content. **INDUSTRIAL FERMENTATION** CRISPR is used to genetically modify microbes like yeast used in wine making, baking and brewing to improve its efficiency of fermentation.
Gene editing and embryonic cells	**MORATORIUM ON GENE EDITING OF EMBRYONIC CELLS** • In 2018, a Chinese scientist announced the birth of the 1st gene-edited babies. After this WHO urged countries to ban experiments that would lead to more gene-edited babies. • Gene editing of embryonic cells is banned across the world. In 2019, ICMR issued the National Guidelines for Gene Therapy which also **bans gene-editing** of embryonic cells. **Note**: The Chinese scientist modified the CCR5 gene on the embryonic cells of the couple to make them resistant to the HIV virus. (**CCR5** is a gene that codes for receptors in our immune cells which HIV uses like a gateway to get inside the cell). **RESEARCH ON EMBRYONIC CELLS** • In spite of the world-wide moratorium on gene editing of embryonic cells, research is allowed on embryonic cells less than 14-days old to understand the nature of many inherited diseases. • Accordingly following research is going on: ○ Pre-implanted human embryos are being tested for understanding inherited heart disease. ○ Genome of embryonic cells is edited using CRISPR-Cas9 to study the cause of infertility. ○ Research on genes linked to beta thalassaemia, inherited blood disorder, in human embryos using base editing techniques is being carried out.
CRISPR and Gene Drive: Global fight for Malaria	**WHAT IS GENE DRIVE?** • **Under normal law of inheritance,** a specific trait from an organism has a 50/50 chance to be passed. (Offspring inherit one copy of each gene from each parent, resulting in a random chance of expressing either mother's version or father's version) • **Gene Drive** is the use of gene-editing techniques to alter the law of inheritance to pass on a particular genetic trait from one generation to next, faster than normal. • This is achieved by editing a particular gene in a way that it can copy and paste itself into its corresponding location on the other chromosome, instead of the 50/50 inheritance pattern that occurs naturally. • This copying and pasting occurs during the production of reproductive cells (sperm or egg), resulting in a higher probability that the gene will be passed down to the next generation.

Click here for INDEX



- CRISPR is being used to edit a gene called 'doublesex' in female mosquitoes which are the main transmitters of malaria.
- When the female mosquitoes inherit two copies of the disrupted gene, they develop like males and are unable to bite or lay eggs.
- This genetic tweak of double-sex gene follows gene drive inheritance. With this, in 8 generations female mosquitoes were completely eliminated.

25. CAR-T CELL THERAPY: THE FUTURE MAINSTAY OF CANCER TREATMENT

BASICS OF CANCER

- **Cell division** is the process by which a parent cell divides into two daughter cells. If this process goes on forever unchecked, cell division reaches dangerous levels which is not desirable.
- Thus, in order to maintain balance (homeostasis), cells have adapted themselves to a process called apoptosis (programmed cell death).
- **Cancer** is a condition of uncontrolled cell growth and division due to absence of apoptosis. Cancer occurs when some disruption of the DNA in a normal cell interferes with the cell's ability to regulate cell division.
- DNA disruption can be caused by chemicals that mutate DNA or by sources of high energy (Sun, X-rays, Nuclear radiation), even infection by viruses and also due to environmental, and lifestyle factors.

TREATMENT OF CANCER

- To treat cancer, the rapidly dividing cells must be removed surgically or killed, or their division slowed down. This is done in two ways: (i) Chemotherapy and (ii) Radiation therapy.

CHEMOTHERAPY

- Drugs that interfere with cell division are administered, slowing down the growth of tumours.
- But these drugs disrupt the cell division of normal cells too, causing complications. **E.g.**,
  - Extreme fatigue due to reduction in production rate of red blood cells (RBCs).
  - Increases bruising and bleeding, as well as a susceptibility to infection as it reduces production of platelets and white blood cells (WBCs).

RADIATION

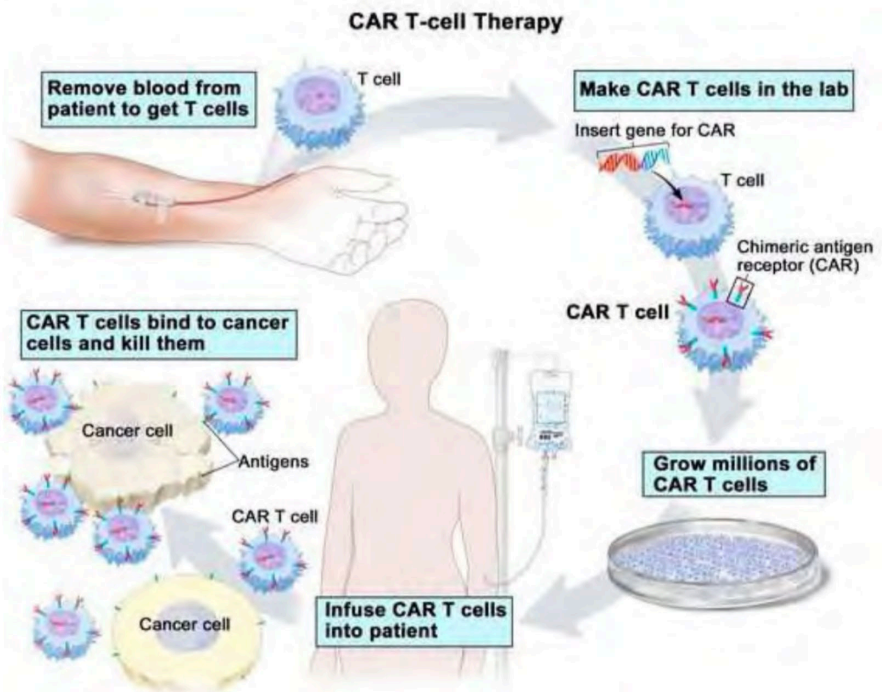
- Also works by disrupting cell division, but it is more targeted. It directs high-energy radiation only at the part of the body where a tumour is located.
- However, the radiation process is not perfect, and the nearby tissues are often harmed.

26. CAR T-CELL THERAPY

- Chimeric antigen receptor (CAR) T-cell therapy is a cell-based gene therapy which involves genetically modifying our immune cells called T-cells to help them attack cancer cells.

- T-cells are special cells (a type of WBCs) whose primary function is cytotoxic (attack and kill pathogens and foreign cells).
- It is the job of B-cells (another type of WBCs) to identify the pathogen and signal other immune cells to do their job. Now, as cancer cells are not foreign cells, B-cells cannot recognise them as foreign bodies and hence, cannot present it to the immune system (T-cells) as enemy cells.

- Alternatively, if we can genetically alter T-cells to recognise the cancer cells, it will kill the cells. This is what CAR T-cell therapy does.



Mechanism:

- In the therapy, T-cells are harvested from the patient's blood.
  - Researchers genetically modify these cells, using the CRISPR system, so that they express specific proteins on their surface known as chimeric antigen receptors (CAR).
  - These cells are then multiplied in the laboratory and inserted back into the patient.
  - This genetic modification allows CAR T-cells to effectively bind to the cancer cells (identify them) and destroy them.
- As CAR T-cells directly activate the patient's immune system against cancer, it makes the treatment more clinically effective than Radiotherapy and Chemotherapy.
- Presently, CAR T-cell therapy has been approved for leukaemia and lymphoma.

Limitations:

CAR T-cell therapy could induce an immune response like increased cytokine release which can lead to fever, low blood pressure, neurological symptoms and organ damage.

- Further, CAR T-cell therapy is best suited for certain blood cancers and may not be effective for all types of cancer.

NexCAR19: India's own CAR-T cell therapy

- Central Drugs Standard Control Organisation (CDSCO) has granted market authorisation/approval for NexCAR19. With this India has its indigenous CAR-T and gene therapy platform.
- NexCar19 is developed indigenously by ImmunoACT (a company incubated at IIT Bombay).

- The therapy is designed to target cancer cells that carry CD19 protein. This protein acts like a flag on cancer cells, which allows CAR-T cells to recognise and attach themselves to the cancer cells and start the process of elimination.
- The therapy is for people with B-cell lymphomas who did not respond to standard treatments like chemotherapy, leading to relapse or recurrence of the cancer.

IMPORTANT CUTTING-EDGE TECHNOLOGIES FOR CANCER CARE

S. No.	Technology	Details
1.	Image-guided Radiation Therapy	Form of radiation therapy that uses imaging techniques to precisely locate and treat cancerous tissue. Allows for higher doses of radiation to be delivered to tumour while minimising exposure to surrounding healthy tissues.
2.	Proton Therapy	Type of radiation therapy that uses high-energy proton beams to destroy cancerous cells. Particularly useful to treat tumours located in sensitive areas (brain, eyes and spinal cord) where traditional radiation therapy can cause severe side effects.
3.	Precision Medicine	Uses genomic information (genetic profile of their tumour) to personalise treatment for cancer patients.
4.	Radiomics	Uses advanced computer algorithms (AI-powered healthcare) to analyse medical images, such as X-rays, CT scans, and MRIs to improve diagnosis, treatment planning and prognosis.

➔ NOBEL PRIZE IN MEDICINE 2023

- The Nobel Prize in Medicine for 2023 has been awarded to Hungarian biochemist Katalin Karikó and American physician-scientist Drew Weissman for their ground-breaking work on **nucleoside base modification of messenger Ribonucleic Acid** (mRNA). Their discoveries were critical in the development of effective mRNA vaccines, including those used against COVID-19.

Working Principle of mRNA Vaccine:

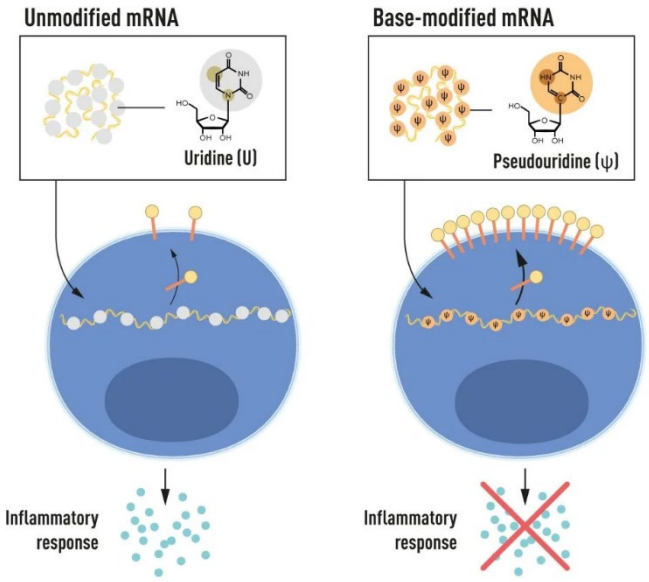
- Unlike most vaccines containing a weakened or killed bacteria or virus, mRNA vaccines use the mRNA molecule instead of an actual bacteria or virus.
- When mRNA enters the human body through a vaccine, our cells read the mRNA as a set of instructions to build proteins (translation) that match up with parts of the pathogen called antigens. **E.g.,** Cells produced the spike proteins found on the surface of COVID-19 virus.
- Our immune system recognises the foreign protein as an invader and triggers an immune response by creation of antibodies and T-cells specifically designed to target that protein.
- Also, the immune system also develops memory T-cells, which remember the viral protein to trigger a strong immune response if the body encounters the real virus in the future.

The Challenge:

- Initially, the significant challenges in mRNA-based therapies, including mRNA vaccines, was the rapid degradation of mRNA by the body.

- When introduced into the body, mRNA molecules were quickly broken down by cellular enzymes and the immune system.
- This problem of rapid degradation of mRNA was solved after the innovation of nanoparticles and use of lipid nanoparticles (LNPs) which encapsulated and protected the mRNA.

- Further, mRNA vaccine when administered in the initial stage of trials had shown adverse/ unwanted inflammatory responses in the body.



CONTRIBUTIONS OF KARIKÓ AND WEISSMAN: (NUCLEOSIDE BASE MODIFICATION)

- **Nucleoside base modification of mRNA** refers to the chemical alteration (changes to the structure or composition) or modification of the individual nucleotide bases (Adenosine (A), Cytidine (C), Guanine (G), and Uridine (U)) present in the mRNA molecule.
- Instead of using the standard A, C, G, and U, scientists can replace them with modified/synthetic bases that have different chemical properties. Hence, A nucleoside-modified messenger RNA (modRNA) is a synthetic messenger RNA (mRNA).
- **Karikó and Weissman** were able to successfully deliver modified mRNA into the body. They replaced Uridine with modified bases like Pseudouridine to reduce inflammation and harmful cytokine production associated with mRNA-based therapies.

Benefits of modRNA include:

- ModRNA can help prevent unwanted immune reactions in the body by making the mRNA appear more "natural" to the immune system.
- Modified bases can help stabilise the mRNA, making it last longer.
- Modified bases can improve efficiency of translation (process of converting mRNA into protein), leading to higher protein production.
- ModRNA can be used in vaccine development, protein production and developing personalised medicines.

VACCINES AND THEIR TYPES

Type of vaccines	Description	Diseases covered
Live attenuated vaccines	Contains a weakened version of the living microbe so that it can not cause disease.	Measles, mumps, rubella (MMR combined vaccine) Varicella (chickenpox) Influenza (nasal spray) Rotavirus
Inactivated vaccines	Virus is first killed with chemicals, heat, or radiation and then is used to make the vaccine. Inactivated vaccines usually do not require refrigeration, and they can be easily stored and transported in a freeze-dried form.	Hepatitis A, Influenza, polio, rabies

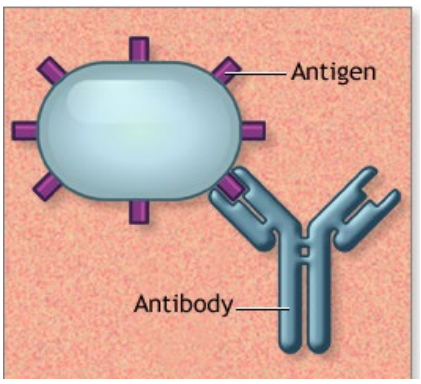
Sub-unit vaccine	A piece of the virus that is important for immunity, like the spike protein of COVID-19, is used to make the vaccine.	Hepatitis B Human papillomavirus vaccines
Toxoid vaccines	Contains a toxin or chemical made by the bacteria or virus. They make a person immune to the harmful effects of the infection, instead of to the infection itself.	Diphtheria and tetanus
Polysaccharide Vaccines	Unique type of inactivated subunit vaccine composed of long chains of sugar molecules that make up the surface capsule of certain bacteria.	Pneumococcal disease, meningococcal disease, and Salmonella Typhi
Biosynthetic vaccines	Contains man-made substances that are very similar to pieces of the virus or bacteria.	HIV
DNA vaccine	The gene that codes for the COVID-19 spike protein is inserted into a small, circular piece of DNA, called a plasmid. The plasmids are then injected as the vaccine.	ZyCoV-D
m-RNA vaccine	The vaccine contains mRNA. mRNA is processed in cells to make proteins. Once the proteins are produced, the immune system will make a response against them to create immunity.	Covishield Covaxin

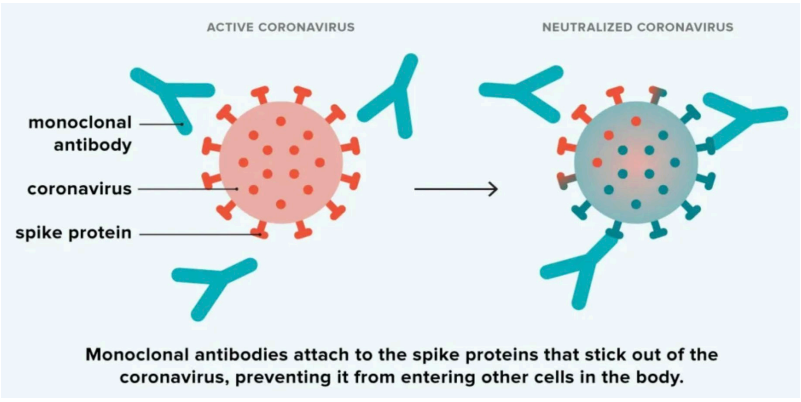
27. MONOCLONAL ANTIBODIES

- Recently, India reached out to Australia to procure monoclonal antibody doses to combat the Nipah virus outbreak in Kerala. The dosage has to be administered at an early stage of infection.

ANTIBODY

- Proteins produced by the immune system that neutralise any foreign substance (bacteria, virus) entering the human body.
- Antibody attaches itself to an antigen (a foreign substance, usually a disease-causing molecule) and helps the immune system eliminate it from the body.





MONOCLONAL ANTIBODY

- Laboratory-made proteins to serve as substitute antibodies and mimic their behaviour to protect against diseases and foreign substances.
- They are specifically engineered and generated to target certain diseases and are meant to attach themselves to the specific disease-causing antigen.

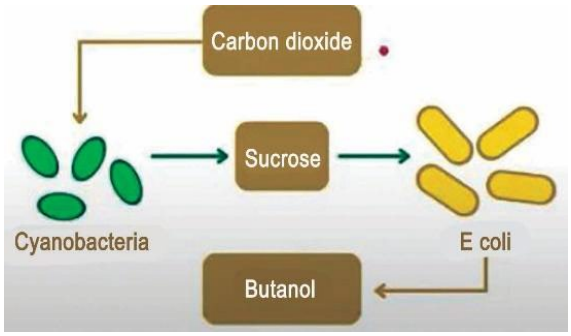
- **E.g.,** Monoclonal antibodies during COVID-19 pandemic were engineered to bind to the spike protein of SARS-CoV-2 virus. The binding prevents the protein from exercising its regular functions, including its ability to infect other cells.

➔ SYNTHETIC BIOLOGY: FUTURE OF BIOENGINEERING

- In February 2022, DBT mooted the need for a National Policy on Synthetic Biology aimed at striking a balance between harnessing the potential benefits and mitigating potential risks of synthetic biology.

28. WHAT IS SYNTHETIC BIOLOGY?

- While biotechnology is the use and modification of biological organisms to produce useful products, synthetic biology is the construction of novel biological systems to produce useful products.
- It is a novel field in biology that works bottom-up as opposed to the top-down approach of biotechnology.
- This has been made possible as a result of the development of bioinformatics which has opened the gate for producing novel products by mimicking nature.



- As we understand the design of plants at the molecular level, we will be able to design similar systems to do the same artificially. This is what we do in an artificial leaf.
- Another way is to engineer two or more biological systems to produce useful products. Under the following example we are merging photosynthesis of cyanobacteria to produce a chain of carbohydrates (starch) and anaerobic respiration of so-produced starch by E.coli to produce alcohol.

29. 1ST ARTIFICIAL CELL: SYNTHIA

- In 2010, a US scientist created of the world's first artificial cell with a synthetic chromosome. (Synthia)
- In 2016, the same scientist created an artificial cell with the smallest known genome ever, that he completely created from scratch (473 genes) called syn 3.0.(Synthia 3.0).

30. SYNTHETIC BASES: A 8-LETTER DNA: HACHIMOJO

- Japanese scientists have produced an 8-letter DNA instead of the 4-lettered one that nature has produced.
- 4 out of 8 were natural (AGCT) and 4 artificial ones (SBPZ). This could have potential benefits in DNA Data storage.

31. SYNTHETIC E.COLI

This is the latest synthetic genome we have created till date.

POTENTIAL APPLICATIONS

- With the advancement in our understanding of genes and gene expression we could make synthetic genomes to express very specific traits with specific applications.
- Some potential areas could be:
  - Producing synthetic algae for high-efficiency photosynthesis that can be used in CCUS technology.
  - Synthetic microbes as agents of bioremediation: **E.g.,** Plastic-eating bacteria are suitable only for certain kinds of plastics. If we can mimic the process with a synthetic genome, we can have novel organisms that can be used for bioremediation.

- Antibiotics are now being made by engineering a completely artificial gene sequence to code for a protein (polypeptides). These are known to kill E.coli, Staphylococcus aureus etc.
- Can replace Genetically Modified biologics like Insulin.
- Anti-malarial polypeptide is made using an artificial sequence.

32. DISEASES IN NEWS

Nipah Virus (NiV)	• Zoonotic disease that can be transmitted to humans through direct contact with infected animals, especially bats and pigs. Can also be transmitted through contaminated food or directly from person to person. • Fruit Bats (flying foxes) are natural reservoir/primary carriers of Nipah virus. • **Symptoms:** Fever, muscle pain, and respiratory problems (similar to that of influenza). Inflammation of the brain and late onset of Encephalitis can also occur. • **Treatment:** Currently, there are no approved vaccines available.
Human papillomavirus (HPV)	• Small, double-stranded DNA virus capable of infecting women and men. • Can cause cancer in the cervix, vulva, vagina, penis, anus, and throat. • **Transmission:** Any intimate skin-to-skin contact and sexually transmitted via vaginal, anal, or oral sex. • **Cervavac,** India's first Quadrivalent HPV Vaccine, developed by the Serum Institute of India, prevents entry of four of the most common types of HPV 16, 18, 6 and 11. • The vaccine has been approved for girls and boys aged between 9 and 26 years.
Monkey Pox	• Zoonotic disease caused by the virus belonging to the Orthopoxvirus genus. • Animal-to-human transmission can occur from direct contact with the blood, bodily fluids, or cutaneous or mucosal lesions of infected animals. • **Symptoms:** Characterised by rash or skin lesions that are usually concentrated on the face, palms of the hands, and soles of the feet.
Pompe Disease	• Rare and progressive genetic disorder in which a complex sugar called glycogen builds up in the lysosomes. • The autosomal recessive disorder is caused by a deficiency or malfunction of a specific digestive enzyme called acid alpha-glucosidase (GAA) responsible for breaking down glycogen into glucose. • This leads to accumulation of glycogen which causes progressive muscle weakness and can affect various organs, including heart, respiratory system, and liver. • **Treatment:** Currently, no cure exists, and Enzyme replacement therapy to replace the deficient GAA enzyme is the mainstay of treatment.
Duchenne's Muscular Dystrophy	• Rare genetic disorder characterised by progressive muscle degeneration and weakness due to the alterations of a protein called dystrophin (dystrophin helps in wear and tear and regeneration of muscles). • As a result, the body cannot produce dystrophin, which weakens the muscles, and patients become wheelchair-bound in early teens and die prematurely. • **Cause:** Most cases of DMD are inherited as an X-linked recessive trait (passed on through the mother, who is a carrier). The disease primarily affects boys, but in rare cases, it can affect girls.

Kala Azar or Visceral leishmaniasis	• Slow progressing Neglected Tropical Disease and zoonotic infection caused by a protozoan parasite of genus Leishmania. • Transmitted by the sand fly found in moist mud and sand close to livestock. • The parasite primarily infects the reticuloendothelial system and may be found in abundance in bone marrow, spleen and liver. • It is the second-largest parasitic killer in the world after Malaria.
Scrub Typhus	• Bacterial illness caused by Orientia tsutsugamushi and transmitted to humans through bites of infected chiggers (small mites). • These mites inhabit areas with dense vegetation (grassy fields, forests) with ample moisture to thrive.
Kyasanur Forest Disease/ Monkey fever	• Tick-borne viral haemorrhagic fever caused by a virus. • Endemic to the South-western part of India (first noticed in the Kyasanur Forest area in Karnataka). • **Transmission:** Primates (Monkeys) come in contact with infective ticks. Human beings who visit the endemic forest area can contract the disease.
Lumpy Skin Disease	• Highly contagious disease caused by lumpy skin disease virus that primarily affects cattle. • **Transmission:** Biting insects such as flies and mosquitoes and possibly ticks. Also spread by direct contact to skin lesions, saliva, nasal discharge, milk, or semen of infected animals. Not a zoonotic virus i.e., cannot spread to humans via milk consumption. • **Symptoms:** Formation of nodules/lumps on skin, head, neck, back, and genitalia, high fever, sharp drop in milk yield, loss of appetite, thinness or weakness in animals.
Foot and Mouth Disease	• Highly contagious viral vesicular disease of cloven-hoofed animals such as cattle, buffaloes, sheep, goats and pigs etc. • **Symptoms**: Abscesses and ulcers to the mouth and foot that prevent the animal from eating and walking, reduced milk yield, infertility, reduced working capacity. • Human infection is rare, and is not transmitted to humans via meat consumption. • The Department of Animal Husbandry and Dairying aims to eradicate FMD by 2030 through vaccination of livestock.
Sickle Cell Anaemia (SCD)	• Inherited/genetic blood disorder that affects haemoglobin, the protein in RBCs that carries oxygen to all parts of the body. • Healthy RBCs are soft and round. In SCD, the haemoglobin is abnormal, which causes the RBCs to become hard and sticky and look like a "sickle." • These rigid, sticky cells die early and often get stuck in blood vessels, clogging the flow of blood. As a result, different parts of the body do not get the oxygen they need. • This can cause pain and other serious health problems such as infection, acute chest syndrome and stroke.

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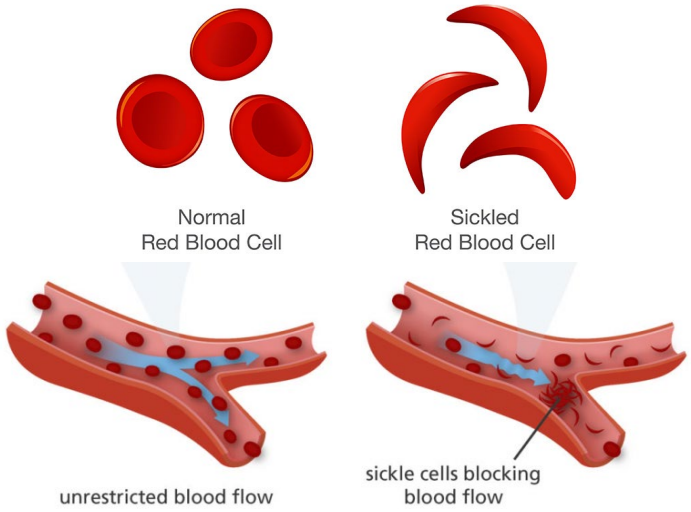
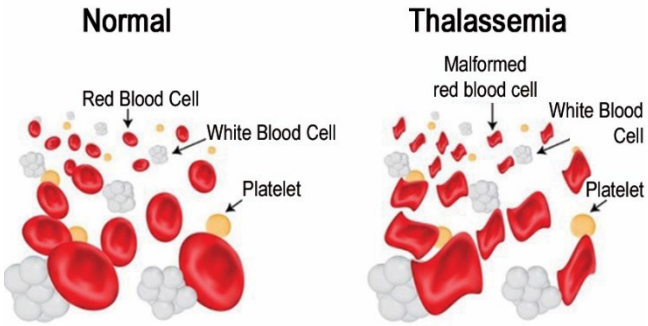
	
Haemophilia	• Rare inherited/genetic bleeding disorder that impairs the body's ability to make blood clots. • People with haemophilia have lower levels of clotting factors, which can lead to excessive bleeding, even after a minor injury. • It is an X-chromosome linked recessive disorder which means that it is more common in males than in females (Females are carriers of haemophilia genes). • Lifelong condition with no permanent cure. Treatment typically involves replacing deficient clotting factors through infusions.
Thalassemia	• Inherited blood disorder characterised by abnormal haemoglobin production, which in turn, leads to Anaemia. • Results from a mutation in one or more of the genes that make haemoglobin. It is passed down from one or both parents through their genes. • **Treatment:** Bone marrow transplantation (very costly). Mainstay treatment is repeated blood transfusions every two to three weeks to survive. 
Alzheimer	• Progressive neurological disorder that causes the brain to shrink (atrophy) and brain cells to die, which primarily affects memory (dementia) and cognitive function. • Caused by abnormal build-up of proteins in and around brain cells, which either form plaques (Amyloid protein) or tangles (Tau protein) around brain cells.
Down's syndrome	• Genetic condition caused by the presence of an extra copy of chromosome 21. • People with Down's syndrome have 47 chromosomes instead of the usual 46. • Lifelong condition that affects physical and intellectual development with no cure.

Human immuno-deficiency virus (HIV)	• RNA virus that damages the immune system. HIV primarily targets CD4 cells (type WBCs), essential for the proper functioning of the immune system. • If left untreated, HIV can lead to AIDS (acquired immunodeficiency syndrome). • **Transmission:** Contact with certain bodily fluids (infected blood, semen, or vaginal fluids) of a person with HIV. Can transmit from an HIV-positive mother to child during childbirth, breastfeeding, or pregnancy. • Not transmitted by insect vectors (HIV can only survive in human blood).
Rabies	• Vaccine-preventable zoonotic disease caused by a RNA virus which infects the central nervous system of mammals, including humans. • **Transmission:** Bite of an infected animal (dogs, cats, bats, monkeys, foxes), contact with saliva or other bodily fluids of infected animal. • **Symptoms**: Fever and headache, hallucinations, paralysis and hydrophobia. • **Treatment**: • Once symptoms appear, no cure for rabies (100% fatal).
Influenza	• Influenza (flu) is a highly-contagious respiratory illness caused by influenza viruses. • Influenza viruses are of four different types: A, B, C and D. • **H3N2** (HongKong Flu) and **H1N1** (Swine Flu) viruses are subtypes of Influenza A virus. Influenza A is associated with severe respiratory illness and deaths in humans. • **H5N1** (Avian influenza/ Bird Flu) is also a subtype of the Influenza A virus that primarily infects birds but can also infect humans and other mammals.
Tuberculosis (TB)	• Airborne communicable disease caused by bacteria Mycobacterium tuberculosis. • Can cause- Pulmonary TB (infection in lungs, 80% cases) and extra-pulmonary TB which can infect brain, uterus, stomach, mouth, kidneys and bones. • **High-risk groups:** People with weak immunity like those infected with HIV, Under-nutrition, Diabetes, Smoking and Alcohol consumption. • India has more than 25% of the total TB patients in the world. • **Treatment:** DOTS strategy (Directly Observed Treatment Short Course) is a WHO-recommended cost-effective strategy.
Malaria	• Potentially life-threatening disease caused by plasmodium parasites transmitted through the bite of infected female Anopheles mosquitoes. • Mosquirix is the world's first vaccine against the parasitic disease. • Currently, Malaria is a notifiable disease in 33 (States and UTs) in India. (Notifiable disease is required by law to be reported to government authorities, any failure to notify would be a criminal offence). • India has the vision to be malaria-free by 2027 and to eliminate it by 2030.
Disease X	• Not a specific disease but name given to a potential novel infectious agent currently unknown but could pose a serious microbial threat to humans in the future.
Antimicrobial resistance (AMR)	• Resistance acquired by any microorganism (bacteria, viruses, fungi, parasite) against antimicrobial drugs or treatments to which they were previously susceptible. **Sources of development of AMR:** • Microbes may develop resistance to antibiotics over time through natural mutation.

	• Can be acquired from vertical gene transfer i.e., during the process of bacterial division, the drug resistance gene is transmitted from parent to offspring. • Can be acquired by a microbe from other microbes through swapping genes via horizontal gene transfer i.e., genetic sequences associated with antimicrobial resistance may pass on from one microbe to another in the community. • Incomplete doses of medication and self-medication. • Inappropriate disposal of unused or expired medication can expose microbes in the environment. • Using antibiotics in farm animals and herbicide use to control weeds may enrich Antimicrobial resistance gene (ARGs) and Mobile genetic element (MGEs) by altering soil microbiomes. • Microplastics and untreated solid and liquid waste, biofilms can act as a reservoir of AMR microbes. **Note:** In India, Antibiotics are included in Schedule H and H1 of the Drugs Rules, 1945. These drugs have specific caution labelling requirements and are sold by retail only under the prescription of a Registered Medical Practitioner.

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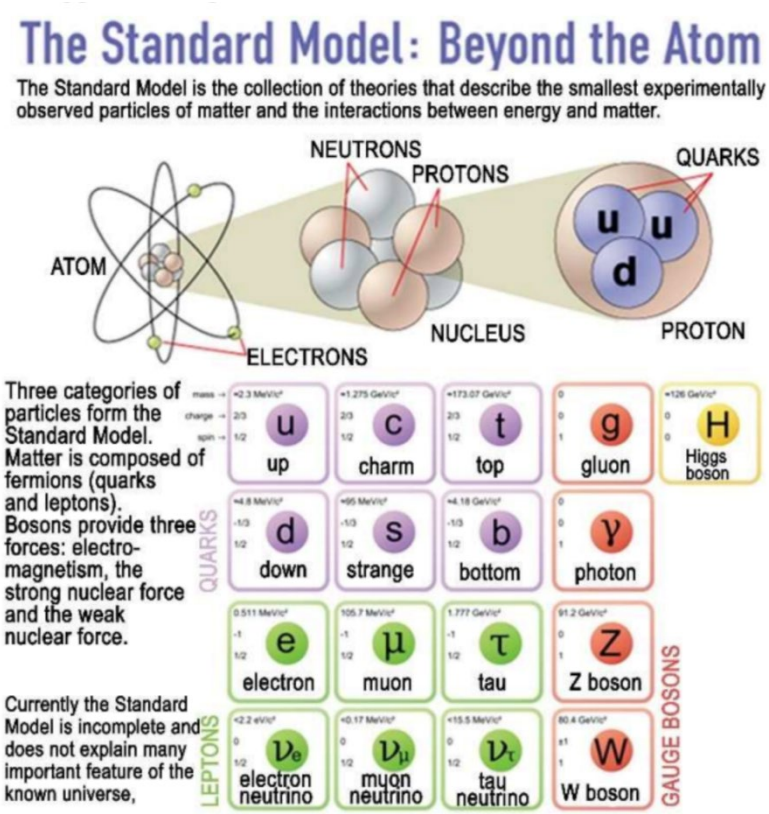
2 CHAPTER SPACE TECHNOLOGY

➔ BASIC PHYSICS AND ASTRONOMY

1. STANDARD MODEL OF PHYSICS

- The fundamental questions that have intrigued humans for long are "What is the world made of?" and "What holds it together?".
- The Standard Model is an attempt to explain these questions. The Model describes the **behaviour of six types of quarks, six types of leptons, three fundamental forces** (Strong force, Electromagnetic force & Weak force) and their **four associated particles** (Bosons), plus the Higgs boson.
- As per the Model:
  - All the known matter is made up of **fundamental particles called quarks and leptons.**
  - These particles interact with each other in accordance with rules known as the **'fundamental forces'**.
- **Limitations:** Currently, the Model is incomplete and does not explain Gravitational force. (Graviton, the force-carrying particle for gravity, has not been discovered yet) and does not explain the existence of dark matter and dark energy.



FUNDAMENTAL PARTICLES

1. Quarks:

- Quarks are elementary particles that are considered fundamental constituents of matter.
- They combine to form composite particles known as **hadrons** (such as protons and neutrons), which are the building blocks of atomic nuclei.
- There are 6 principal quarks, and they interact through the exchange of other elementary particles called gluons.
- A quark exhibits confinement, which means that the quarks are not observed independently but always in combination with other quarks. This makes determining their properties (mass, spin, and parity) impossible to measure directly.

2. Leptons:

- Leptons, alongside quarks, are fundamental building blocks of matter.
- There are 6 known leptons - Electron, Muon, Tau, three types of Neutrinos.

Note: Fermions (Quarks + Leptons) are the particles which have half-integer spin.

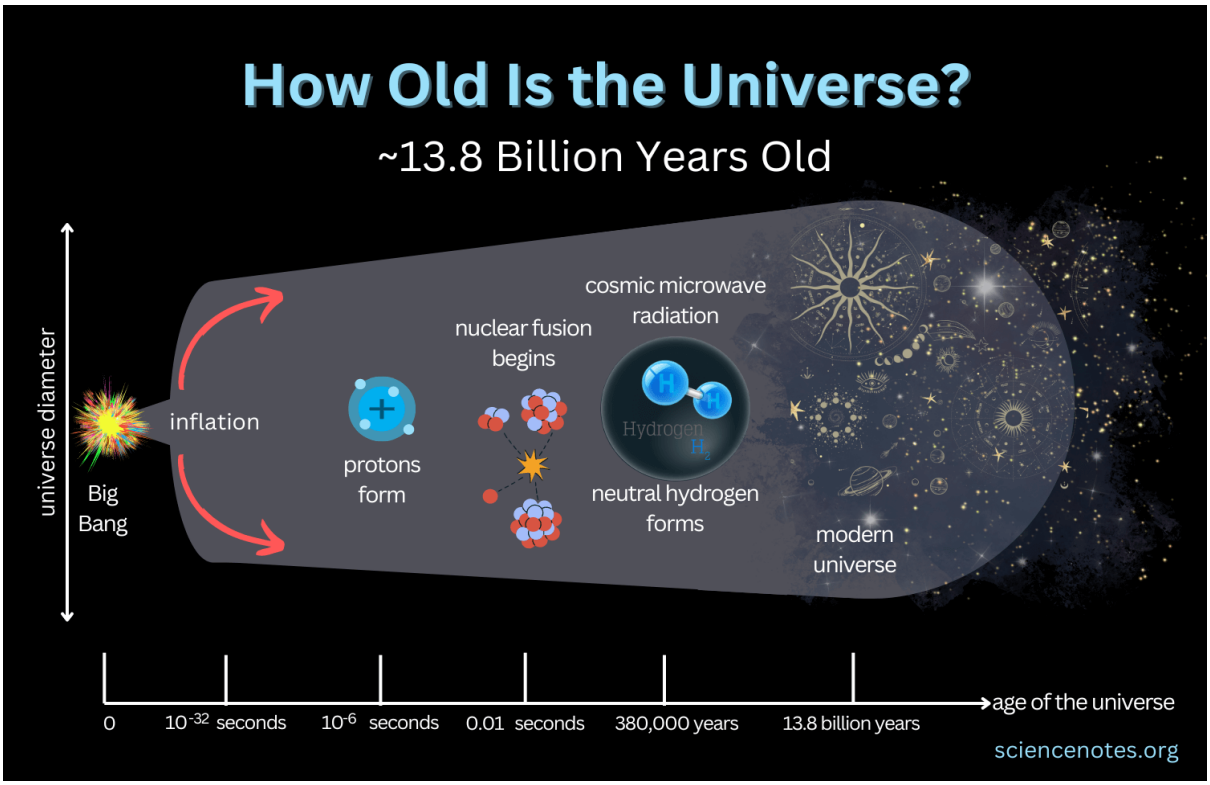
3. Bosons:

- Boson is a collective name given to particles that carry fundamental forces.
- Each fundamental force has its own corresponding **force carrier** (boson).
  - Strong force is carried by gluon
  - Electromagnetic force is carried by photon
  - W and Z bosons are responsible for the Weak force.

2. EVOLUTION OF UNIVERSE

BIG BANG THEORY

- Big Bang theory is the prevailing cosmological model for the universe's origin and evolution.
- **Origin from a Singularity**: Approximately 13.8 billion years ago, all the matter and energy in the universe were created from an incredibly hot, dense state called a Singularity in an enormous explosion- "Big Bang".
- **Inflation (Rapid expansion):** After the explosion, the universe underwent a period of rapid expansion called inflation.
- **Cooling and Particle formation:** As the universe expanded and cooled, fundamental forces and particles formed. The first fraction of a second witnessed the creation of elementary particles like quarks and gluons.
- **Big Bang nucleosynthesis (light element formation):** After a few minutes, protons and neutrons formed, allowing for the creation of the light elements - Hydrogen, Helium - through a process called Big Bang nucleosynthesis.
- **Formation of stars and galaxies**: Over billions of years, gravity caused the light elements to clump together, forming stars and galaxies. Over time, heavier elements were forged within stars and dispersed through stellar explosions, enriching the universe for future solar system formation.



Hubble's Law and Expanding Universe:

- Discovered by Edwin Hubble in 1929, Hubble's law states that galaxies farther away from us are receding at a faster velocity compared to closer galaxies.
- This recession velocity is proportional to the distance of the galaxy. The farther a galaxy is, the faster it's moving away from us. Thus, the universe is constantly expanding.

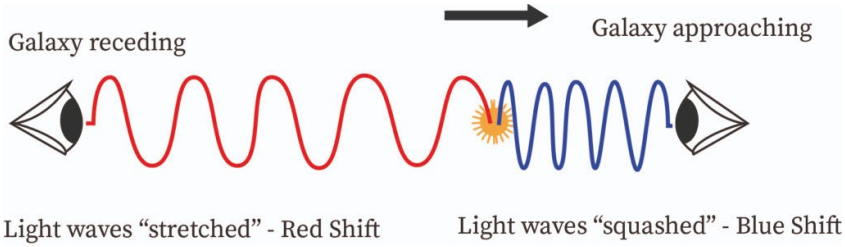
SUPPORTING EVIDENCE FOR BIG BANG THEORY

1. Cosmic Microwave Background Radiation:

- CMB is a form of electromagnetic radiation that permeates the entire universe and is almost uniform in all directions.
- It is considered to be the oldest light in the universe and is often referred to as the faint afterglow heat radiation from a very hot, early universe.
- The expansion of the universe stretched CMB's wavelength, shifting it from high-energy photons to the microwave range (long wavelength) as we observe today. This expansion is indeed evidence for the Big Bang.

2. Redshift of Galaxies:

- Redshift is a phenomenon observed in the light emitted by distant objects, such as galaxies or quasars.
- When an object moves away from an observer, the light it emits gets stretched or "shifted" toward longer wavelengths or towards the red end of the electromagnetic spectrum. This is interpreted as a consequence of the universe's ongoing expansion.



3. Abundance of Light Elements:

- The observed abundance of light elements like hydrogen and helium closely matches the predictions of Big Bang nucleosynthesis.

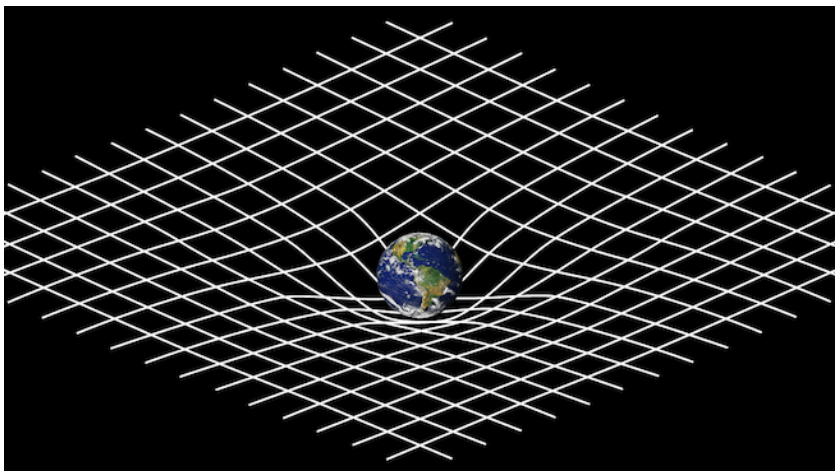
3. GENERAL THEORY OF RELATIVITY (GTR)

- GTR is a fundamental theory of gravitation published by Albert Einstein in 1915.
- According to the theory:
  - Massive objects cause a curvature in space-time structure, which causes other objects to move along a curved path.
  - Speed of light is constant in all inertial reference frames. (Speed of light remains the same for all observers, regardless of their position or motion within a gravitational field)
- GTR predicted the existence of gravitational waves, black holes, time dilation, gravitational lensing (light is deflected by objects with very strong gravity), and expansion of the Universe.

KEY PREDICTIONS OF GTR

1. Gravitational waves:

- Ripples in space-time caused by accelerating massive objects (similar to ripples in a water pond). The curvature of spacetime is directly proportional to the mass of the object causing the curvature, i.e., the greater the mass, the greater the curvature of spacetime it causes.
- The waves travel at the speed of light and squeeze and stretch anything in their path.
- Gravitational radiation is exceedingly difficult to detect because gravity is the weakest of the four fundamental forces. The waves were finally detected in 2015 by LIGO - Laser Interferometer Gravitational-Wave Observatory.



2. Black holes:

- Regions of spacetime where gravity is so strong that not even light can escape. Black holes have been observationally confirmed. (Details later in the segment)

3. Time dilation:

- Time dilation refers to the idea that time is relative and runs/passes at different rates for different observers, depending on their relative motion or their positions in a gravitational field.
- Closer an object's velocity is to the speed of light, the more pronounced the time dilation effect becomes.
- GTR predicts that time runs slower in stronger gravitational fields. This has been experimentally verified using high-precision atomic clocks, observations of Quasars etc.

4. IMPORTANT PARTICLES YOU OFTEN HEAR

1. Higgs Boson:

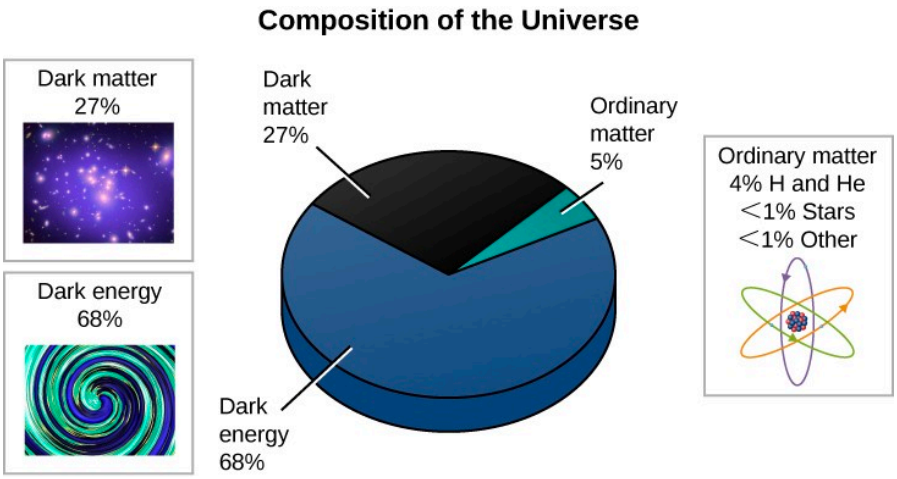
- In the 1960s, Peter Higgs suggested that just after the Big Bang, in the early stages, the fundamental particles did not have any mass. As the Universe cooled, an invisible force field got formed which has been termed as Higgs Field.
- The associated particles with the Higgs field are the Higgs Bosons. It has been theorised that any particle that interacted with these Higgs Bosons got mass, and those particles that were left out of the Higgs field remained massless.
- As these Higgs bosons grant mass to particles like electrons, quarks, etc. (the primary condition for existence of matter), they were termed as the 'God particle'.
- The Higgs boson was discovered by the Large Hadron Collider in 2012.

2. Neutrinos:

- Neutrinos belong to a group of fundamental particles called leptons in the Standard Model.
- They have no electric charge and very little mass (nearly massless).
- They very rarely interact with matter and that is why they are called "ghost particles". This means they can travel through vast distances, including entire planets, almost undetected.
- **Source of Neutrinos:** Stars, Supernovae, Galaxies, Nuclear reactions.

5. DARK MATTER AND DARK ENERGY

- Dark matter and dark energy together make up **95% of the Universe.** (68% dark energy and 27% dark matter).
- Only the remainder (5%) is composed of **fermionic matter,** i.e., things on the Earth, planets, stars, etc.



Dark Matter:

- Dark matter is completely invisible. It does not interact with matter, emits no light or energy and thus cannot be detected directly by conventional sensors and detectors.
- Scientists are confident it exists, because of the gravitational effects it has on galaxies and galaxy clusters.

Dark Energy:

- Existence of dark energy was theorised 25 years ago, when a team of researchers found that the expansion of the Universe was speeding up or accelerating, instead of slowing down due to gravity (inwards pulling force). This is hypothesised to be happening due to a mysterious form of energy called dark energy.

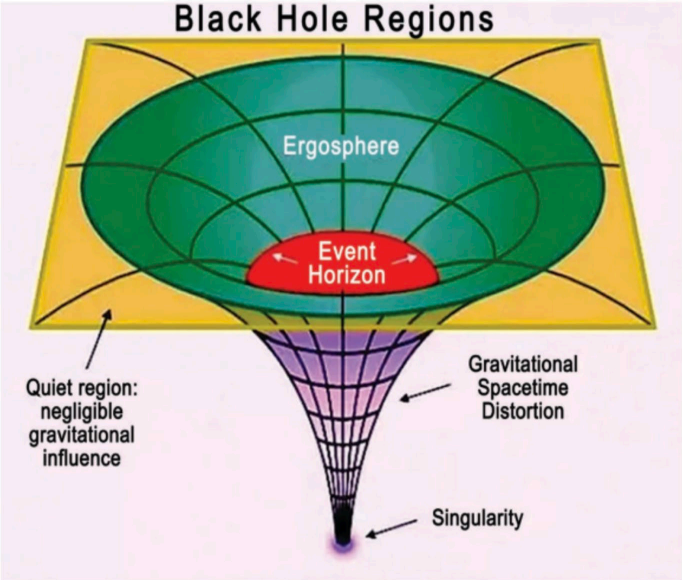
Characteristics of Dark Energy:

- Dark energy has been hypothesised as a repulsive force or anti-gravity, i.e. while gravity tends to make objects attract, dark energy would pull them apart by increasing the space between them. Thus, dark energy has an expansionary effect.
- As our universe is expanding, it indicates that dark energy has a greater abundance than dark matter.
- Dark energy is a property of space, so it does not get diluted as space expands.
    - Normally, as the universe expands the density of mass and radiation in it decreases.
    - However, the density of dark energy remains constant throughout. This means the dark energy in the universe is ever increasing, in order to keep the energy-density constant. Thus, dark energy should be energy inherent in the fabric of space itself.

6. BLACK HOLES

- Regions of spacetime where gravity is so strong that nothing, including light and other electromagnetic waves, has enough energy to escape.
- **Formation:** A black hole forms when a massive star (at least three times the mass of our Sun), exhausts its fuel, explodes in a supernova, and collapses under gravity into an incredibly dense core called a singularity.
- **Types:**
    - **Stellar Black Hole:** Formed by the collapse of a single massive star.
    - **Intermediate Black Hole**: Formed by the collapse of a star having mass between 100 and 1,00,000 times that of our sun.
    - **Supermassive Black Hole:** Masses ranging from millions to billions of times that of the sun, found at the centres of most galaxies.
- Black holes are not directly observable with telescopes that detect X-rays, light, or other forms of electromagnetic radiation. However, their presence can be inferred through their effects on surrounding matter and the gravitational waves they produce.

- **E.g.,** If a black hole passes through a cloud of interstellar matter or if a star passes close to a black hole, it will draw matter inward in a process known as accretion. As the attracted matter accelerates and heats up, it emits electromagnetic radiation into space. This reflects the presence of black holes.
- Merger of two blackholes produces powerful gravitational waves. The detection of these waves (through LIGO) can confirm the existence/ location of the black holes.



TERMS RELATED TO BLACK HOLES

Singularity:

- A singularity refers to a point of infinite density and infinitesimal size at the centre of a black hole.
- It is a region of extreme spacetime curvature, where the fabric of space and time becomes highly distorted.

Event Horizon (a point of no return):

- It is like a boundary around a black hole (around the singularity). Once anything (matter, energy, light) crosses this boundary, it can not escape unless it travels faster than the speed of light (which is impossible).
- Hence, not even light, can escape the black hole's gravity because the speed needed to escape at the event horizon should be greater than the speed of light.

Ergosphere:

- The Ergosphere is a bigger sphere, outside the event horizon of a black hole, where matter can enter and then return (escape the black hole's gravitational pull), if they are moving with speeds very close to the speed of light.
- Rotating (Kerr) black holes have an ergosphere. In the Ergosphere, spacetime is dragged along with the rotation of the black hole.
- Ergosphere derives its name from the fact that energy can be extracted from the black hole via the Penrose process. Researchers have proposed the concept of directing objects into the ergosphere of a black hole, allowing it to accelerate there along the black hole's direction of rotation, resulting in an increased velocity upon exiting. This energy 'gain' will translate to the black hole losing some angular momentum.

Accretion disc:

- A flat, rotating structure of matter (such as gas, dust, or other material) that forms around a black hole.
- The material in the accretion disc spirals inward due black hole's gravitational attraction.
- As it spirals inward, the material often heats up due to friction and gravitational forces, emitting various forms of electromagnetic radiation, including visible light, X-rays, gamma rays and radio waves.

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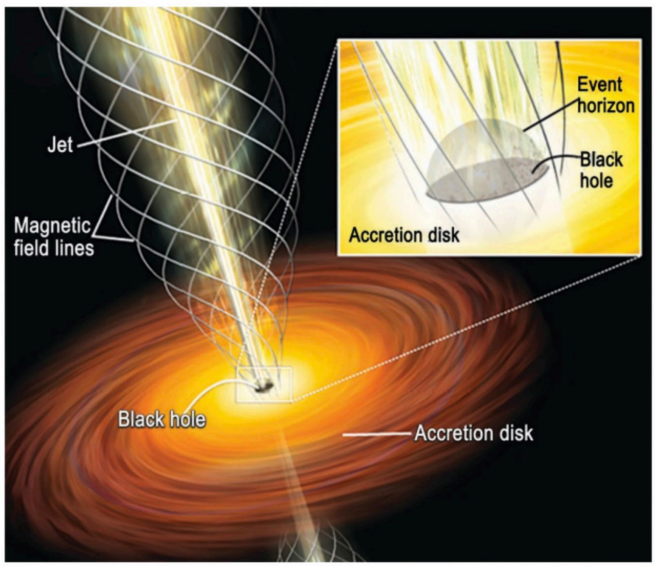


Spaghettification:

- Spaghettification refers to the effect of extreme gravitational pressure on any particle or body of matter, in particular, when exposed to the extreme forces of the black hole.
- When a particle draws too close to the event horizon, it is stretched into long thin shapes. **E.g.,** If an astronaut falls into the event horizon, as the gravity is inversely proportional to distance, the pull on the falling astronaut's legs will be substantially greater than the pull on his or her upper torso. Subsequently, stretching him like spaghetti (pasta).

Black Hole Mass Gap

- Gap between the mass of the heaviest Neutron star (maximum mass around 2.2 solar masses) and the lightest Black hole (around 5 solar masses) is called Black Hole Mass Gap.
- At the boundary between neutron stars and black holes there is always the possibility that some new, as yet unknown, astrophysical object might exist.
- Recently, an object has been detected in the star cluster NGC 1851, whose mass (2.09-2.7 times solar Sun) falls within the black hole mass gap.

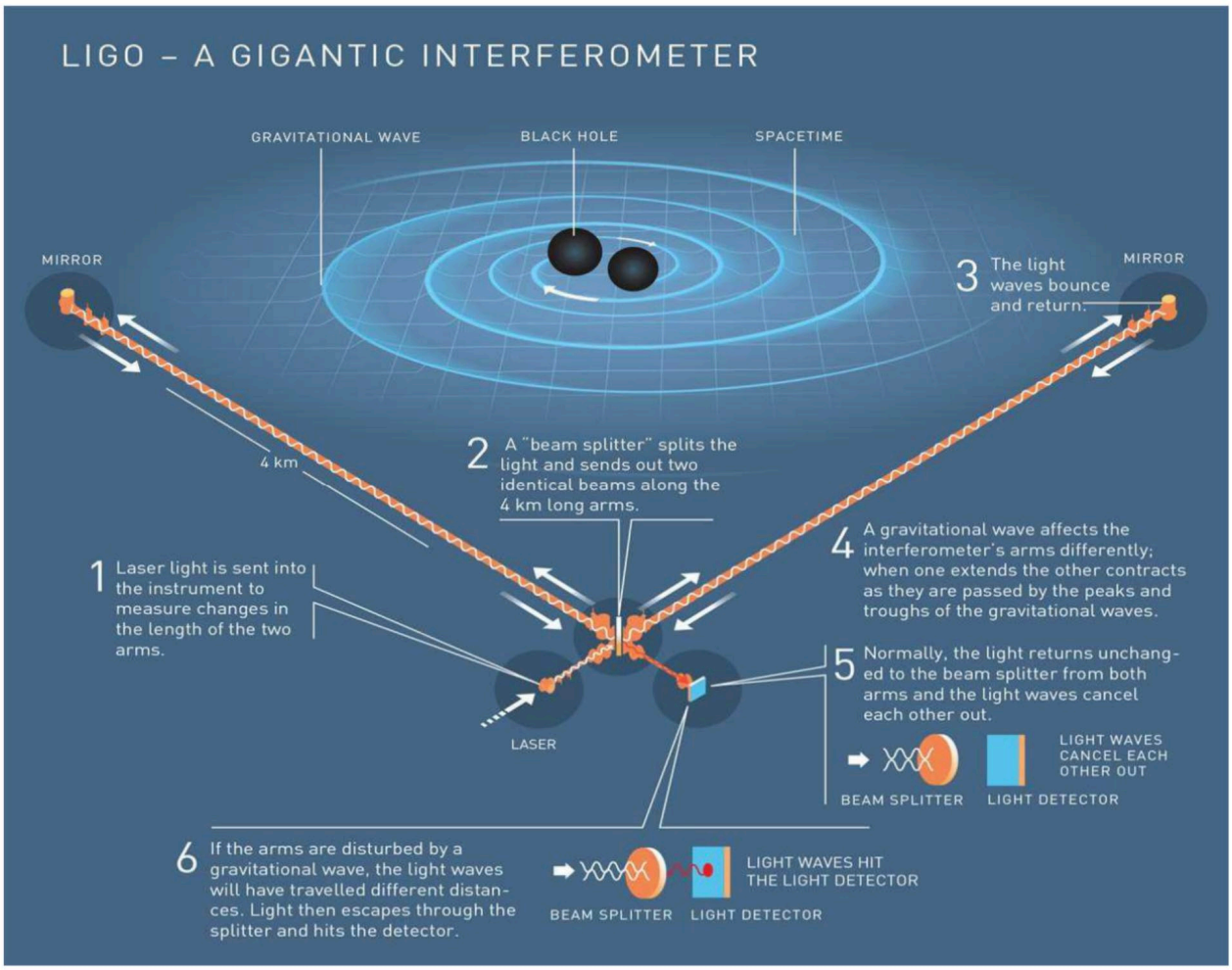
→ UNVEILING THE UNIVERSE'S SECRETS

7. LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)

- LIGO consists of two widely-separated interferometers within the United States—one in Hanford, Washington and another in Livingston, Louisiana—operated in unison to detect gravitational waves.

Working:

- LIGO comprises two 4-km-long vacuum chambers, built perpendicular to each other. Highly reflective mirrors are placed at the end of the vacuum chambers.
- Light rays are fired simultaneously in both vacuum chambers. They hit the mirrors, get reflected, and are captured back.
  - In normal circumstances, the light rays in both chambers would return simultaneously.
  - But when a gravitational wave arrives, one of the chambers gets a little elongated, while the other one gets squeezed a bit. In this case, light rays do not return simultaneously, and there is a phase difference. The presence of a phase difference marks the detection of a gravitational wave.



Significance:

- Provides a direct measurement of gravitational waves to study their properties.
- Allows scientists to observe and study mergers of black holes and neutron stars.
- Provide valuable insights into the early universe and advances our understanding of fundamental physics.

LIGO India Project:

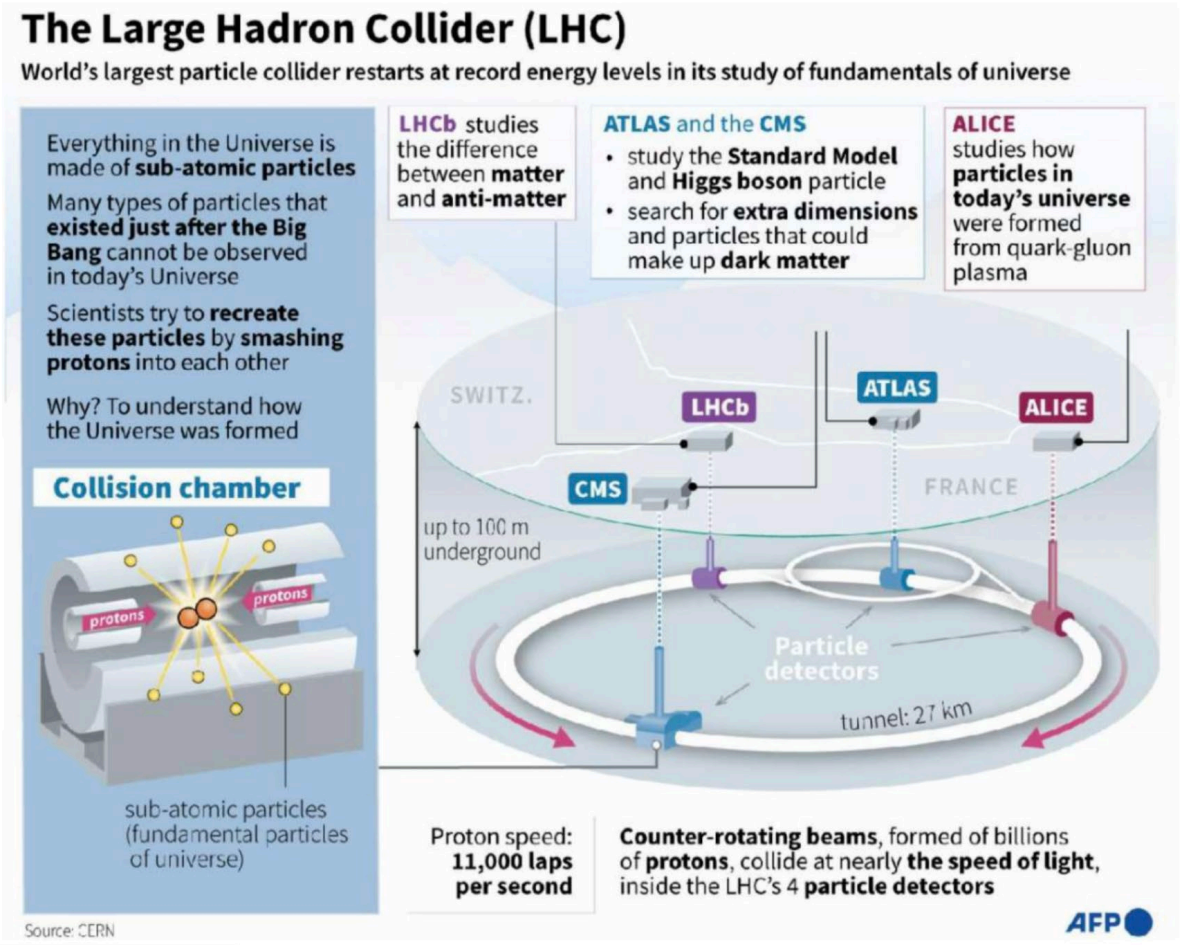
- Government has approved a gravitational-wave detector project in India costing Rs 2,600 crores, estimated to be built by 2030.
- **Location:** Hingoli district, Maharashtra.
- While two LIGOs can detect gravitational waves, a third observatory is required for better triangulation of the location of a source of gravitational waves.

8. LARGE HADRON COLLIDER (LHC)

- LHC is the world's largest and most powerful particle accelerator constructed by the European Organisation for Nuclear Research (CERN).
- It lies in a tunnel 27 kilometres in circumference and 175 metres beneath the France-Switzerland border near Geneva.
- Inside the LHC, two high-energy particle beams of protons are directed at each other at nearly the speed of light and made to collide in the 27-kilometre accelerator ring. The proton beam is guided around the accelerator ring by a strong magnetic field maintained by superconducting electromagnets.

- These high-energy collisions recreate conditions similar to the Big Bang, and generate new particles. Using detectors scientists study their properties and interactions, which can provide insights into fundamental particles, dark matter and possibly new physics beyond the Standard Model.
- The ATLAS and CMS detectors of LHC discovered the Higgs boson in 2012.

Hadrons: Subatomic particles composed of two or three fundamental particles known as quarks, which are held together by strong Nuclear force. **E.g.,** Protons, Neutrons.



Amaterasu particle:

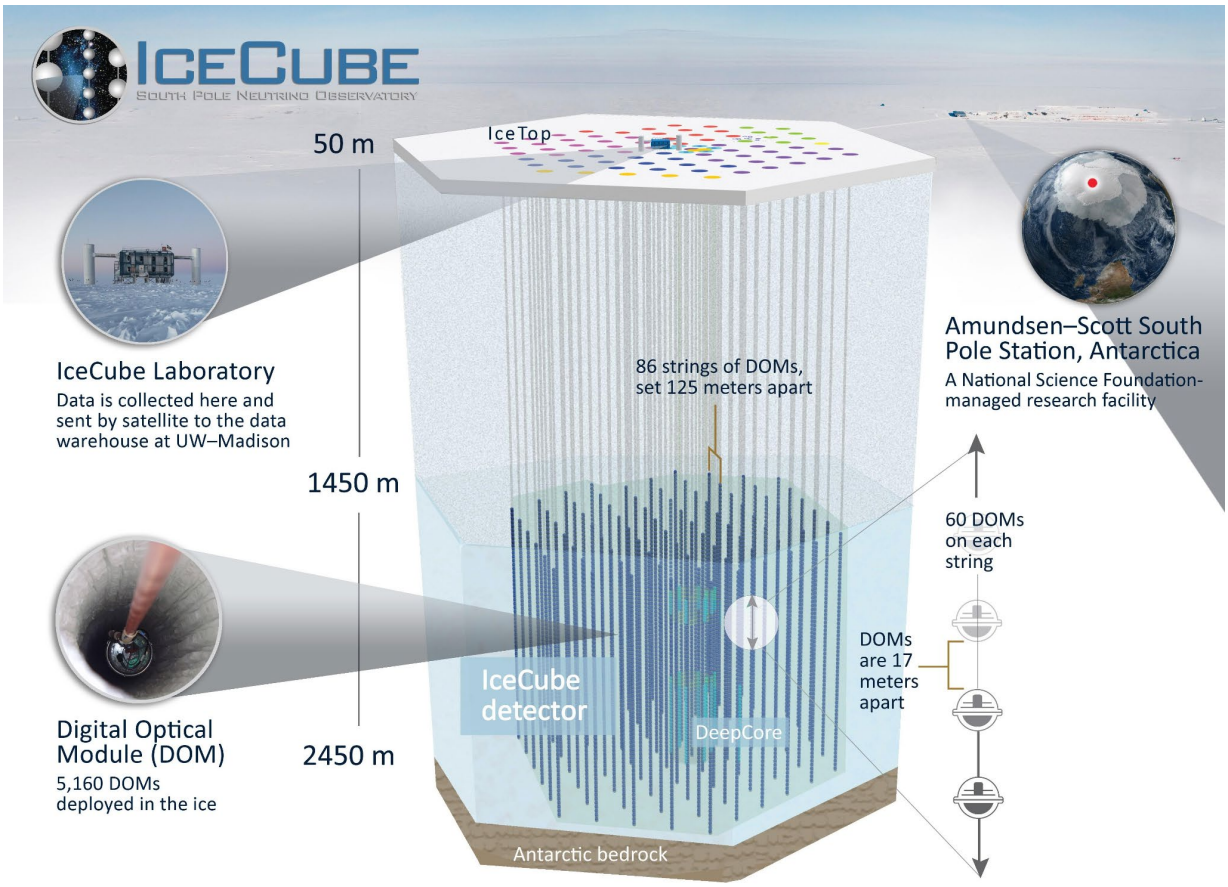
- The Amaterasu particle, named after the sun goddess in Japanese mythology, is an extremely high-energy cosmic ray detected in 2021 and later identified in 2023, using the Telescope Array Project observatory in the United States.
- It has an energy exceeding 240 exa-electron volts (EeV). This is millions of times more powerful than the particles produced by the Large Hadron Collider.
- It is second only to the "Oh-My-God" particle, another high-energy cosmic ray detected in 1991 with 320 EeV energy.

9. ICECUBE NEUTRINO OBSERVATORY

- The world's biggest 'neutrino telescope' is a cubic kilometre in size and contains thousands of sensors called Digital Optical Modules (DOMs) buried more than 1.4 km beneath the ice plus multiple detectors above the surface.
- These DOMs are designed to detect the Cherenkov radiation produced by neutrinos.
- **Location**: Amundsen–Scott South Pole Station in Antarctica.

Working:

- Neutrinos rarely interact with matter. However, when a neutrino interacts with an atom in the ice, it creates a secondary particle that travels faster than light in the ice. This faster-than-light travel creates a faint blue light called Cherenkov radiation.
- The DOMs detect the Cherenkov radiation and send a signal to the surface. By studying the pattern of Cherenkov radiation, scientists can learn about the energy and direction of the neutrino that caused it.



Why study Neutrino?

- There are discrepancies between Standard Model's predictions (Neutrino is massless) and the observed behaviour of neutrinos (have non-zero mass). Studying these anomalies could lead to the discovery of new physics beyond the Standard Model.
- Mechanism by which neutrinos acquire mass is still not fully understood. Studying their properties might shed light on the Higgs mechanism and mass generation in general.
- Neutrinos can travel vast distances with minimal interaction, hence, they carry information about the early universe, moments after the Big Bang. Studying them can provide insights into the universe's evolution.

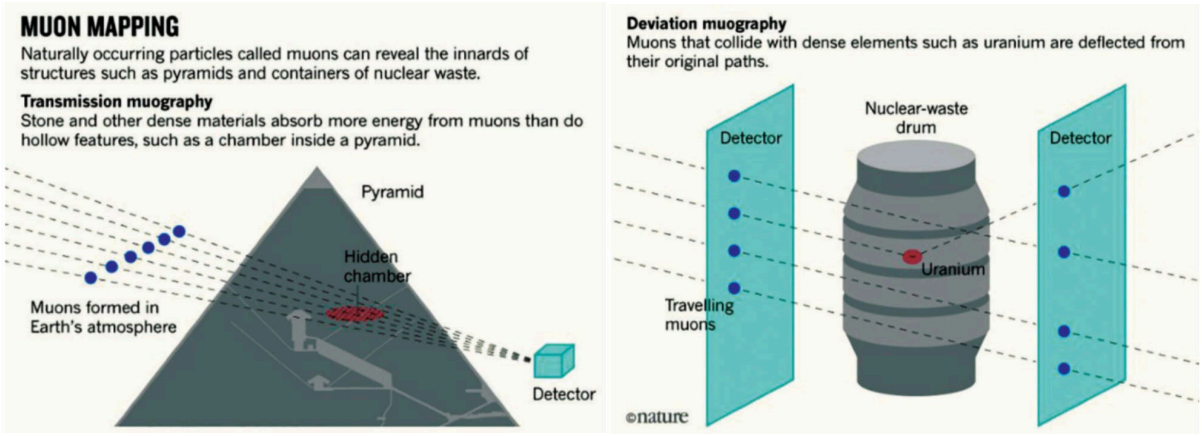
Important Observatories	Description
Indian Neutrino Observatory	• Proposed underground laboratory at Bodi West Hills near Madurai, Tamil Nadu. **Opposition:** • TN is opposing the move as the proposed site will fall within the confines of Periyar tiger corridor and Mathikettan Shola National Park in the Western Ghats. • As the observatory will be at a depth of 1 km mountain rock will be subject to vertical stress and may create rock bust and roof collapse. • Harmful effects of radiation. (This is misplaced as neutrinos are harmless)

Cubic Kilometre Neutrino Telescope	• European detector under-construction off the coast of France, Italy, and Greece, at the bottom of the Mediterranean Sea.
China's planned Neutrino observatory	• China is planning to build the world's largest neutrino observatory under the ocean. **China Plans World's Largest "Ghost Particle" Detector 1 Kilometer Under The Ocean** *To catch the most elusive known particles you need a lot of water.* DR. ALFREDO CARPINETI Published March 23, 2023

10. MUON TOMOGRAPHY OR MUOGRAPHY

Muons:

- Muons are elementary particles (a type of leptons) constantly produced in the Earth's upper atmosphere by cosmic ray interactions.
- They are about 200 times more massive than electrons and do not lose much energy as they travel, which allows them to penetrate more deeply into materials than X-rays or other forms of radiation.



Muon Tomography:

- A technique used to image the interior of dense objects or structures using cosmic ray muons.
- When muons pass through matter, their trajectory is affected by the density and composition of the material.
- By measuring the paths of muons as they pass through an object from different angles, it is possible to create a 3D image of the object's internal structure.
- **Advantage**: Non-invasive imaging technique (does not require any drilling or excavation).

Uses:

- Image interior of archaeological sites (pyramids in Egypt), volcanoes to monitor for potential eruptions.
- Inspect integrity of spent fuel rods and other components of nuclear reactors.
- Used in customs security to detect contraband and other illicit materials in shipping.

➔ STARS AND STELLAR PHENOMENA

11. SUPERNOVA

- Incredibly powerful stellar explosions that occur when a massive supergiant star reaches the end of its life.
- These explosions release an astonishing amount of energy, up to 10^44 joules.

Click here for INDEX

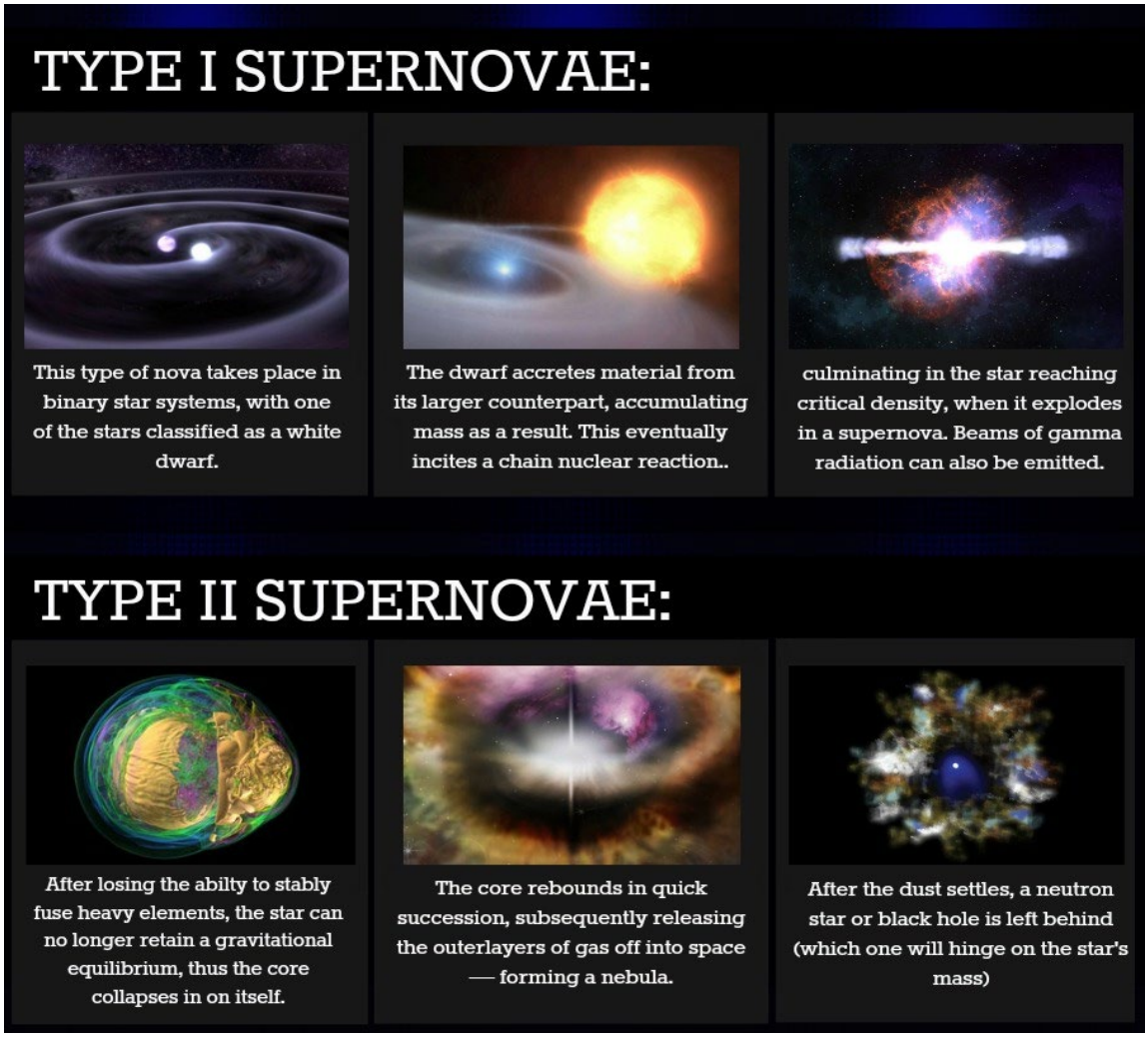
TYPES:

Type I:

- Occur in binary star systems where one of the stars is a white dwarf (a dense, Earth-sized remnant of a star that has exhausted its nuclear fuel and collapsed under its own gravity).
- The white dwarf accretes matter from its companion star until it reaches a critical mass, known as the **Chandrasekhar limit** (1.4 times the mass of the Sun).
- The pressure and temperature at the core of the white dwarf become so high that carbon and oxygen nuclei in the core begin to fuse rapidly into heavier elements, primarily iron.
- The fusion process proceeds at an ever-increasing rate, leading to a thermal runaway/uncontrolled nuclear reaction that releases an immense amount of energy, causing the white dwarf to explode.

Type II:

- Star is a delicate balance between two forces: the outward energy and pressure created by nuclear fusion and the inward gravitational force, as a result of the star's large mass.
- Core-collapse supernovae occur when massive stars (at least 8 times the mass of our Sun) reach the end of their lives. As the core runs out of nuclear fuel, gravity starts to gain the upper hand, and the star collapses under the force of gravity.
- The core collapse triggers a massive shockwave that eventually blows off the outer layers of the star. It leads to the formation of a **neutron star** (or a black hole, if the star is extremely massive).



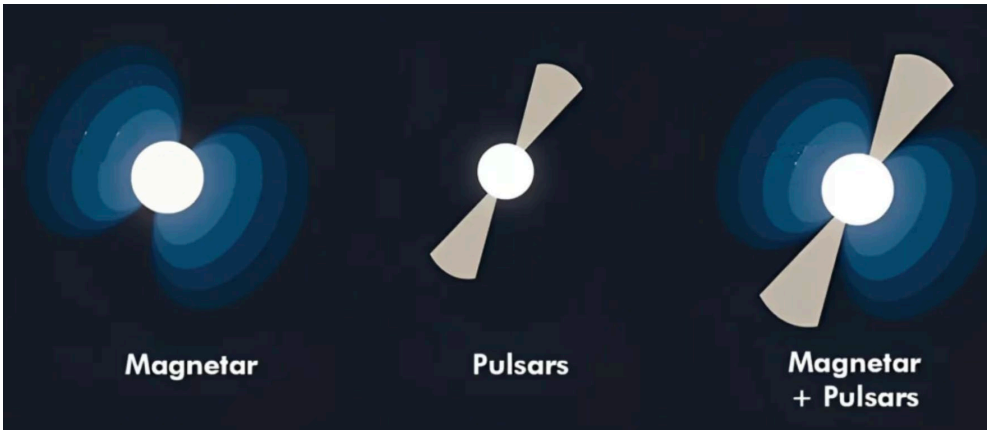
Significance:

- Supernovae are responsible for creating and dispersing heavy elements like iron, gold, and uranium into space, essential for the formation of stars, planets and life.

- Supernovae have a consistent peak brightness and are used as "standard candles" in cosmology to measure cosmic distances.

12. NEUTRON STARS

- Incredibly dense remnants/ leftover core of supermassive stars that have exploded as supernovae.
- The immense gravity of the core crams protons and electrons together, which combine to form neutrons. Neutron stars do not have an event horizon.
- **Size:** Typically only 15-30 kilometres in diameter.
- **Mass:** 1.4 to 2.2 times our Sun. (densest known stellar objects, second only to black holes)
- **Fast Spinners:** Rotate incredibly fast, with periods as short as a fraction of a second. This rapid spin is a result of the conservation of angular momentum.
- They possess extremely strong magnetic fields, which can give rise to intense radiation emissions (radio waves, X-rays, and gamma rays) and particle streams, which are observable as pulsars.



Types of Neutron Stars:

(a) Pulsars: Emits an electromagnetic beam out of their poles. The difference between pulsars and neutron stars is that other neutron stars do not shoot a pulse (beam) as strong as pulsars.

(b) Magnetars: Have powerful magnetic fields (in the range of 10^{15} gauss) as compared to other neutron stars. They are the most powerful known magnetic objects in the Universe.

13. QUASARS

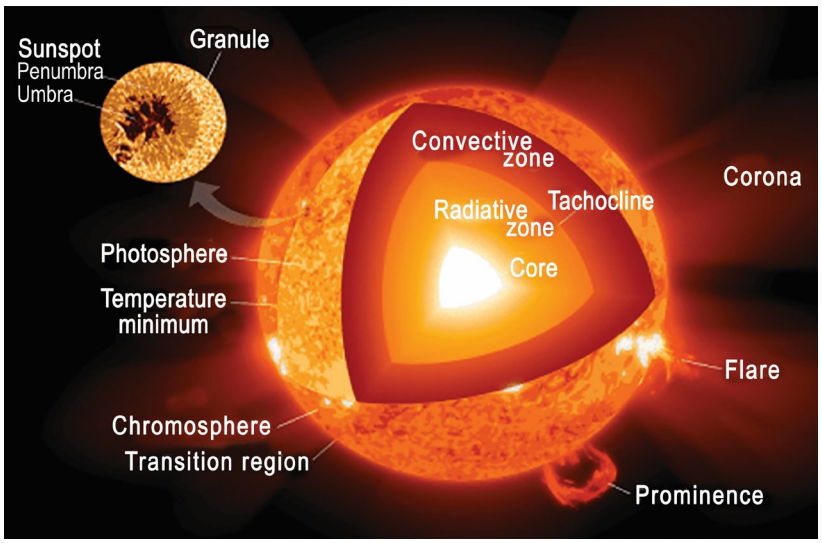
- Quasars are not actually stars but active galactic nuclei (AGN) located at extreme distances from Earth.
- They are the bright cores of distant galaxies powered by supermassive black holes. The intense gravitational forces exerted by these black holes cause the surrounding material to heat up and emit enormous amounts of energy, including visible light and radio waves.
- They are the most luminous objects (equivalent to the combined light of hundreds of billions of stars) in the known universe, outshining entire galaxies. As a general rule, the most luminous quasars indicate the fastest-growing supermassive black holes.
- The nearest quasar is Markarian 231, which lies about 600 million light-years from Earth.

14. FAST RADIO BURST (FRB)

- Bright and brief bursts of electromagnetic radiation seen in radio-wave frequencies (usually last a thousandths of a second).
- Exact cause of FRB is unknown but the sources include magnetars, colliding neutron star binaries, and merging white dwarfs.

15. SUN

- **Composition:** Hydrogen (about 74%), Helium (24%) and other elements in trace amounts.
- **Energy Source**: Nuclear Fusion (Hydrogen atoms combine to form Helium in its core).
- **Size and Mass:** Approximately 109 times Earth's diameter and about 333,000 times Earth's mass.
- **Distance:** Average distance from Earth to the Sun, known as one astronomical unit (AU), is about 93 million miles (150 million kilometres).

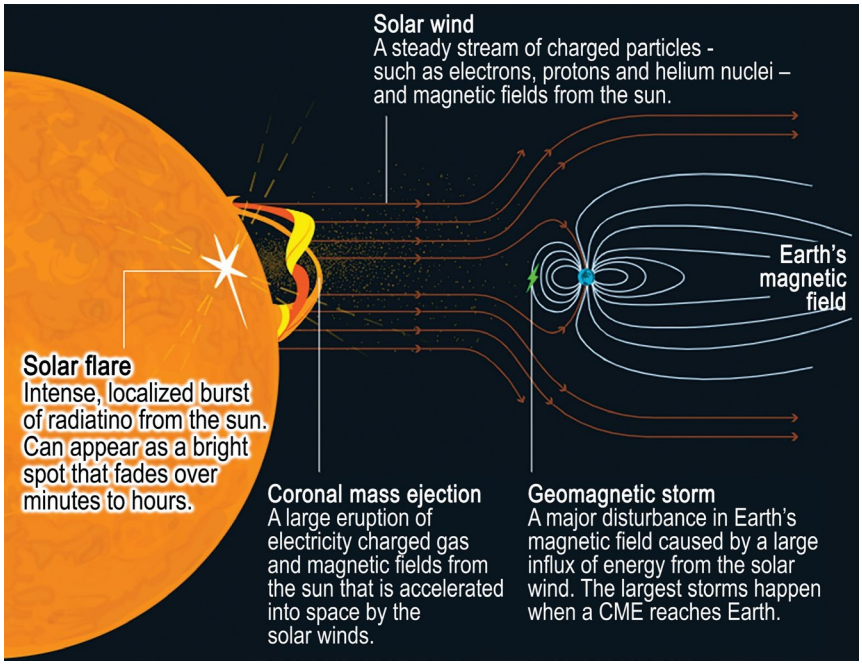


Layers of the Sun:

- **Core:** Innermost region where nuclear fusion occurs.
- **Radiative Zone**: Above the core, energy is transported outward by photons through this layer.
- **Convective Zone**: This layer is closer to the surface and transports energy through the movement of hot gas (plasma) cells.
- **Photosphere**: Visible surface of the Sun, where most of its energy is radiated into space as visible light.
- **Chromosphere**: Thin layer between photosphere and corona. (named for its reddish colour, most easily observed during a total solar eclipse)
- **Corona**: Outermost and extremely hot layer of Sun's atmosphere, visible as a halo during solar eclipses.

Key terms:

- **Heliosphere:** Vast, bubble-like region of space dominated by the Sun's solar wind and magnetic field emanating from the Sun. It extends far beyond the orbit of Pluto and protects the solar system from harmful cosmic rays.
- **Solar Magnetic Field:** Sun has a complex magnetic field generated by the motion of charged particles in its interior. This field plays a crucial role in the behaviour of the Sun, including the formation of sunspots, solar flares, and CMEs.



- **Sunspots:** Temporary spots on the Sun's photosphere that appear darker than the surrounding areas. They are cooler parts of the Sun's surface caused by massive changes in its magnetic field.
- **Solar Wind:** Created by the outward expansion of plasma (a collection of charged particles) from the Sun's corona. This plasma is continually heated to the point that the Sun's gravity can not hold it down. It then travels along the Sun's magnetic field lines that extend radially outward.

- **Solar Flares:** Massive explosion on the Sun's surface that releases intense bursts of radiation across almost the entire electromagnetic spectrum (from radio waves to X-rays). Solar flares can disrupt radio communications, satellite operations, and power grids on Earth.
- **Coronal Mass Ejections:** Large expulsions of plasma and magnetic fields from the sun's corona into space. When they interact with Earth's magnetic field, they can cause geomagnetic storms, which can impact power grids, GPS systems, communication networks and orbiting satellites and trigger Aurora displays.
- **Picoflare jets:** Relatively small jets of charged particles expelled intermittently from the sun's corona at supersonic speeds for 20 to 100 seconds. These charged jets are a source of the solar wind. These jets carry approximately one-trillionth the energy of the largest flares the sun is capable of producing. ("Pico" denotes 10^{-12} or one trillionth of a unit). It has significant effects on the large-scale solar system as well as on Earth's magnetic field and poses risks to satellites.
- **Geomagnetic storms:** A geomagnetic storm is a disturbance in the Earth's magnetic field caused when a solar wind shock wave or cloud of the magnetic field interacts with the Earth's magnetic field.

➔ SPACE TECHNOLOGY AND MISSIONS

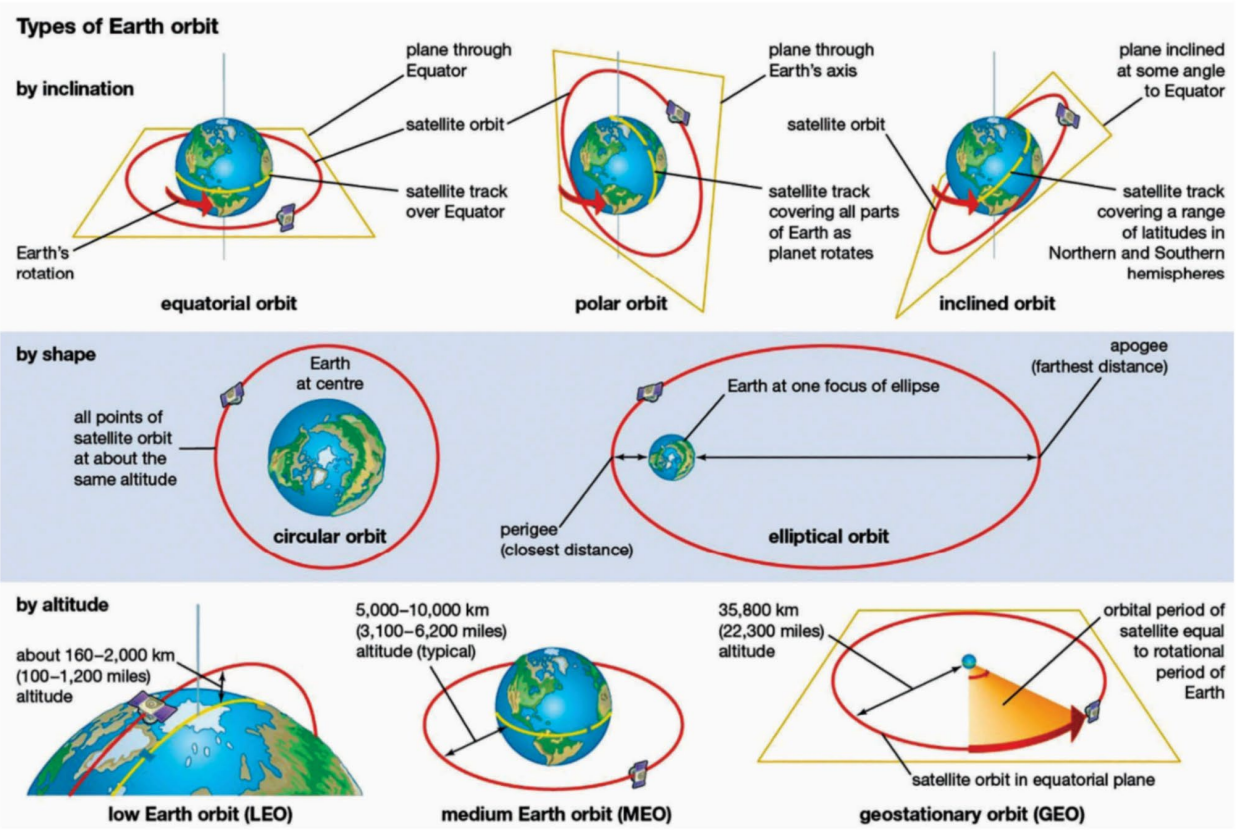
16. TYPES OF ORBITS

1. Low Earth Orbit (LEO):

- **Altitude:** Between 160 km and 1000 km above Earth.
- Satellites in this orbit take approximately 90 minutes to circle Earth.
- **Utility:** Satellite imaging, location of International Space Station.

2. Medium Earth Orbit (MEO):

- **Altitude:** 2,000 to 36,000 km above the Earth's surface.
- **Utility:** Satellite navigation, Communication, and Earth observation. **E.g.,** Global Positioning System.



3. Geostationary Earth Orbit (GEO):

- GEO is located at an altitude of 35,786 km above Earth.
- Satellites in GEO circle Earth above the equator from West to East following Earth's rotation – taking 23 hours 56 minutes and 4 seconds – by travelling at the same rate as the Earth. This makes satellites in GEO appear to be 'stationary' over a fixed position from the Earth.
- **Utility:** Telecommunication satellites, weather monitoring satellites to continually observe specific areas.

4. Polar Orbit:

- Orbit that passes over or near the Earth's poles and covers the entire surface of the Earth over a period of time.
- A type of LEO (between 200 to 1000 km).

5. Sun-Synchronous Orbit (SSO):

- A particular kind of polar orbit. Satellites in SSO are synchronous with the Sun i.e., they are synchronised to always be in the same 'fixed' position relative to the Sun. Hence, the satellite will always observe a point on the Earth as if constantly at the same time of the day.
- Satellites in SSO can be used to investigate how weather patterns emerge, monitor emergencies (like forest fires, floods), accumulate data on deforestation & rising sea levels.

6. Transfer Orbits:

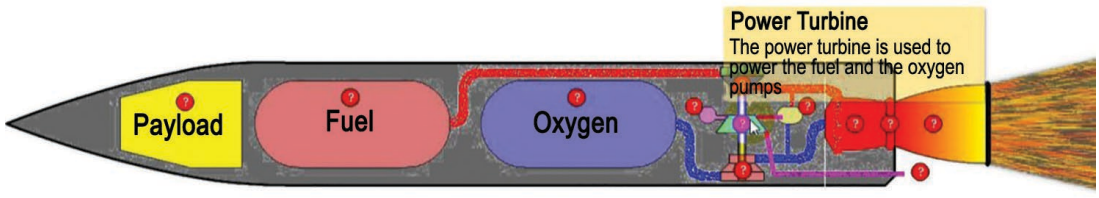
- Special kind of orbit used to transfer a satellite from one orbit to another, typically used for interplanetary missions.
- When satellites are launched from Earth and carried to space with launch vehicles, they are not always placed directly in their final orbit.
- Satellites are instead placed on a transfer orbit from where, by using relatively little energy, the satellites can move to the destination orbit.

17. ROCKET PROPULSION

- A rocket has to clear earth's atmosphere to travel in space or go into an orbit.
- The minimum height for a satellite to go into the Earth's orbit is approximately 200 km.
- At a certain initial speed, as the satellite tries to go off at a tangent to the earth, the Earth's gravity pulls it back.

PRINCIPLE BEHIND ROCKET PROPULSION: NEWTON'S 3RD LAW OF MOTION

- The only means available for any object to be put in orbit is rocket propulsion.
- Newton's third law of motion governs the working of a rocket engine, viz., For every action, there is an equal and opposite reaction.
- The mass of gas escaping through a rocket's nozzle gives a push or commonly called thrust to the rocket to fly in the opposite direction.



Performance metric of a rocket: Thrust and Specific impulse

- Power generated by the rocket engine is balanced by the thrust in the opposite direction on the rocket itself, resulting in pushing the rocket at a certain initial velocity. More the power of the engine, more the thrust, more is the initial velocity.

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- Efficiency of a rocket is expressed in terms of specific impulse (the amount of thrust derived from one kilogram of propellant (rocket fuel) in one second of engine operation). Specific impulse depends on two things: quality of fuel used and performance of the engine. Higher the specific impulse, the higher is the push to the rocket.

18. LAUNCH VEHICLES OF ISRO

1. POLAR SATELLITE LAUNCH VEHICLE

- Workhorse of ISRO known for its reliability, versatility, and cost-effectiveness since 1994.
- **Stages**: Four-stages launch vehicle
  - First stage is powered by a solid rocket motor (strap-on motors to provide additional thrust to the rocket to overcome air resistance).
  - Second stage uses a liquid propulsion system (Vikas Engine)
  - Third stage is a solid rocket motor
  - Fourth stage is a liquid-fueled engine
- PSLV can deliver payloads of up to:
  - 3250 kg to Low Earth Orbit
  - 1600 kg to Sun Synchronous Orbit
  - 1400 kg to Geosynchronous Transfer Orbit
- **Successful launches:** Chandrayaan-1 Mission (2008), Mars Orbiter Mission/Mangalyaan (2013), 104 satellites at one go (2017).

GEOSYNCHRONOUS SATELLITE LAUNCH VEHICLE

- **Stages:** Three-stage launch vehicle
  - **First Stage:** Uses four strap-on solid boost motors (HS200).
  - **Second Stage**: Liquid core stage (L110) powered by two Vikas liquid engines.
  - **Third Stage:** Cryogenic Upper Stage with cryogenic engine using liquid Hydrogen and liquid Oxygen for high specific impulse and efficiency.
- GSLV can carry more than 2,200 kg to geostationary orbits, and over 6,000 kg to LEO.
- **Issues:** GSLV has a patchy track record, has flown 16 times of which 4 are unsuccessful (high failure rate for any rocket). The problems have mainly been with the cryogenic engine used by GSLV that is reverse-engineered on a Russian design.

LAUNCH VEHICLE MARK-3

- LVM3 (previously referred to as Geosynchronous Satellite Launch Vehicle Mark III, GSLV Mk III) is a three-stage medium-lift launch vehicle developed by ISRO.
- **Stages:** Three-stage launch vehicle
  - **First stage**: Solid fuel S200 stage.
  - **Second stage:** Liquid fuel L110 stage. (Vikas Engine)
  - **Third stage:** Cryogenic fuel C25 stage (uses 25 tonnes of a mixture of liquid Hydrogen and Liquid oxygen). This upper stage (CE-20 cryogenic engine) is developed entirely in India.
- **Payload capacity** (one of the most powerful rockets in ISRO's fleet):
  - 4,000 kilograms to geosynchronous transfer orbit (GTO).
  - 10,000 kilograms to low Earth orbit (LEO).
- Primarily designed to launch communication satellites into geostationary orbit.
- **Successful launches:** Chandrayaan-2, Chandrayaan-3. Human-rated LVM-3 is due to launch crewed missions under Gaganyaan Mission.

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SMALL SATELLITE LAUNCH VEHICLE

- New small satellite launch vehicle developed by ISRO to launch small satellites to LEO on 'launch-on-demand' basis.
- Three-stage Launch Vehicle configured with three Solid Propulsion Stages and liquid propulsion based Velocity Trimming Module (VTM) as a terminal stage.
- Can launch Mini, Micro, or Nanosatellites (10 to 500 kg mass) up to 500 km in LEO.
- Capable of multiple orbital drop-offs i.e., launch multiple microsatellites in one launch.
- SSLVs will cost 1/10th of a PSLV and will need only 72 hours for launch in comparison to 45 days for PSLV.

➔ ROCKET FUEL TECHNOLOGIES

19. VIKAS ENGINE

- Family of liquid-fueled rocket engines.
- Hypergolic propellant - ignites spontaneously on contact.
- **Fuel:** Dimethyl Hydrazine
- **Oxidizer:** Nitrogen Tetroxide (N_2O_4)
- **Applications:** Powers various stages of India's launch vehicles:
  - Second stage of the PSLV
  - Second stage and strap-on boosters of GSLV Mark II
  - Core stage (L110) of LVM3

20. LOx METHANE ENGINE

- Liquid Propulsion Systems Centre of ISRO is developing Lox methane-powered rocket engines.
- The 'LOx methane' engine uses methane as fuel and liquid oxygen as oxidizer.

Advantages:

- Can be synthesised in space (Methane can be synthesised using water and carbon dioxide in space).
- It is non-toxic. (Di-Methyl Hydrazine and Nitrogen tetroxide is said to be highly toxic)
- Higher specific impulse
- Less bulky and easy to store
- Does not leave a residue upon combustion.

21. ION ROCKETS

- Ion rockets are the rockets of the future for deep space exploration.
- They are much more efficient than conventional rockets that use chemical fuels.
- While chemical fuels generate velocities of up to 2 to 3 km/s, ion rockets can achieve velocities around 20-80 km/s.
- Ion rockets use electric propulsion systems, typically ions, to generate thrust and propel rockets.
- The ions are accelerated using an electric field and expelled at high velocities, resulting in a continuous thrust.
- Small scale ion propulsion is used in a number of missions including NASA's Dawn mission and Deep Space mission, ESA's LISA Pathfinder and Japan's Hayabusa Mission.

22. ISRO'S CRYOGENIC ENGINE (CE-20)

- CE-20 is an indigenous cryogenic engine developed by ISRO.

- **Fuel:** Liquid hydrogen and liquid oxygen as propellants stored at extremely low temperatures (around -253°C for hydrogen and -183°C for oxygen).

Advantages:

- Cryogenic propellants have a high energy density, high fuel efficiency and high specific impulse (more thrust per kilogram of propellant). This allows rockets to carry less fuel, reduces their overall weight and can carry heavier payloads or travel further.
- Cryogenic engines are throttleable (ability to vary/adjust their thrust levels during flight). This capability is essential for precise control during ascent, orbit insertion, manoeuvring, and controlled reentry of a rocket.

Challenges:

- They require complex and expensive infrastructure to store and handle extremely cold propellants.
- Initial development process of cryogenic engines and maintenance is expensive.

23. ROCKET LAUNCH STATIONS IN INDIA

Considerations for selecting a rocket launch site in India:

- **Proximity to Equator:** Satellites launched from near the equator towards the east direction will get an initial boost equal to the velocity of the Earth surface. The initial boost helps in cutting down the cost of rockets used to launch the satellites.
  - Earth rotates counterclockwise (West to East), and the surface velocity of rotation varies from point to point on the Earth.
  - It is about 1600 km per hour or about 465 metres per second near the equator. The velocity gradually reduces moving towards the poles and is zero at the poles.
  - However, this initial boost can only benefit satellites in geo-stationary orbit or which circle the Earth parallel to the equator. (usually communication satellites)
  - Polar satellites are launched in southward or northward direction and therefore cannot take advantage of the Earth's rotation.
- **Location on Eastern coast:** This is so that in case of any launching failure, the debris falls harmlessly in Bay of Bengal or Indian Ocean and not on the main hinterland.

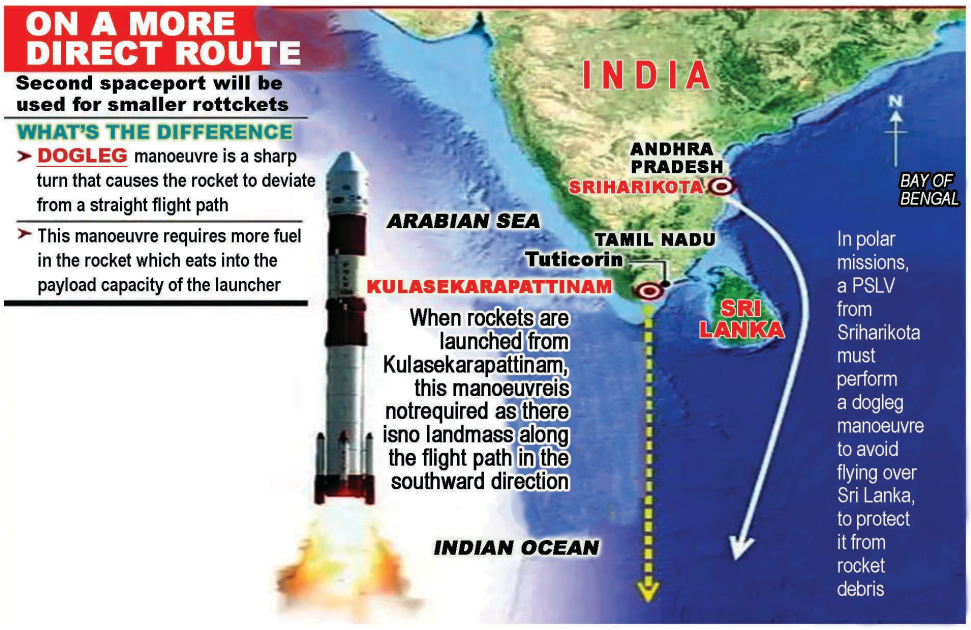
24. LAUNCH STATIONS OF ISRO

1. Satish Dhawan Space Centre (SHAR):

- India has SHAR in Sriharikota, Andhra Pradesh spread over 145 sq. km. that has two launch pads for PSLV and GSLV flights (heavier satellites).

2. Kulasekarapattinam spaceport:

- Foundation stone for India's new spaceport for SSLV was laid at Kulasekarapattinam.
- **Location:** Thoothukudi district, Tamil Nadu.



- **Will launch:** Smaller payloads like Nano and Microsatellites.

- **Project cost:** ₹950-crores, expected to take nearly two years to complete.

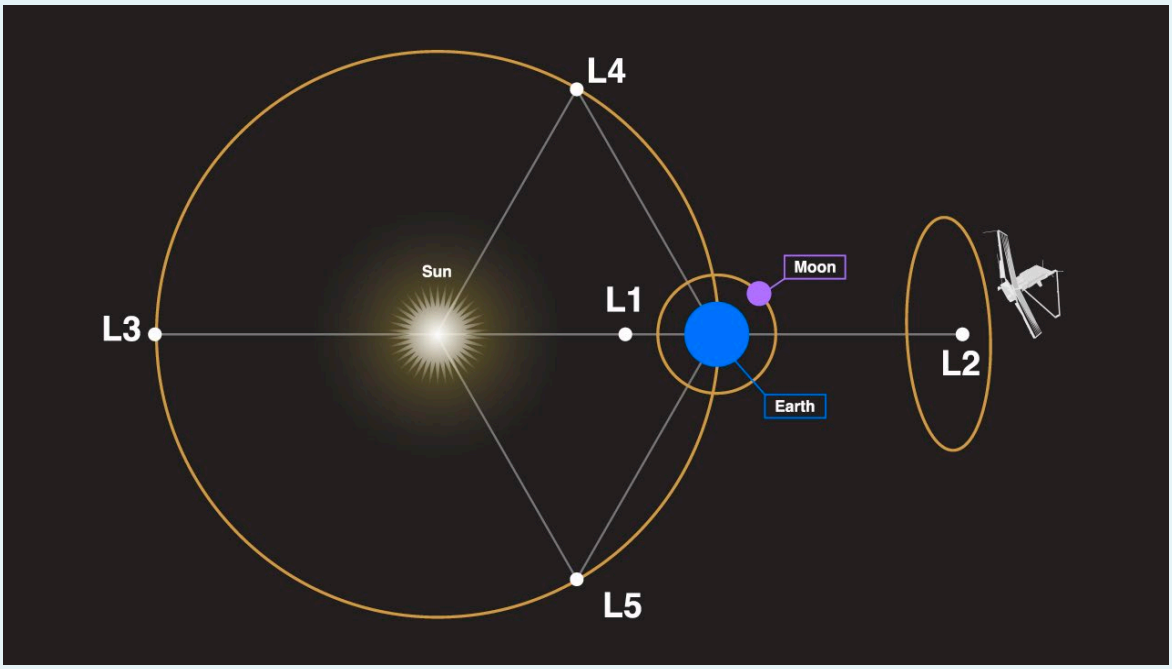
ADVANTAGE OF KULASEKARAPATTINAM

- Kulasekarapattinam gives the benefit of launching straight in southward direction, i.e., dogleg manoeuvre is not required, thereby saving the rocket's fuel and improving payload capability.

➔ IMPORTANT SPACE MISSIONS OF ISRO

25. ADITYA L1 MISSION

- India's first space-based observatory to study the Sun successfully launched from SHAR in September 2023.
- Launched into low earth orbit using PSLV. Aditya-L1 went multiple orbital manoeuvres and took around 126 days to travel to its final destination at Lagrangian Point L1.
- **Objectives:** To study Solar upper atmospheric dynamics (photosphere, chromosphere, and Corona), coronal heating mechanism, origin of coronal mass ejections, and flares etc.
- **Payloads:** Weighing 1475 kg, it will carry seven payloads, including:
  - **Solar Ultraviolet Imaging Telescope** (SUIT): To image the Sun in 200-400 nanometre (nm) of Ultraviolet band. SUIT's imager will continuously record the entire disk of the Sun. Images of various layers could improve understanding of the Sun's immediate atmosphere.
  - **Visible Line Emission Coronagraph** (VELC) is the Corona/Imaging and Spectroscopy payload to focus on Sun's Corona.
  - **Solar Low Energy X-ray Spectrometer** (SoLEXS) and **High Energy L1 Orbiting X-ray Spectrometer** (HEL1OS) will study X-ray flares emitted by the Sun over a wide range of X-ray energy range.
  - **Aditya Solar wind Particle Experiment** (ASPEX), during the cruise phase, will turn on and start performing in-situ measurements of solar particles and ions.
  - **Plasma Analyser Package for Aditya** (PAPA) will study solar wind and energetic ions.
  - **Magnetometer** (MAG) to measure low-intensity interplanetary magnetic field in space.



  - **Lagrange points** are positions in a moving two-body system where the **combined gravitational forces of two large bodies** (such as the Sun and Earth or Earth and the Moon) acting on a third body of smaller mass cancel each other out.

- While absolute neutralisation is not achievable due to the influence of other celestial bodies (such as Moon, Mars, and Venus etc.), they provide a stable position where a spacecraft may be "parked" to make observations.
- There are **five Lagrange points** located along the line connecting the two larger celestial bodies.
- **L1 point:** Located roughly 1.5 million kilometres from Earth. It provides an uninterrupted view of the Sun (the satellite can view the Sun without eclipses).
- **L2 point:** Provides an unobstructed view of the Universe and is stable enough for long-duration observations. Location for space-based observatories (James Webb Space Telescope).
- **L3 point:** Lies behind the Sun, opposite to Earth. Offers the potential to observe the far side of the Sun. Possible location for a future space-based observatory.
- **L4 and L5 point:** Stable locations but are relatively farther from Earth than L1.

26. GAGANYAAN MISSION

- Envisages demonstration of human spaceflight capability by launching a crew of 3 members to a Low earth Orbit of 400 km for a 3 days mission and bringing them back safely to earth, by landing in Indian sea waters.
- Crewed flight is planned for 2025 on the Human Rated LVM3 as the launch vehicle.
- Human Space Flight Centre will coordinate the Indian Human Spaceflight Programme and will be responsible for the implementation of the project.
- If completed on schedule, India will become the world's fourth nation to conduct independent human spaceflight after Russia, United States and China.

COMPONENTS OF GAGANYAAN

Crew Module

- A crew module and service module. The crew members have been shortlisted by the IAF and ISR.
- Crew will perform micro-gravity and other scientific experiments.

Crew Module Atmospheric Re-entry Experiment (CARE)

- Gaganyaan would return back to Earth. While re-entering Earth's atmosphere, the spacecraft needs to withstand very high temperatures created due to atmospheric friction.
- A prior critical experiment was carried out in 2014 along with LVM3, when the CARE capsule successfully demonstrated that it could survive atmospheric re-entry.

Crew Escape System - PAT

- The Crew Escape System is an emergency accident avoidance measure.
- In July 2018, ISRO completed the first successful flight 'pad abort test' or Crew Escape System.

Environmental Control & Life Support System ECLSS

- ECLSS will:
  - Maintain steady cabin pressure and air composition
  - Remove carbon dioxide and other harmful gases
  - Control temperature and humidity
  - Manage parameters like fire detection and suppression

Vyom Mitra

- ISRO's female humanoid robot that will test-flight Gangayaan.
- Vyom Mitra was built by ISRO's Inertial Systems Unit, Thiruvananthapuram.

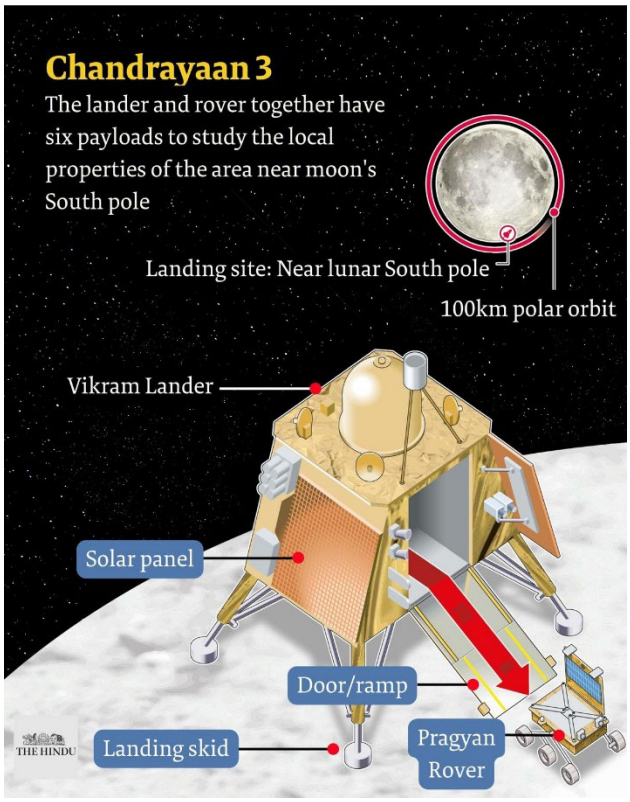
Space-borne Assistant and Knowledge Hub for Crew Interaction (SAKHI) App

- A digital platform integrated to the space suits of astronauts to:
  - Assist astronauts regarding technical documents and training manuals digitally.

- Monitor vitals (blood pressure, heart rate and oxygen saturation), hydration level, sleep patterns throughout the mission.
- Maintain mission log and keep crew connected with the onboard computer and ground-based stations on Earth.

27. CHANDRAYAAN-3

- Lunar exploration mission by ISRO, a follow-on mission to Chandrayaan-2.
- Successfully demonstrated ISRO's end-to-end capability in safe landing and roving on the South pole of the Moon (near side of the moon).
- Comprised an indigenous propulsion system, lander module (Vikram) and a rover (Pragyan).
- **Major objectives:**
  - Demonstrate a safe and soft landing on the surface of the Moon
  - Conduct rover operations on the Moon
  - Conduct on-site experiments on the Lunar surface.
- On August 23rd, 2023, Vikram Lander made its historic touchdown on Moon and subsequently Pragyan rover was deployed.
- **Duration:** Rover operated for one lunar day (roughly equals 14 Earth days).
- The lander and the rover have scientific payloads to collect samples of the moon, do in-situ experiments. The Vikram lander would transmit data back to Earth for comprehensive analysis by scientists.
- **The Virtual Launch Control Centre** at the Vikram Sarabhai Space Centre played a vital role in continuous real-time monitoring of the launch activities from SHAR.
- The International Astronomical Union (IAU) has approved the name **"Statio Shiv Shakti"** for the landing site of Chandrayaan-3's Vikram lander.
- With the success of the mission, India joined the United States, Russia, and China to successfully land on the Moon.



ADVANCED TECHNOLOGIES IN CHANDRAYAAN-3

Propulsion module:

- **Spectro-polarimetry of Habitable Planet Earth** (SHAPE) to gather data on the polarisation of light reflected by Earth to assist with exoplanet searches.

Lander payloads:

- **Chandra's Surface Thermophysical Experime**nt (ChaSTE) to measure thermal conductivity and temperature on the surface.
- **Instrument for Lunar Seismic Activity** (ILSA) to detect Moonquakes.
- **Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere** (RAMBHA) to measure the density of near-surface plasma, encompassing ions, and electrons, and monitor its temporal variations.
- **Langmuir Probe** to estimate the density and variation of plasma, or superheated gas, in the Moon's environment.

- **Laser Retroreflector Array** (from NASA) to measure distances using laser ranging to understand the dynamics of the Moon system.

Rover payloads:

- **Alpha Particle X-ray Spectrometer** (APXS) to look for elements in the lunar soil and rocks
- **Laser Induced Breakdown Spectroscopy** (LIBS) to examine the chemical and elemental composition of the lunar surface.

Why was the South Pole chosen?

- Water ice has been detected at both poles of the Moon, but the South Pole has more area in permanent shadow and colder temperatures, having higher possibility of presence of water.
- Due to extremely cold temperatures, anything trapped in the South Pole would remain frozen without undergoing much change. The rocks and soil, here, could provide clues to the early solar system.
- The South Pole is located in the South Pole-Aitken basin, which is a huge crater. There may be material from the deep crust and upper mantle of the Moon on or near the surface.

Facts about Moon:

- **Lunar soil** contains several elements such as iron, silicon, potassium, manganese, and magnesium. However, it does not contain organic matter such as microbes and insects.
- Lunar soil is hydrophobic and is exposed to extremely unhealthy amounts of solar radiation.
- The Moon takes roughly the same amount of time to complete one full orbit around the Earth as the Earth takes to complete one full rotation on its axis.
- As a result, one side of the Moon always faces the Earth, while the other side (far side) faces away from Earth. Thus, we can see only one side of the Moon.
- **Far side of the Moon** has a dramatically different landscape as compared to the near side (face of the Moon visible from Earth). It has a thicker crust by almost 20 km.
- Far side of the Moon has almost no characteristic dark spots. Dark spots are large basaltic plains formed from ancient volcanic eruptions on the Moon.
- **Chandrayaan-1** (India's first lunar mission, 2008) gave definitive proof of the presence of water ice in more than 40 craters on the poles of the Moon.
- In 2020, **NASA's SOFIA Observatory** found the first evidence of water on the Moon in a sunlit spot, indicating that the presence of water on the Moon was widely distributed.
- **Chang'e 4 mission** (China 2019) is the only one to have landed on the far side of the Moon, till 2024.

28. PSLV ORBITAL EXPERIMENTAL MODULE (POEM)

- POEM is an experimental mission or platform to perform in-orbit experiments using the final, and otherwise discarded, stage of ISRO's PSLV.
  - PSLV is a four-stage rocket where the first three spent stages fall back into the ocean, and the final stage (PS4) — after launching the satellite into orbit — ends up as space junk.
  - In POEM, the spent final stage will be utilised as a stabilised platform to perform experiments.
- POEM has a dedicated Navigation Guidance and Control (NGC) system which will act as the platform's brain for attitude stabilisation with specified accuracy.
- POEM will derive its power from solar panels mounted around the PS4 tank, and a Li-Ion battery. It will navigate using four sun sensors, a magnetometer, gyros & NavIC.

29. LUNAR POLAR EXPLORATION MISSION (LUPEX) OR CHANDRAYAAN-4

- Planned joint lunar mission by ISRO and Japan Aerospace Exploration Agency.

- Expected to be launched in 2026 or later.
- **Objective:**
  - To confirm the presence of water in the polar regions of the moon and investigate its potential usability.
  - To explore the lunar polar region's suitability for establishing a base on the Moon.
- Launch vehicle for the mission will be a Japanese rocket, the lander system will be developed by ISRO while the Rover by JAXA, and its landing point will be the South pole of the moon.

30. SHUKRAYAAN MISSION

- ISRO's planned orbiter to Venus, expected by 2028.
- Main goals to study:
  - surface and atmosphere of Venus and its chemistry
  - Interaction of the planet with solar radiation.

Venus:

- Venus has a solid surface by virtue of being one of the four inner planets besides Mercury, Earth and Mars. It is nearly the same size as the Earth.
- Its atmosphere is composed of 95% carbon dioxide (high greenhouse effect), making it the hottest planet in our Solar system.
- Volcanic eruptions on Venus release sulphur dioxide (SO2) which interacts with the atmosphere to produce hot sulfuric acid clouds that envelop the planet.
- About 80% of the surface of Venus is composed of flat plains of volcanic origin.
- Its rotation period is longer than its orbital period. (Rotation on its own axis - 243 days, Orbital period around the sun - 224.7 days)
- It has retrograde rotation, i.e., Venus spins on its axis from east to west.
- Due to the slow rotation of Venus, it has no global magnetic field. (Earth's magnetic field is due to rotation of iron core)

➔ IMPORTANT GLOBAL SPACE MISSIONS

S.No.	Space Missions	Description
1.	**Artemis Mission**	• Joint mission of NASA, ESA, JAXA and Canadian Space Agency. • **Aim:** To land the first woman and person of colour on the Moon, create a lunar base, and lay the groundwork for a future trip to Mars. • **Artemis 1:** An uncrewed test flight of the Orion spacecraft around the Moon (launched in 2022) • **Artemis 2:** Fly astronauts around the Moon and back without landing, planned in 2025. • **Artemis 3**: Land the first humans near the lunar south pole, planned in 2026. • **Artemis 4:** Mission to the Gateway lunar space station in 2028.
2.	**Jupiter Icy Moons Explorer (Juice)**	• **Launched by:** European Space Agency in April 2023

	mission	• Mission spacecraft to study Jupiter and its three largest icy moons — Europa, Ganymede, and Callisto. • Particular emphasis on Ganymede as a planetary body and potential habitat. • The spacecraft will arrive at Jupiter in 2031. • After a series of visits to Europa and Callisto, Juice will enter the orbit of Ganymede in 2034.
3.	**Origins, Spectral Interpretation, Resources Identification and Security-Regolith Explorer (OSIRIS REx)**	• Asteroid study and sample return mission by NASA. • **Launched in** 2016 to study asteroid Bennu and returned to Earth with a sample for analysis in 2023. • Sample analysis may reveal clues about the birth of our solar system (4.5 billion years ago) and genesis of life on Earth. **About Bennu:** • Small Carbon-rich asteroid. • Little less than 500 metres in depth. • More than 4.5 billion years old. • Classified as a "near-Earth object" because it passes relatively close to Earth every six years.
4.	**Ingenuity Mars Helicopter**	• **Launched by:** NASA • Autonomous helicopter that operated on Mars from April 2021 to January 2024 as part of Mars 2020 mission. • Travelled to Mars attached to the belly of the Perseverance rover and was deployed to the surface after landing in Jezero Crater. • Ingenuity became the first aircraft to conduct a powered and controlled extra-terrestrial flight. • The helicopter has been retired/grounded after flying 72 times over three years, after a portion of its twin rotor blades broke off, leaving it incapable of further operation.
5.	**Psyche Mission**	• **Launched by:** NASA in 2023 • To explore a 225-kilometre metallic asteroid called Psyche located between Mars and Jupiter. • Psyche is believed to be primarily composed of iron-nickel. • Studying it could provide invaluable insights into the composition of Earth's core. • The Psyche spacecraft also hosts NASA's Deep Space Optical Communications (DSOC) experiment.
6.	**Double Asteroid Redirection Test (DART)**	• Collaboration between NASA and the Johns Hopkins University Applied Physics Laboratory. • Successfully crashed a spacecraft into asteroid Dimorphos in 2022. • First ever test of a planetary defence technique involving a kinetic impactor to deflect an asteroid.

		• Demonstrated the capability of redirecting the trajectory of an asteroid by impacting it with a spacecraft.

31. INTERNATIONAL SPACE STATION

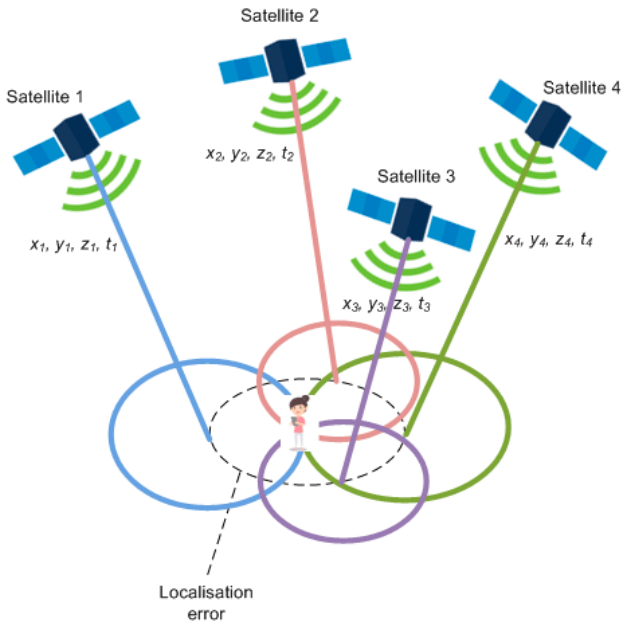
- Modular space station (habitable artificial satellite) and the single largest man-made structure in low Earth orbit.
- **Launched** in 1998, it is a multinational collaborative project involving five space agencies: NASA (United States), Roscosmos (Russia), JAXA (Japan), ESA (Europe), CSA (Canada)
- It circles the Earth in roughly 92 minutes and completes 15.5 orbits per day, hosting a maximum of seven astronauts.
- Serves as a microgravity and space environment research laboratory in which scientific research is conducted in astrobiology, astronomy, meteorology, physics, and other fields.
- **Note:** ISRO is working to set up Bhartiya Antariksh Station by 2035.

➔ SATELLITE-BASED NAVIGATION SYSTEM

- Satellite-based navigation system consists of a network of satellites and receiving devices that allows users to determine their precise location (in latitude, longitude, and altitude) and obtain accurate time information anywhere on Earth.
- Presently, there are **four global satellite-based navigation systems.**
  - **United States:** Global Position System (GPS)
  - **Russia:** Global Navigation Satellite System (GLONASS)
  - **China:** BeiDou Navigation Satellite System (BDS)
  - **European Union**: Galileo
- **Japan** has a four-satellite regional navigation system (Quasi-Zenith Satellite System).
- **India** has its own Indian Regional Navigation Satellite System- NavIC (Navigation with Indian Constellation).

How does GPS work?

- GPS receiver picks up signals from multiple GPS satellites that are in view of the receiver's location.
- Each satellite sends out radio signals at the speed of light that includes information about the satellite's location and the precise time the signal was transmitted.
- GPS receiver measures the time it takes for the signals to reach it from each satellite.
- Using the known locations of the satellites and the time it took for the signals to travel, the GPS receiver can calculate the distance between itself and each satellite.
- With the distance measurements from at least four satellites (trilateration), the GPS receiver can determine an object's precise 3-D position (latitude, longitude, and altitude).
- A GPS receiver can also provide additional information such as speed, direction, and time by continuously updating its position based on the signals received from the satellites.



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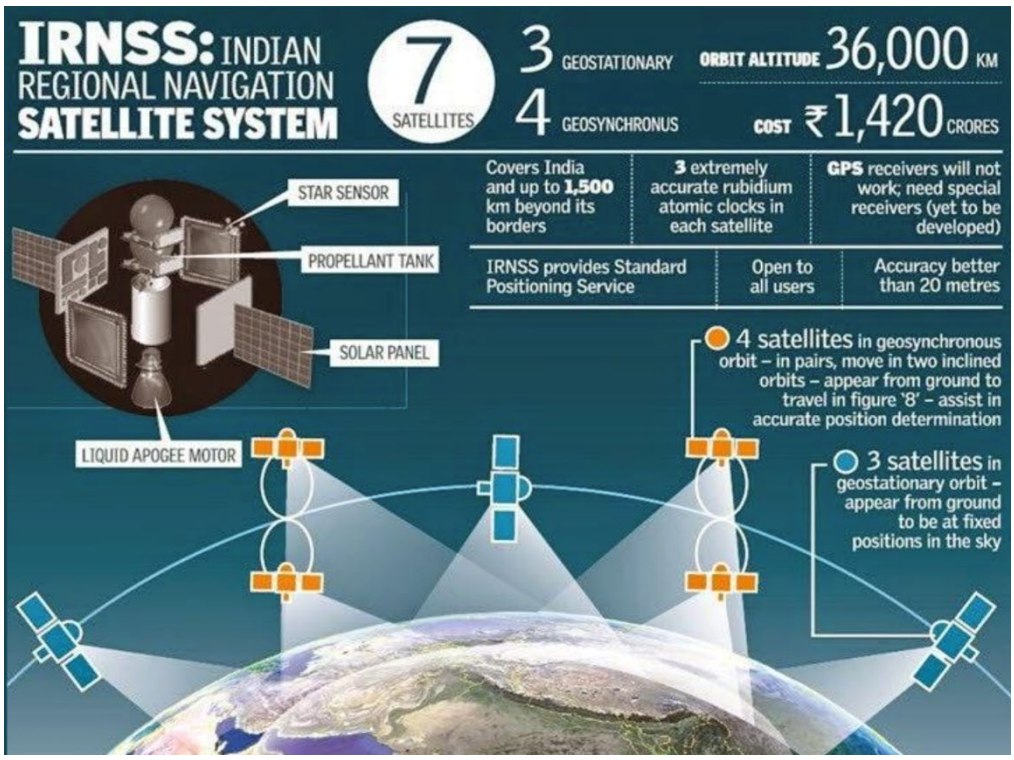
Applications of GPS (navigation system) include:

- Terrestrial, aerial, and marine navigation **E.g.,** Location-based services in mobile devices, visual and voice navigation for drivers.
- Vehicle tracking and supply chain management
- Mapping, survey and geodetic measurements **E.g.,** Mapping of terrains, creating digital maps, and conducting land surveys, Terrestrial navigation aid for hikers and travellers
- Precision agriculture **E.g.,** Yield monitoring, variable rate application of fertilisers and pesticides.
- Meteorology **E.g.,** GPS receivers on weather balloons and satellites provide data on atmospheric conditions to monitor and predict weather patterns more accurately.
- Seismology- To monitor ground movements and tectonic plate activity, aiding in earthquake research and early warning systems
- Disaster Management
- Military Operations- GPS for navigation, target tracking, and coordination of operation.

32. NAVIGATION WITH INDIAN CONSTELLATION (NavIC):

- NavIC (earlier known as Indian Regional Navigation Satellite System) is a satellite navigation system developed by ISRO.
- Consists of a constellation of seven satellites. Three satellites are located in the geostationary orbit and the remaining four are located in geosynchronous orbits.
- Can provide positioning, navigation, and timing services to users across India and the region extending up to 1,500 km around the country.
- Designed to provide position accuracy of better than 20 metres and timing accuracy of better than 50 nanoseconds.
- NavIC offers two types of services:
    - **Standard Positioning Service**: Available to all users and provides positioning accuracy of around 20 metres throughout the Indian region.
    - **Restricted Service**: Encrypted service primarily intended for authorised users such as the military, government agencies, and other security-sensitive applications.



Second-generation NavIC satellite (NVS-01):

- ISRO launched NVS-01 on board GSLV MK-II in 2023. NVS-01 is the first of the second-generation satellites envisaged to augment the NavIC services.
- Existing satellites in NavIC use L5 (protected frequency specifically assigned to India) and S band frequency signals.
- NVS-01 will send signals in a third frequency, L1, besides the L5 and S. This will enhance NAVIC's compatibility with other global navigation systems like GPS that also use L1.
- The satellite will have a Rubidium atomic clock onboard, indigenously developed by Space Application Centre-Ahmedabad.

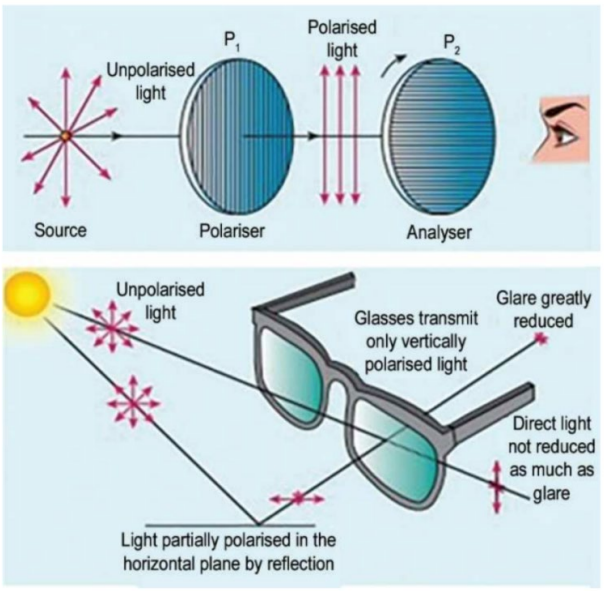
➔ IMPORTANT SATELLITE MISSIONS

33. X-RAY POLARIMETER SATELLITE (XPOSAT) MISSION:

- India's first dedicated satellite to study the polarisation of cosmic X-rays and dynamics of bright astronomical X-Ray sources like pulsars, black holes and neutron stars.
- World's second polarimetry mission using X-Ray. The first is NASA's imaging X-ray Polarimetry Explorer launched in 2021.
- **Launched in:** 2024 (lifespan: 5 years)
- Designated for observation from LEO (~650 km altitude)
- **Carries two scientific payloads:**
  - **POLIX** (Polarimeter Instrument in X-Rays) will observe about 40 bright astronomical sources, and measure the degree and angle of polarisation, in the medium X-ray energy band (8-30keV).
  - **XSPECT** (X-Ray Spectroscopy and Timing) will observe a variety of sources like X-ray pulsars, black hole binaries, low-magnetic field neutron stars, active galactic nuclei, and conduct fast timing and high spectroscopic resolution in the soft X-ray energy band (0.8-15 keV).

What is Polarisation?

- Light travels in the form of transverse electromagnetic waves. The light emitted by sources like the sun, bulb, candle etc. has vibrations in several planes (oscillates in all directions), and it is called unpolarised light.
- **Polarisation** is the phenomenon of restricting the vibration of light waves to one specific direction/plane. **E.g.,** Polarised sunglasses have a special filter that allows only light with a specific polarisation direction to pass through, which helps to reduce glare and improve visibility by blocking unwanted polarisations.



Significance of X-ray polarisation measurements:

- In space, X-rays get polarised due to multiple reasons. **E.g.,** X-rays can be polarised when subjected to strong magnetic fields or due to interactions with material present around black holes etc.

- Polarisation measurements of X-rays (angle and degree of polarisation) emanating from sources like magnetars, neutron stars, black holes etc. can provide information about the bright X-ray emitting sources (their composition, temperature, and density) and complex processes they undergo.
- Can help in deducing the orientation and strength of magnetic fields in celestial objects.
- Can help to understand the behaviour of high-energy particles in extreme environments.

34. NASA-ISRO JOINT SATELLITE – NISAR

- Joint active remote sensing satellite project between NASA and ISRO.
- Low Earth Orbit earth observation satellite placed in sun-synchronous orbit (747 km).
- Can scan nearly all the planet's land and ice surfaces twice every 12 days to collect data.
- First radar imaging satellite to use dual frequencies. Consists of both L-band and S-band synthetic aperture radar (SAR) instruments.
    - **L-band SAR** operates at a frequency of around 1-2 GHz. Lower frequency (higher wavelength) of L-band SAR allows it to penetrate through vegetation and soil, making it useful for monitoring changes in forest cover, soil moisture etc.
    - **S-band SAR** operates at a frequency of around 2-4 GHz. S-band SAR has a higher resolution than L-band SAR. Typically used for applications where higher resolution is required, such as monitoring changes in urban areas or coastal zones.

Applications:

- Earthquakes and volcanology
- Distribution of carbon stocks in terrestrial biomass.
- Vulnerability of wetlands by studying the extent of inundation
- Geomorphology, movement of sea ice and hydrology
- Movement of glaciers and ice sheets thereby monitoring climate change.

35. RE-ENTRY OF SATELLITE AND SPACE DEBRIS

Space Debris:

- Human-made objects in space that are no longer in use, such as discarded rocket stages, defunct satellites etc.
- The debris can remain in orbit for years or decades, increasing the risk of collisions with active spacecraft.

Kessler's Syndrome:

- Phenomenon in which the density of objects in the Low Earth Orbit grows so high that collisions between two objects could cause a massive cascade of space junk and trigger further collisions.

Controlled re-entry attempt by ISRO:

- ISRO attempted the controlled re-entry of a decommissioned weather satellite (Megha Tropiques-1) to clear out space debris.
- After a series of 20 manoeuvres over eight months, the orbit of the satellite was lowered such that it re-entered the dense atmosphere of Earth and burnt up over the Pacific Ocean. (Upon re-entry, the atmospheric friction causes satellites to heat up to extremely high temperatures).
- Controlled re-entry is possible only for satellites in LEO. These manoeuvres, however, are not usually attempted because fuel reserves have to be maintained in the satellite after mission life is over.
- For attempting to bring down a satellite from geo-stationary or geosynchronous orbit, a huge fuel reserve would be needed, thus making the satellite heavier and costlier at launch.

Project NETRA:

- Initiative by ISRO, an early warning system in space to detect debris and hazards to Indian satellites and thus gaining capability in space situational awareness (SSA).

- NETRA will use telescopes, radars, data processing units, and other tools to spot and track objects as small as 10 cm, up to a range of 3,400 km.

36. RLV LEX-02 MISSION

- ISRO's RLV LEX-02 mission was conducted at the Aeronautical Test Range (ATR) in Chitradurga, Karnataka in 2024.
- Second in a series of test flights to demonstrate the autonomous landing capability of a reusable launch vehicle (RLV).
- The mission involved a winged vehicle called Pushpak, which was carried to an altitude of 4.5 kilometres by an Indian Air Force Chinook helicopter.
- Once at the designated altitude, Pushpak was released and had to autonomously perform a series of manoeuvres to precisely land on the runway.

KEY ACHIEVEMENTS OF THE MISSION

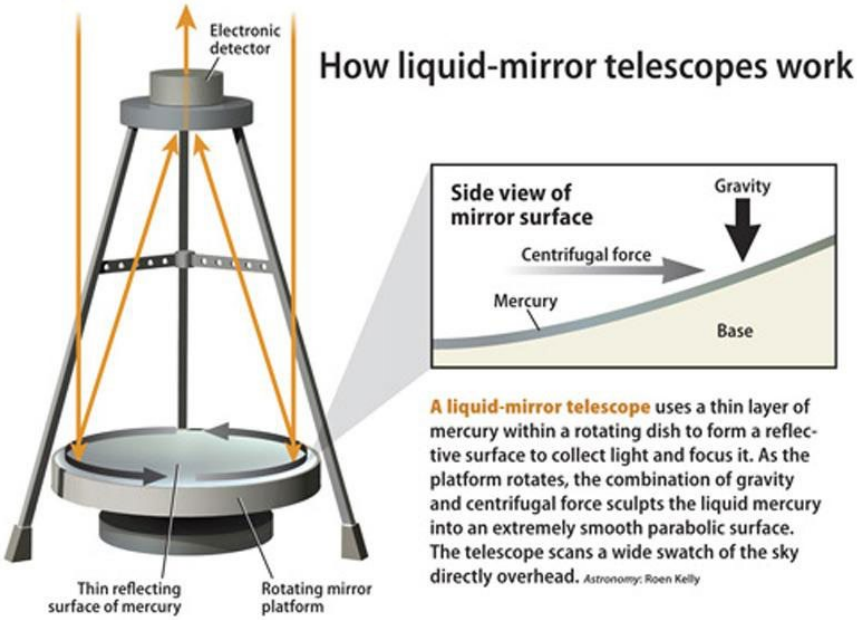
- Simulated the autonomous landing capability of a reusable launch vehicle returning from space. Would be a critical step towards developing future Orbital Re-entry missions.
- Validated the performance of indigenously developed technologies in control, navigation, landing gear, and deceleration systems.
- Provided valuable data for the design and development of future reusable launch vehicles.

37. BLUEWALKER 3 SATELLITE

- A prototype satellite, a part of a planned constellation of over a hundred similar satellites intended to deliver mobile or broadband services anywhere in the world.
- Launched by a US-based company. The largest commercial antenna system ever deployed in low-Earth orbit.
- The satellite is among the brightest objects in the night sky resulting from a massive phased-array antenna.
- **Concerns**: Its large size and bright reflective surfaces could interfere with astronomical observations, and radio frequencies (close to bands reserved for radio astronomy) may hamper radio telescope observations.

➔ IMPORTANT TELESCOPES

S. No.	Telescopes	Description
1.	**International Liquid Mirror Telescope**	• Asia's largest Liquid Mirror Telescope was inaugurated at Devasthal observatory in Uttarakhand. • Employs a 4-metre-diameter rotating mirror made up of a thin layer of liquid mercury, to collect and focus light.

		• Enhances India's capabilities to explore the mysteries of the deep celestial sky and astronomy. 
2.	**Giant Metrewave Radio Telescope (GMRT)**	• **Location**: Near Pune, Maharashtra. • Array of 30 fully steerable parabolic radio telescopes, each 45 metres in diameter, spread over a 25-kilometre area. • One of the world's largest and most sensitive radio telescopes operating at metre wavelengths (low frequencies).

3.	**Square Kilometre Array (SKA) project**	• Group of radio telescopes being built in South Africa and Australia in two phases. First phase is expected to begin operations by 2029.
		• Capable of detecting faint radio signals from extreme distances, with eventually over a square kilometre (one million square metres) of collecting area.
		• Will operate in two different ranges of radio frequency.
		  ○ South-African array will scan for mid-frequency signals, between 350 MHz and 15.4 GHz.
		  ○ Australian telescopes will work in the low-frequency range of 50-350 MHz.
		• India officially gained full membership in the SKA Project in January, 2024.

4.	**Thirty Meter Telescope (TMT)**	• International project which aims at building a 30-metre diameter telescope at Mauna Kea, Hawaii, USA. • The telescope has a segmented mirror (made up of 492 individual segments) which makes it three times as wide as the world's largest existing visible-light telescope. • Precisely aligned, these segments will work as a single reflective surface of 30 m diameter. • Upon construction, TMT would be one of the world's most advanced and capable ground-based optical and infrared observatory. • Joint effort of institutions in Canada, China, India, Japan, USA.

5.	**Euclid Space Telescope (EST)**	• Launched in 2023 by the European Space Agency. • **Location:** Lagrangian Point 2 (1.5 million km away from Earth) • To create the largest cosmic 3D map of the universe to better understand the distribution of dark matter and reveal the influence of dark energy in the early universe. • The European Space Agency has unveiled the first images captured by EST. (picture of a group of thousands of galaxies)
6.	**Event Horizon Telescope (EHT)**	• Network of 8 radio telescopes located in Hawaii, Arizona, Chile, Mexico and Spain, and at the South Pole. • It is synchronised in such a way that, in effect, they form a radio telescope of the size of the earth itself. • In 2019, the 1st ever picture of a black hole was captured by EHT. • In May 2022, the supermassive blackhole at the centre of the Milky way galaxy was captured.
7.	**Hubble Space Telescope**	• **Location:** Low Earth orbit (540 km) • Large optical/ultraviolet telescope for deep sky observations • **Launched:** 1990 by NASA and ESA.
8.	**James Webb Space Telescope (JWST)**	• **Launched:** 2021 by NASA. • **Location:** Orbiting the Sun at the L2 Lagrange point (1.5 million km from Earth) • Largest infrared telescope ever built (6.5 metre primary mirror). • Detects near-infrared and mid-infrared wavelengths to observe faint and distant objects.

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3 CHAPTER NUCLEAR TECHNOLOGY

1. BASICS

- An atom is made up of a Nucleus (with Protons and Neutrons) and electrons revolving around the nucleus.
- Mass of the atom is concentrated in the Nucleus.
  - Number of protons (Z) in an atom determines the atomic number of an element.
  - Total number of Protons and Neutrons, called Nucleons, is called the Atomic Mass Number (A).
- Atoms can be stable or unstable, and the instability is caused by the neutrons in their nucleus.
- All elements with atomic numbers greater than 83 are considered radioactive, including Uranium (92), Plutonium (94), and Thorium (90).
- These elements have unstable atomic nuclei, and over time, they decay by releasing energy and radiation to reach a more stable configuration.
- They release energy in the form of three types of radiations: **alpha, beta, and gamma.**

THREE TYPES OF RADIATIONS

Feature	Alpha (α) Radiation	Beta (ß)Radiation	Gamma (γ) Radiation
Composition	Helium nucleus (2 protons, 2 neutrons)	Beta-minus (electron). Beta-plus (positron)	High-energy electromagnetic wave (photon)
Charge	Positive (2+)	Beta-minus (negative –), Beta-plus (positive +)	Neutral (no charge)
Mass	Largest and heaviest	Lighter than alpha, heavier than gamma	No mass (pure energy)
Penetrating Power	Lowest	Medium	Highest
Stopped by	Paper, skin	Aluminum sheet	Concrete, human tissue
Ionizing Power	High	Medium	Low

RADIOACTIVE HALF-LIFE

- For a given radioisotope, the radioactive half-life is the time for half the radioactive nuclei in any sample to undergo radioactive decay.
- After two half-lives, there will be one fourth the original sample, after three half-lives one eighth the original sample, and so forth.

APPLICATIONS OF RADIOACTIVITY

1. **Radioisotope Thermo-electric Generator:** A radioactive material is used which when decays produces heat. This heat is in turn used by a generator to produce electricity. **E.g.,** New Horizon spacecraft which went to Pluto uses this kind of device.
2. **Medical Imaging:** Radioactive isotopes are used in medical imaging techniques such as X-rays, CT scans, PET scans, and MRI scans.
3. **Radiation Therapy:** Radioactive isotopes are used to treat various types of cancer through radiation therapy.

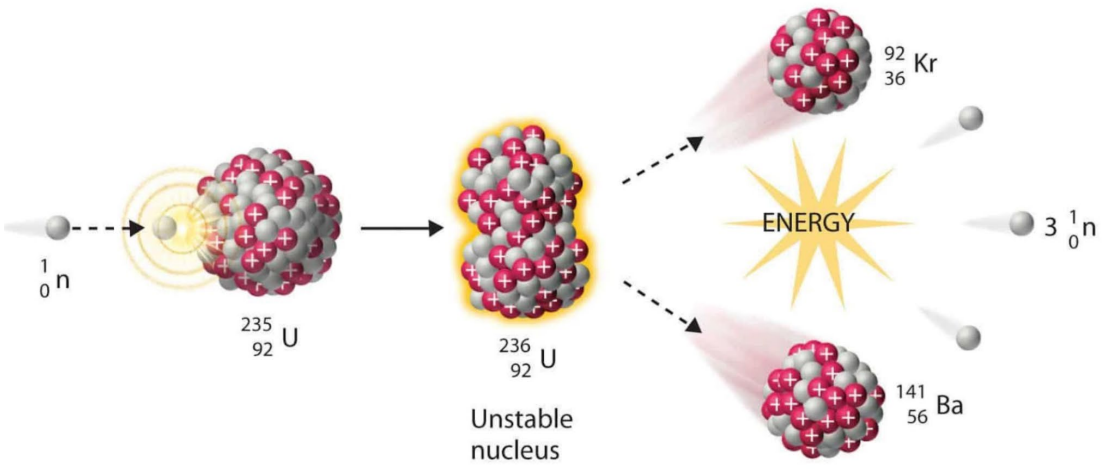
4. **Smoke Detectors:** Smoke detectors use a small amount of radioactive material to detect smoke and trigger an alarm.
5. **Industrial Radiography:** Radioactive isotopes are used in industrial radiography to test the integrity of metal structures such as pipelines and oil rigs.
6. **Carbon Dating:** Radioactive isotopes are used in carbon dating to determine the age of ancient fossils and artefacts.
7. **Nuclear Power:** Radioactive isotopes are used to generate electricity in nuclear power plants.
8. **Food Irradiation:** Radioactive isotopes are used to sterilise and preserve food products, preventing spoilage and disease.
9. **Geological Dating:** Radioactive isotopes are used to determine the age of rocks and minerals in geology.
10. **Sterilisation:** Radioactive isotopes are used to sterilise medical equipment, surgical instruments, and other devices to prevent the spread of infection.

RADIOACTIVE DATING

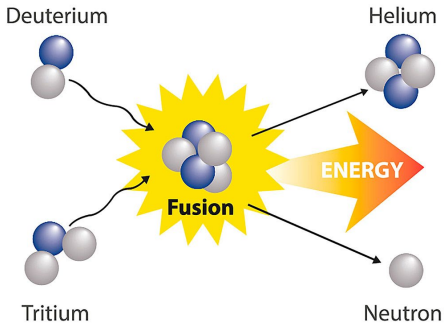
- Carbon-14 is produced in the atmosphere due to the interaction of cosmic rays with Nitrogen-14.
- We all have a certain amount of C-14 in our bodies (23% of the human body) as do plants and all living beings.
- Each gram of radioactive C-14 in our bodies decay at the rate of 12 per minute. (Means it becomes 1/2, 1/4, 1/8, 1/16 etc. every 12^{th} minute.) The decayed C-14 is further replaced with atmospheric C-14 as we eat.
- When an organism dies, the remaining C-14 gradually turns into Carbon-12.
- **C-14 dating** measures the ratio of C-14 to C-12 to determine how many years have passed since an organism died.
- Carbon-14 dating can be used to determine/estimate the age of organic remains between 500 years and approximately 60,000 years.

2. NUCLEAR PROCESSES

- **Nuclear Fission:** It involves disintegrating a heavy atom's nucleus, such as uranium or plutonium, into two or more smaller nuclei. **E.g.,** A high-energy neutron collides with the nucleus of a U-235 atom, causing it to split into two smaller nuclei, additional neutrons (usually 3) and enormous energy.



- **Nuclear Fusion:** Process of combining two or more nuclei to form a heavier nucleus and release high-energy radiation. This process occurs naturally in stars, where the high temperature at the core allows for the nuclei to overcome the repulsive electromagnetic force and fuse together. **E.g.,** Combination of hydrogen nuclei to form helium, releasing energy in the form of neutrinos, gamma rays, and positrons.



Parameter	Nuclear Fission	Nuclear Fusion
Definition	Splitting of a large atom into smaller ones	Fusing of two or more tighter atoms into a larger one
Natural occurrence	Spontaneous fission of some elements occurs at a slow rate	Occurs in stars
By-products	Highly radioactive particles	Neutrons (can induce radioactivity)
Conditions	High-speed neutrons required	High density & high temperature
Energy Requirement	Relatively low	Extremely high
Energy Released	Millions of times more than chemical reactions	Three to four times more than fission (can vary depending on isotopes)
Nuclear weapon	Fission bomb {atomic bomb)	Fusion bomb (hydrogen bomb) uses fission to trigger fusion
Energy production	Used in nuclear power plants (current technology)	Experimental technology for power production
Fuel	Uranium (primary fuel)	Hydrogen isotopes (Deuterium and Tritium)

3. NUCLEAR FUEL: FISSILE AND FERTILE

FISSILE MATERIAL: READY FUEL FOR FISSION

- Fissile isotopes readily undergo fission when hit by neutrons, releasing a tremendous amount of energy. **E.g.,** Uranium-235 (U-235), Uranium- 233 (U-233) and Plutonium-239 (Pu-239).
- However, fissile materials like U-235 make up a small portion of Natural Uranium (less than 1%). Naturally occurring Uranium is composed of three major isotopes:
  - **Uranium-238** (99.284% natural abundance)
  - **Uranium-235** (0.711%)
  - **Uranium-234** (0.005%)
- U-235 atoms is the only nuclide existing in nature (in appreciable amount) that is fissile with thermal neutrons.

URANIUM ENRICHMENT

- Since naturally occurring Uranium does not have a high enough concentration of U-235, Uranium enrichment is necessary to create an effective nuclear fuel out of mined Uranium.
- In enriched Uranium, the percent composition of U-235 has been increased through the process of isotope separation.

- Enriched Uranium is a critical component for both civil nuclear power generation and military nuclear weapons.
  - Typically, Uranium used for power generation is enriched to levels between 3% and 5% U-235.
  - Weapon-grade uranium is considered to have been enriched above 90% U-235.

FERTILE MATERIAL: BREEDING POTENTIAL

- Though not directly fissile by slow neutrons, fertile isotopes can absorb neutrons and transmute into fissile materials through radioactive decay.
  - **Nuclear transmutation** often refers to the conversion of one nuclide into another within the fuel or target material. This process can involve the absorption of a neutron, the emission of a neutron, or the capture and subsequent decay of a particle.
- **Common fertile materials** include Uranium-238 (U-238) and Thorium-232 (Th-232).
  - Uranium U-238 cannot by itself make the reactor achieve criticality, so it has to be converted to fissile plutonium (Pu-239) in a nuclear reactor.
  - Thorium Th-232 is a fertile material that has to be converted to fissile U-233.

Criticality of Nuclear Reactor:

- **Nuclear reactor is said to be critical** when the number of neutrons produced in Nuclear fission reactions equals the number of neutrons lost through absorption, leakage, and other processes. This equilibrium state allows for a sustained and controlled chain reaction.
- **Supercriticality** refers to a state where the rate of neutron production exceeds the rate of neutron losses, causing the overall neutron population to increase rapidly. This can lead to an uncontrolled chain reaction and a dangerous power surge.

4. TYPES OF REACTORS

- Presently, India operates 22 nuclear reactors across eight sites, with a total capacity of 6,780 MW.
- Among these 18 reactors are Pressurised Heavy Water Reactors and 4 are Light Water Reactors.

KEY COMPONENTS OF A NUCLEAR REACTOR

Nuclear Fuel:

- Core of a nuclear reactor houses the fuel (typically enriched U-235) pellets contained in long, thin metal tubes called fuel rods.

Moderator:

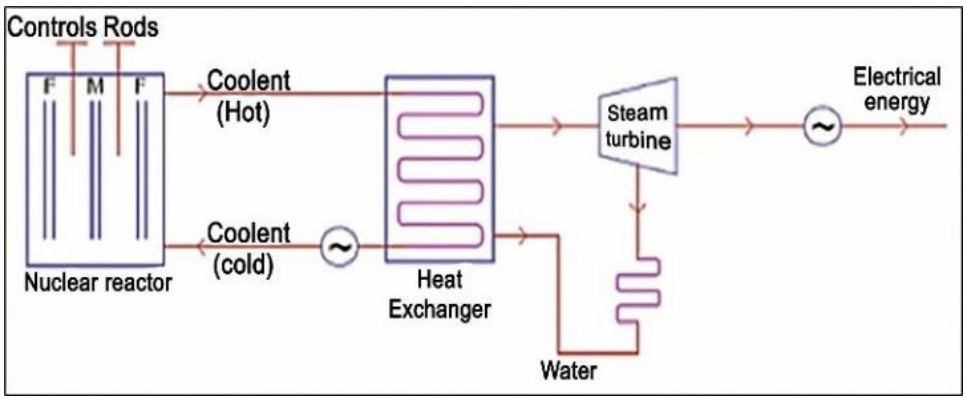
- Located within the reactor core, the moderator slows down neutrons released from fission.
- These neutrons are initially high-energy (fast neutrons). For a sustained chain reaction, neutrons need to be slowed down to thermal neutrons, which are more likely to cause fission in other U-235 atoms.
- **E.g.,** Ordinary water (light water reactors), heavy water (deuterium oxide), and graphite.

Control Rods:

- Control rods are made of materials that readily absorb neutrons.
- They are inserted or withdrawn from the core to control the rate of fission (regulate the number of neutrons available to cause fissions) and the power output of the reactor.

Coolant:

- Coolant circulates throughout the reactor core, absorbing immense heat produced by the ongoing nuclear chain reaction to prevent the reactor from overheating, which could lead to a meltdown. **E.g.,** Water, Liquid Sodium.

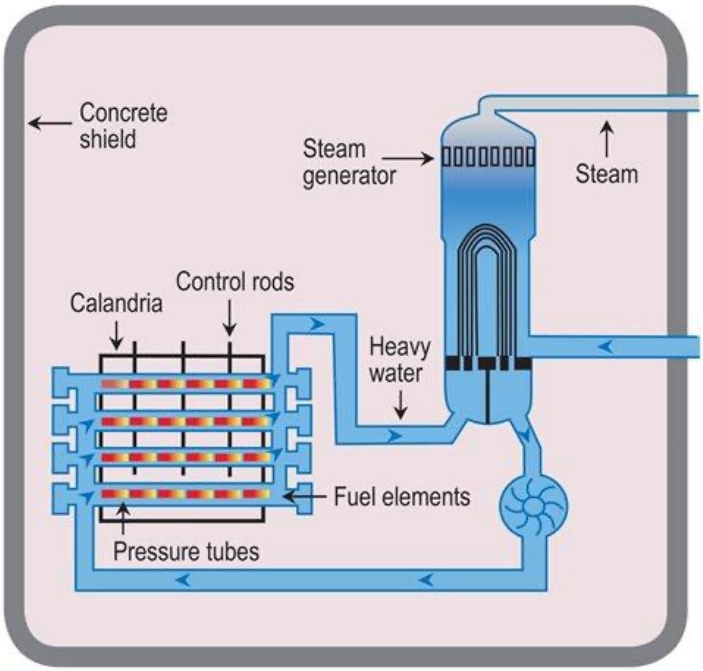


The heat generated by the chain reaction of nuclear fission produces steam. The steam is used to move a turbine which generates electricity.

5. IMPORTANT TYPES OF NUCLEAR REACTORS IN INDIA

1. Pressurised Heavy Water Reactor (PHWR):

- **Fuel:** Natural uranium (unenriched)
- **Moderator and Coolant:** Heavy water as both moderator and coolant.
- **Cooling System:** Uses a combination of heavy water and light water to cool the reactor. Heat is transferred to a secondary loop, which then generates steam to drive turbines.
- **Control Rods:** Boron or cadmium control rods.
- **Fuel requirement:** Annual requirement of fuel (UO2) of a 700 MW PHWR (at 85% Capacity Factor) is about 125 tons.
- **Advantages:** Use natural uranium fuel, produce less high-level radioactive waste, and operate at lower pressures compared to some other reactor types.



2. Light Water Reactor (LWR):

- **Fuel:** Low-enriched Uranium
- **Moderator and Coolant:** Light water (ordinary H2O)
- **Cooling System:** Employs a pressurised water system to transfer heat from the reactor core to a secondary loop, which generates steam for turbines.

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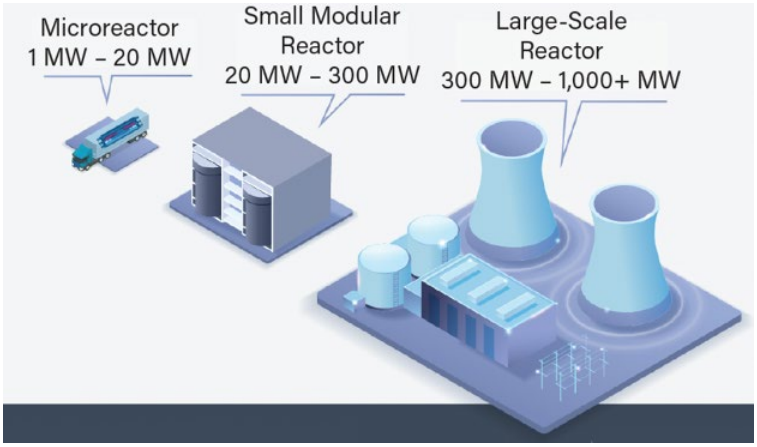
- **Control Rods:** Boron or other neutron-absorbing materials.
- **Fuel requirement:** Annual requirement of fuel (UO2) of a 1000 MW LWR (at a capacity factor of 90%) is about 25 tons.
- **Advantages:** Have a proven track record for safety and reliability. However, they require enriched uranium and produce more high-level radioactive waste compared to PHWRs.

3. Fast Breeder Reactor (FBR):

- Prototype Fast Breeder Reactor (PFBR) is being implemented by Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI).
- **Fuelled by**: Mixed Oxide (MoX) Fuel (It generally contains between 3% and 5% Plutonium Oxide blended with 95–97% natural or depleted Uranium Oxide).



4. Small Modular Reactors (SMR):

- Advanced nuclear reactors with a power capacity of up to 300 MW per unit, which is about one-third of the generating capacity of traditional nuclear power reactors.
- They are characterised by smaller size, modular design, and enhanced safety features.
  - **Small** – a fraction of the size of a conventional nuclear power reactor.
  - **Modular** – possible for systems and components to be factory-assembled and transported as a unit to a location for installation.
  - **Reactors** – harnessing nuclear fission to generate heat to produce energy.
- **Applications:** Electricity generation in remote regions, energy requirements for industrial processes, water desalination, nuclear submarines etc.

Advantages:

- SMRs are adaptable and can be scaled up or down to supply more or less power.
- Only need to refuel every 3-7 years, as opposed to every 1-2 years for conventional nuclear plants.
- Extensive use of passive safety features to shut down and cool reactors under abnormal circumstances, reducing the risk of catastrophic failures.
- Have relatively lower-capital requirements, can make nuclear power more accessible.

Challenges:

- Higher cost per unit of electricity production in SMRs due to supply-chain issues and the absence of economies of scale.
- SMRs are inferior to conventional reactors with respect to radioactive waste generation and disposal options and require spent fuel storage & disposal facilities.

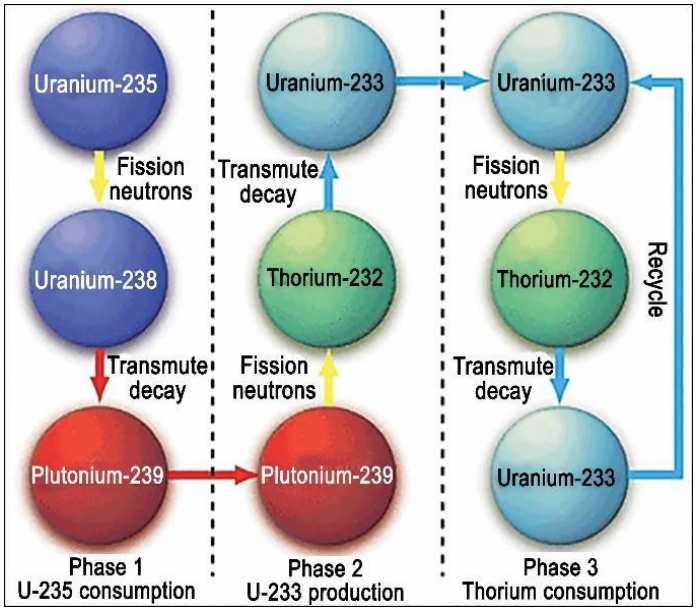
6. THREE-STAGE NUCLEAR PROGRAMME OF INDIA

- The Department of Atomic Energy's 3-stage nuclear programme is a strategy for a sustainable, continuous, reliable, and self-dependent supply of nuclear energy.

- India has a limited availability of Uranium reserves (about 2% of global Uranium reserves). The programme is developed with the aim of utilising the vast Thorium reserves of India.
  - India has about 25% of global thorium in the form of monazite sands along its coastline.
  - They are found in coastal and inland placer sands on the beaches of Kerala, Tamil Nadu, Odisha, Andhra Pradesh, Maharashtra, and Gujarat, and in the inland riverine sands of Jharkhand and West Bengal.

1ST STAGE: PRESSURISED HEAVY WATER REACTORS (PHWRS)

- First stage includes the setting up of PHWRs and associated fuel cycle.
- Based on natural Uranium that contains 99.3% U-238 and 0.7% U-235.
- U-235 being fissile sets up the chain reaction and U-238 being non-fissile gets converted to Pu-239 as a by-product (spent fuel) which is in turn used in the Fast Breeder Reactors in the 2nd stage.



2ND STAGE: FAST BREEDER REACTORS (FBR)

- FBR uses the Uranium-Plutonium Mixed Oxide (MOX) fuel.
- The reactors use a mix of Plutonium-239 (byproduct/radioactive waste produced in the 1st stage) and Uranium-238, as part of their MOX fuel.
  - The U-238 surrounding the fuel core undergoes nuclear transmutation to produce more fuel (Pu-239).
  - Since the amount of Plutonium produced inside the reactor is more than that initially used, it is called the Breeder reactor.
- The reactor uses fast neutrons without the need for a moderator to slow them down. Fast neutrons are more efficient at inducing fission in certain isotopes, such as plutonium-239.
- Further, FBR can aid in conversion of fertile Thorium 232 to fissile Uranium 233 that will be used in the 3rd stage.

Significance of FBR:

- Significant reduction in nuclear waste generated as FBR utilises/reprocesses the radioactive waste (Plutonium-239) as fuel from the first stage.
- Advanced reactor with inherent passive safety features ensuring a prompt and safe shut down of the plant in the event of an emergency.
- Both the capital cost and the per unit electricity cost is comparable to other nuclear and conventional power plants.
- Stepping stone for the third stage of India's Nuclear Programme.

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3RD STAGE: THORIUM-BASED REACTORS

- The third stage is focussed on building Advanced Heavy Water Reactor to utilise India's vast Thorium reserves.
- In the thermal breeder reactors, Thorium-232 will be converted into Uranium-233, by transmutation.

To showcase the practicality of this phase, 40 kW Thorium based KAMINI reactor is already operational in Kalpakkam, Tamil Nadu.

CIVIL LIABILITY FOR NUCLEAR DAMAGE ACT (CLNDA), 2010

- India enacted the Civil Liability for Nuclear Damage Act (CLNDA) in 2010 to provide a quick compensation mechanism for victims of a nuclear accident.
- The Act establishes a **strict and no-fault liability** for nuclear plant operators, meaning they are liable for damage regardless of fault.
- However, the operator of the nuclear installation, after paying the compensation for nuclear damage shall have the **right to recourse** where-
  - The nuclear incident has resulted as a consequence of an act of supplier or his employee, which includes supply of equipment or material with patent or latent defects or sub-standard services.
  - The nuclear incident has resulted from the act of commission or omission of an individual done with the intent to cause nuclear damage.
- The operator will have to maintain a financial security to cover its **maximum liability of ₹1,500 crore** for civil nuclear damage and requires the operator to cover liability through insurance or other financial security.
- In case the damage claims exceed ₹1,500 crore, the gap will be bridged by the Central Government. The government liability amounts to the rupee equivalent of 300 million Special Drawing Rights (SDRs) or about ₹2,100 to ₹2,300 crore.

➔ FUSION REACTORS

- Fusion reactors is increasingly seen as the future of energy security due to following factors:
  - Abundance of fuel (Hydrogen in the form of water in oceans).
  - Clean source of energy as it involves no release of carbon dioxide.
  - Elimination of risk from nuclear waste.
- Two main factors to achieve fusion reaction are fuel and conditions for fusion.
  - A typical fusion reactor uses hydrogen as a fuel that is abundant in the water of the oceans.
  - However, the main problem in fusion is that the hydrogen nuclei repel each other.
- The electric repulsion of two hydrogen nuclei can be overcome by heating the hydrogen to temperatures of millions of degrees C. This is what happens in a typical hydrogen bomb.
- However, the challenge for building a fusion reactor is that such high temperatures leads to high pressure posing the problem of explosion.
- This problem of explosion is currently being addressed in three ways:
  1. The first is to make the hydrogen work at a very low density, so the pressure will not get high. This is the approach used in the **Tokamak approach**.
  2. The second method is to let the hydrogen explode, but to keep the explosions small. This is done in the **laser method**.
  3. The third way to achieve fusion is by keeping the hydrogen cold. This is called **cold fusion**.

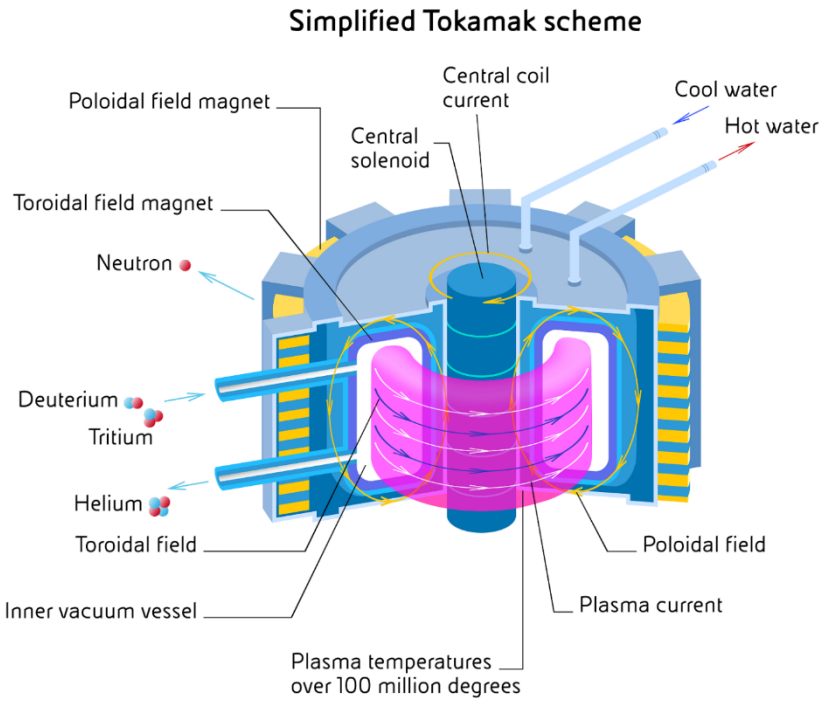
7. INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR (ITER)

PRINCIPLE

- ITER is a fusion reactor that works on the basis of the Tokamak approach.
- **Objective:** To demonstrate the scientific and technological feasibility of controlled fusion for future commercial power generation.
- Tokamak is a specific type of magnetic confinement device. It utilises powerful magnetic fields to confine extremely hot plasma heated to millions of degrees Celsius (creating a soup of charged particles).
- Inside the Tokamak, light isotopes of hydrogen (Deuterium and Tritium) are heated and compressed to undergo nuclear fusion to release enormous amounts of energy.

Details:

- ITER is a fusion reactor launched in 1985.
- **Location:** Saint-Paul-les-Durance in southern France.
- Joint collaboration of 35 countries with members China, European Union, India, Japan, Korea, Russia and the United States.
- ITER is designed to produce 500 MW of fusion power from 50 MW of input heating power.
- ITER project is about 65% complete and is expected to be completed by 2025.



8. COLD FUSION

- Traditional hot fusion requires extremely high temperatures (millions of degrees Celsius) to overcome the electrostatic repulsion between positively charged atomic nuclei (protons).
- Cold fusion proposes achieving fusion at much lower temperatures (possibly room temperature and pressure) by creating an environment where this repulsion is somehow negated.

PROPOSED MECHANISM

- It suggests that introducing a negatively charged particle to a hydrogen nucleus (proton) could neutralise its positive charge.
- This would allow two hydrogen nuclei to get close enough for the attractive nuclear force to overcome the remaining repulsion and initiate nuclear fusion.
- Metals like palladium, zirconium, and nickel, known as "hydrogen absorbers" or "soakers," can potentially facilitate this process.

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4 CHAPTER INTERNET AND COMMUNICATION TECHNOLOGY

1. SEMICONDUCTORS

A semiconductor material has an electrical conductivity value falling between a conductor (such as metallic copper) and an insulator (such as glass). Lattice structure and atomic structure of constituent elements decide whether a particular material will be insulator, metal or semiconductor.

CLASSIFICATION OF SEMICONDUCTORS

I. Based on material:

(i) Elemental semiconductors: Silicon (Si) and (Ge)

(ii) Compound semiconductors:

a. Inorganic: CdS, GaAs, CdSe, InP etc.

b. Organic: Anthracene, Doped pthalocyanines etc.

c. Organic polymers: Polypyrrole, Polyaniline, Polythiophene etc.

Most of the currently available semiconductor devices are based on elemental semiconductors Silicon or Germanium (Ge) and compound inorganic semiconductors.

However, after the 1990s, a few semiconductor devices using organic semiconductors and semi-conducting polymers have been developed.

II. Based on purity:

(i) **Intrinsic semiconductor**: They are pure semiconductors with no impurities. They have no or zero conductivity at very low temperatures. However, as temperature rises, the conductivity of these materials increases.

(ii) **Extrinsic semiconductor:** When a small quantity of small impurity is added to pure semiconductor, the conductivity of the semiconductor is increased manifold. These semiconductors are called extrinsic or impurity semiconductors. The deliberate addition of a desirable impurity is called doping and the impurity atoms are called dopants.

2. LIGHT-EMITTING DIODE (LED)

- LED is an electric component or a semiconductor device that emits light when an electric current flows through it.
- LEDs can produce all three primary colours (red, green, and blue) and different LEDs can be combined on a display board to produce a large variety of colours.

Advantages:

- More efficient than incandescent bulbs and fluorescent lamps, as they convert a higher percentage of electrical energy into light.
- Compact and can be made in very small sizes.
- Much longer lifespan and durability compared to conventional bulbs.
- Light up instantly to their full brightness without any warm-up time, and are particularly useful in applications where quick and frequent switching is required.

3. MICROLED DISPLAY TECHNOLOGY

- MicroLEDs are self-illuminating diodes that have brighter and better colour reproduction than Organic Light Emitting Diode (OLED) display technology.
- MicroLEDs are made up of numerous microscopic LEDs which self-illuminate per display pixel i.e., they produce colours without backlighting or colour filters. It is called a MicroLED panel because its pixels are very small and measured in micrometres.
- While OLEDs use tiny sub-pixels made from organic emissive materials, Micro-LEDs use an inorganic LED structure.

ADVANTAGES OVER OLED

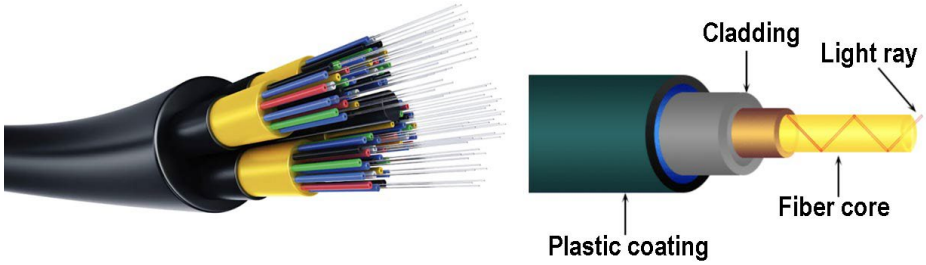
- Increased brightness and better colour reproduction
- Longer lifespan
- Lower power consumption
- Low response time
- Limitless scalability as they can be freely resized in any form.

DISADVANTAGE

High costs and technical difficulties in its development.

4. OPTICAL FIBRES

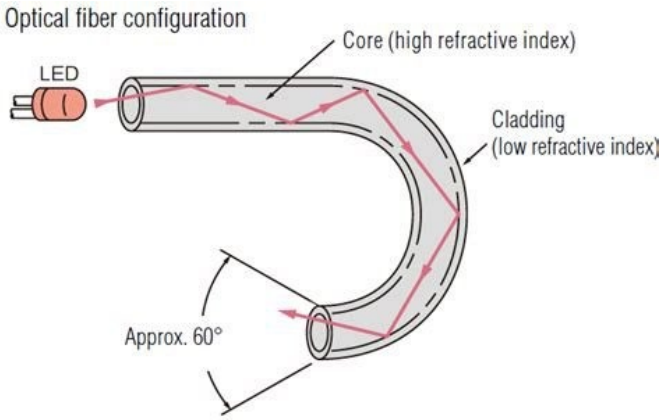
- Thin, flexible, and transparent fibre made of glass (high quality silica) or plastic.
- It is used to transmit information, such as text, images, videos, etc. encoded as digital information or electromagnetic waves/light pulses almost at the speed of light.
- Optical fibres utilise the phenomenon of total internal reflection for transmission.



Structure:

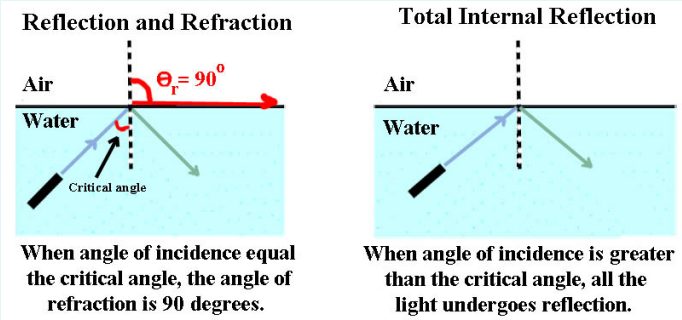
An optical fibre consists of:

- **Core**, which is the innermost part where light travels.
- **Cladding**, which surrounds the core and helps contain the light within the core by reflecting it back into the core.
    - Core and cladding are usually made of materials with different refractive indices, allowing for the total internal reflection of light within the core.
    - Refractive index of the core is higher (denser medium) than the refractive index of the cladding (rarer medium).



Total Internal Reflection (TIR):

- TIR occurs when light travelling from a rarer medium to a denser medium, strikes the boundary of the medium at an angle greater than the critical angle.
- If the angle of incidence is greater than the critical angle, all the light is reflected back into the original medium; none of it is refracted into the second medium.
- This phenomenon is crucial in optical fibres, where it allows light signals to be transmitted over long distances by repeatedly undergoing TIR within the core of the fibre.



Advantages:

- Long distances with minimal loss of signal quality (low signal attenuation).
- Optical waves have high bandwidth, thus allowing a high data-transmission rate, up to several terabits per second in a single fibre.
- Fibre cables are immune to electromagnetic interference and less sensitive to external perturbations such as lightning and bad weather, unlike copper cables.

Applications:

- **Telecommunications**: Used to connect telephone lines, cable television systems, and internet service providers.
- **Medical imaging**: Used in a variety of medical imaging applications, such as endoscopy, ultrasound, and laser surgery.
- **Sensors:** Used in a variety of sensors, such as temperature sensors, pressure sensors, and chemical sensors.
- **Lighting:** Used in a variety of lighting applications, such as decorative lighting, stage lighting, and outdoor lighting.
- **Military:** Used in a variety of military applications, such as communication, surveillance, and targeting.

5. INTERNET

- **Internet:** Global network of interconnected computers and devices that use standardised communication protocols to exchange information.
- **Internet Service Providers** (ISPs): Companies or organisations that provide access to the Internet. They offer various types of connections such as dial-up, broadband, and wireless.
- **World Wide Web (WWW):** An information system on the Internet that allows users to access and navigate through web pages using hyperlinks.

EVOLUTION OF WORLD WIDE WEB

THREE STAGES OF INTERNET CONSUMPTION			
	Web1	**Web2**	**Web3**
Time period	**1990-2005**	**2005-till date**	**2021 - under development**
Where data is stored	Server's file system	On-premises/Cloud	Blockchain, distributed across multiple networks

Examples	Static web pages	User generated content like Social media, and web applications like e-commerce etc.	NFTs, cryptocurrency transaction
Who owns data	Companies running the web pages	Companies that host application, cloud service providers	No one owns the data
Transacting	No transaction possible	Payment gateways for currency transactions	Transaction happens using crypto tokens

- **Web 1.0 [1990 – 2000]:** It is regarded as the first generation of the World Wide Web. Also known as Syntactic web or read only web. Mostly, Web 1.0 was limited to searching info and reading what's already there. There was little user interaction or content contribution. It was disorganised and overwhelming, and soon it came to be dominated by AOL, CompuServe, early Yahoo and other portals. These online service providers were gateway to Web 1.0. (HTML 1.0)
- **Web 2.0 [from mid-2000s]:** This phase was characterised by enhanced user experience and made the internet interactive. Also known as Social Web or read-write web. It enabled users to participate in content creation on social networks, blogs, sharing sites and more. Search engines (Google) and social media platforms (Facebook, Twitter) driven by user-generated content disrupted media, advertising and retail industries. Web 2.0's business model relies on user participation to create fresh content and resultant data being sold to third parties for marketing. Facilitated by HTML 2.0.
- **Web 3.0 [yet to arrive]:** Next stage of web evolution. It would make the internet more intelligent, or process information with near-human-like intelligence through the power of AI systems.

6. WEB 3.0

- Web 3.0 is the next version of the internet where services will run on blockchain.
- It is a decentralised internet that runs on a public blockchain, which is also used for cryptocurrency transactions.
- It will be permissionless and democratic. **For instance**: Twitter will not be able to censor posts and Facebook will not be able to maintain a database of billions of users.
- In a Web 3.0 universe, people will control their own data and will be able to move around from social media to email to shopping using a single personalised account, creating a public record on blockchain of all that activity.
- All data will be interconnected in a decentralised way, unlike current generation of internet (Web 2.0), where data is mostly stored in centralised repositories.
    - Key features of Web 3.0 are: Ubiquity, Semantic Web, Artificial Intelligence and 3D Graphics.
    - Examples of Web 3.0: Most recent examples of Web 3.0 are the NFTs or non-fungible tokens.

NEED FOR WEB 3.0

- **Loss of privacy:** Data is stored in servers of companies that people interact with. Intermediaries become custodians of user data and profit from. For such companies, more time consumers spend creating content, more data the company can collect, helping it to improve its AI algorithm and its advertising engine, a key revenue model for the company. This gives rise to issues of privacy, wherein user data is shared for profit without their consent.
- **Data ownership:** Only centralised repositories are the ones that own user data and profit from it. In Web 3.0, users can own and be properly compensated for their time and data.
- **Plagiarism:** It is very easy to copy original content and build a following around it on social media. Plagiarism makes it harder for creators to get compensated. Web3 might help address that issue as the transparent nature of blockchain makes it easy for anyone to track the originator of content.

KEY DIFFERENCES BETWEEN WEB 2.0 AND WEB 3.0

- Any information that users share on Web 2.0 is stored with a **cloud service provider** whereas in Web3, all services are built on top of a **blockchain**.
- Cloud is controlled by internet giants and is centralised. In blockchain, data is distributed across networks and no single entity owns the information.

METAVERSE AND WEB 3.0

Metaverse is about creating digital avatars and interacting with others in virtual spaces. It does not have to be on a blockchain. The whole point of Web 3.0 is decentralisation.

7. DARK WEB

The total web content on the internet is broadly classified into three broad categories: Surface web, Deep web and Dark web.

SURFACE WEB

- Usual search engines such as Google, Yahoo & Bing etc. can 'look for' and extract content and present it in the form of a website/webpage. For this, web pages are 'indexed' by search engines.
- Only about 10-15% of web content is present on surface web accessible by common searches.

DEEP WEB

- Term used for all those content or web pages that are there on the internet but are not indexed by search engines and therefore not discernible by conventional search engines.
- Thus, webpages on the deep web do not show up in conventional search engines like Google, Yahoo, and Bing etc. About 75-80% of the web content/web pages are on the deep web.
- Common examples of web content on the deep web include financial data, bank account details, emails, personal data etc. that are password protected.

DARK NET/DARK WEB

- Part of the deep web that is intentionally hidden to provide anonymity.
- **Key features:**
  - No webpage indexing by surface web search engines.
  - Virtual traffic tunnels via randomised network infrastructure.
  - Inaccessible by traditional browsers due to its unique registry operator.
  - Further hidden by various network security measures like firewalls and encryption.
- To do this, Dark Net uses a specialised network of computers called relays through which the information passes. Commonly, information on DarkNet passes through at least 3 relay computers between the source and destination.
- In addition, dark net uses network technology that hides the locations of these relay computers (IP address) to ensure anonymity of the users.
- Dark net can be accessed through TOR Browser (Anonymity Network).

THREATS OF DARK WEB

- **Is using the dark web legal?** Using DarkNet is per say is not illegal. By virtue of its ability to provide anonymity, dark net is used by human right activists, free internet activists, media personnel etc. in countries where there are severe restrictions, censorship on internet usage like that in China, Iran, Saudi Arabia etc. Also used by whistleblowers to maintain anonymity.
- **Threats of Dark Web:** Malicious software, Scam, Identity theft monitoring, Illegal sales of COVID-19 vaccines, Drug trafficking, Bitcoin laundering, Drug trafficking

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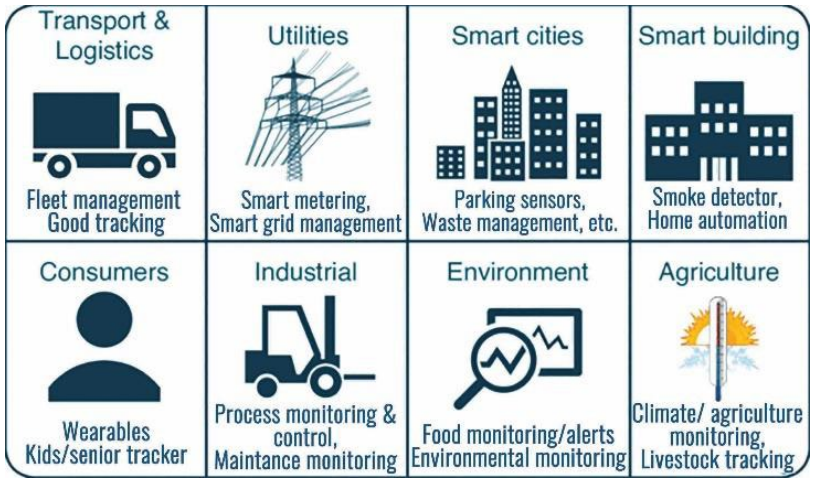
8. INTERNET OF THINGS (IOT)

- IoT refers to a network of physical devices embedded with sensors, software, and other technologies that connect and exchange data with other devices and systems over the internet or other communication networks.
- These devices can communicate and interact with other devices over the Internet, and they can be remotely monitored and controlled by computers and smartphones.

APPLICATIONS OF INTERNET OF THINGS

- **Agriculture:** Sensing for soil moisture & nutrients, controlling water usage for plant growth & determining custom fertiliser are uses of IoT.
- **Energy utilisation**: Smart Grids will be able to detect sources of power outages, can automatically take inputs of solar panel, making possible distributed energy system.
- **Smart cities:** Cellular communication enabled Smart municipal bins, Parking sensors etc.
- **Healthcare:** Personalised analysis of an individual's health and tailor-made strategies to combat illness will be possible. Enhanced patient monitoring and better health outcomes.
- **Manufacturing:** IoT intelligent systems enable rapid manufacturing of new products, dynamic response to product demands, and real-time optimisation of manufacturing production and supply chain networks, by networking machinery, sensors, and control systems together.



- **Environmental monitoring:** Assist in environmental protection by monitoring air or water quality, atmospheric or soil conditions. It can even include areas like monitoring the movements of wildlife and their habitats.
- **Supply chain:** By placing RFID tags on individual products, the exact location of single items in a large warehouse can be shared, thus saving search time, streamlining infrastructure, and lowering labour costs.

9. EVOLUTION OF MOBILE NETWORKS

- Mobile phones communicate through ground-based cellular networks. Cellular networks are divided into 'communication cells' with which our mobile phones and mobile devices communicate.
- Mobile communication involves transmitting voice or data using wireless radio transmission.
- The first mobile systems were based on analogue transmission called 1G.
- The second-generation mobile systems were based on digital transmission.
- Initially, only voice was carried over the network.The commonly used standards for voice communication were GSM and CDMA.
- These days, most mobile communications use Long Term Evolution communication– or LTE which allows us to communicate with voice and data simultaneously over the same network.
- The rules for carrying voice or data in a network are defined under the standards for mobile network communications often seen as 2G, 3G, 4G and 5G.

1G

- Mobile phones began with 1G technology in the 1980s.

- 1G is analog technology that supports only voice communications.
- The maximum speed is 2.4 Kbps.

2G

- First launched in 1991.
- For the 1st time radio signals became digital rather than analog.
- 2G phones are used for data also along with voice.
- Thus, 2G telephone introduced call and text encryption, SMS, picture messages, and MMS.
- Maximum speed under 2G networks with General Packet Radio Service (GPRS) was 50 kilobits per second.
- With Enhanced Data Rates for GSM Evolution (EDGE) the speed went up to 1mbps

GPRS

- Launched in 2000
- Bridge between 2G and 3G.
- It marks the coming of data transmission besides voice communication.
- General Packet Radio Service enabled mobile devices to send and receive emails and pictures.
- GPRS used EDGE and GSM standards for both voice and data transmission.
- GPRS had operating speeds of up to 115 kbit/s.
- It increased to a maximum of 384 kbit/s by using EDGE.

3G

- The introduction of 3G networks in 1998, ushered in faster data-transmission speeds.
- Maximum speed of 3G is estimated to be around 2 Mbps for non-moving devices and 384 Kbps in moving vehicles.
- Further a 3G phone cannot communicate through a 4G network, but a 4G phone can communicate through a 3G or even 2G networks.
- Under both 2G to 3G technologies, data and voice transmission over the different networks using GSM or CDMA technology.

4G

- 4G uses LTE which allows us to communicate with voice and data simultaneously over the same network.
- Applications include amended mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, 3D television, and cloud computing.
- Max speed of a 4G network when the device is moving is 100 Mbps or 1 Gbps for low mobility communication like when stationary or walking.

	1G	2G	3G	4G
Period	**1980-1990**	**1990-2000**	**2000-2010**	**2010-(2020)**
Bandwidth	150/900MH2	900MHz	100MHz	100MHz
Frequency	Analog signal (30 Khz)	1.8GHz (digital)	1.6-2.0 GHz	2-8 GHz
Data rate	2kbps	64kbps	144kbps-2Mbps	100Mbps-lGbps
Characteristic	First wireless communication	Digital	Digital broadband, increased speed	High speed, all IP
Technology	Analog cellular	Digital cellular (GSM)	CDMA, UMTS, EDGE	LTE, WiFi

10. 5G TECHNOLOGY

- Fifth generation (5G) of long-term evolution (LTE) mobile broadband networks is the most recent update.
- The next generation cellular technology will provide faster and more reliable communication with ultra-low latency (Latency is gap time or transmission time for a packet of data).
- The Steering Committee constituted for identifying the 5G deployment roadmap for India recently submitted a report titled 'Making India 5G Ready'. As per a government panel report with 5G data speed would be 2-20 Gbps.

FEATURES OF 5G

- **High data rates** (1Gbps for hotspots, 100Mbps download and 50Mbps upload for wide-area coverage)
- **Massive connectivity** (1 million connections per square kilometre)
- **Ultra-low latency** (1 millisecond)
- **High reliability** (99.999% for mission critical 'ultra-reliable' communications).
- **Mobility at high speeds** (up to 500 km/hr i.e., high-speed trains).

APPLICATIONS IN INDIA

- Will enhance infrastructure efficiencies like **'vehicle platooning'.** Platooning can double vehicle density in roads promoting efficient and safer use of the limited road infrastructure.
- In manufacturing, 5G will enable use of robotics for precision manufacturing.
- 5G can also enable better logistics to track goods from raw materials to product delivery.
- In agriculture, 5G can enable improvement in the entire value-chain, from precision farming, smart irrigation, improved soil and crop monitoring to livestock management.
- In the energy sector, 'smart grids' and 'smart metering' can be efficiently supported enabling growth of alternate energy technologies.
- In healthcare, 5G can enable more effective tele-medicine delivery, tele-control of surgical robotics and wireless monitoring of vital statistics.
- 5G will be used in key government projects such as smart cities and Digital India.

Feature	4G (LTE)	5G (Current Status)	6G (Vision)
Deployment Status	Widely deployed	Limited rollout (October 2022 launch)	Under development (Bharat 6G project initiated)
Speed	Up to 100 Mbps (typical)	Up to 1 Gbps (limited areas)	Up to 1Tbps (theoretical)
Latency	50-100 milliseconds	10-20 milliseconds (limited areas)	Under 1 millisecond (theoretical)
Spectrum Availability	Below 6 GHz bands	Below 6 GHz bands (limited), mmWave auctions awaited	Below 6 GHz bands, mmWave, Terahertz (future)
Applications	Basic mobile broadband, social media, video streaming	Early adoption for enhanced mobile broadband, potential for future VR/AR	Focus on R&D for ultra-high-speed data, mission-critical applications (long term)

5G SPECTRUM

5G primarily operates in three bands, namely the low, mid, and high-frequency spectrums, each of which has its own set of benefits and drawbacks.

LOW BAND SPECTRUM

- It has a lot of potential in terms of coverage and internet and data transfer speed; however, the maximum speed is just 100 Mbps (Megabits per second).

- The low band spectrum may not be ideal for specialised requirements of the business; thus, Telcos may utilise and deploy it for commercial cell phone customers who may not have need for extremely high-speed internet.

MID-BAND SPECTRUM

- It has faster speeds than the low band, however it has restrictions in terms of coverage area and signal penetration.
- This band might be utilised by companies and specialised production units to create captive networks that can be tailored to their specific demands.

HIGH-BAND SPECTRUM

- It has the fastest speed of the three bands, but its coverage and signal penetration intensity are severely restricted.
- Internet speeds in the 5G high-band spectrum have been tested to reach 20 Gbps (gigabits per second), although the greatest internet data speed in 4G has been reported at 1 Gbps in most circumstances.

MILLIMETRE (MM) WAVE BAND

- The millimetre wave band, or mmWave, is a portion of the radio frequency spectrum that spans 24 to 100 GHz.
- As the name implies, this spectrum has a short wavelength and is more likely to give higher speeds and shorter latencies.
- Data transport becomes more efficient and smoother, as existing networks are optimised for lower frequency bandwidths.

SIGNIFICANCE OF THIS MM BAND

- Lower frequency bands may be used to deliver 5G services.
- They can reach longer distances and have been demonstrated to perform well even in congested metropolitan areas.
- However, when it comes to data rates, these bands fall short of the maximum capacity required for a real 5G experience.

So, mmWave is that key component in the 5G jigsaw puzzle for mobile service providers.

11. Wi-Fi and Li-Fi

Wi-Fi (Wireless Fidelity) and Li-Fi (Light-Fidelity) are two different wireless communication technologies that enable data transmission, i.e., offer a way to connect to the internet without physical cables.

S. No.	Parameters	Wi-Fi	Li-Fi
1.	**Medium of transmission**	Relies on radio waves to transmit data wirelessly between devices	Transmits data using visible light or ultraviolet light. LEDs act as transmitters, and a photodetector receives the data.
2.	**Range**	Typically up to 32 metres	Typically around 10 metres
3.	**Frequency**	Radio frequency spectrum, between 2.4 GHz and 5 GHz	Visible light spectrum or UV light spectrum
4.	**Advantages**	Wider range	Faster speed (upto 100 Gbps theoretically), high security
5.	**Disadvantages**	Susceptible to radio-frequency	Shorter range, Requires a direct line of sight

		interference causing latency	communication between the transmitter and receiver.

12. WIFI 6.0

- Next generation standard in WiFi technology. Also known as “AX WiFi."
- It was built in response to the growing number of devices in the world of IoT (Internet of Things) due to faster data transmission rates.

WI-FI CERTIFIED 6 NETWORKS ENSURE

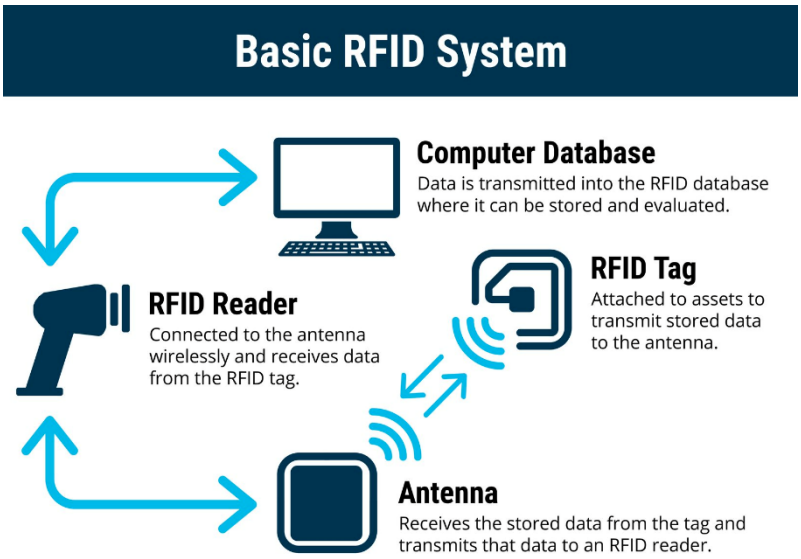
- Each connected device performs at an optimum level, in locations with hundreds or thousands of connected devices.
- Highest standards for security and interoperability.
- Lower battery consumption.
- Increased bandwidth to deliver greater performance with lower latency.

13. NEAR FIELD COMMUNICATION TECHNOLOGY

- A short-range wireless connectivity technology that allows NFC-enabled devices to communicate with each other and transfer information quickly with a single touch.
- NFC transmits data through electromagnetic radio fields between two devices typically requiring a distance of **4 cm or less.**
- Both devices must be equipped with NFC technology and be physically contacting or within a few centimetres of one another for data transmission.
- **Applications:** Contactless banking cards, contactless public transportation tickets, wireless charging, Vending machines, Parking metres, NFC-enabled wristbands (E.g., track patient data in the hospital setting), Inventory and sales monitoring etc.
- **Limitations of NFC:** Can work only on limited distances. Offers exceptionally low information or data transfer rate of a few Kbps.

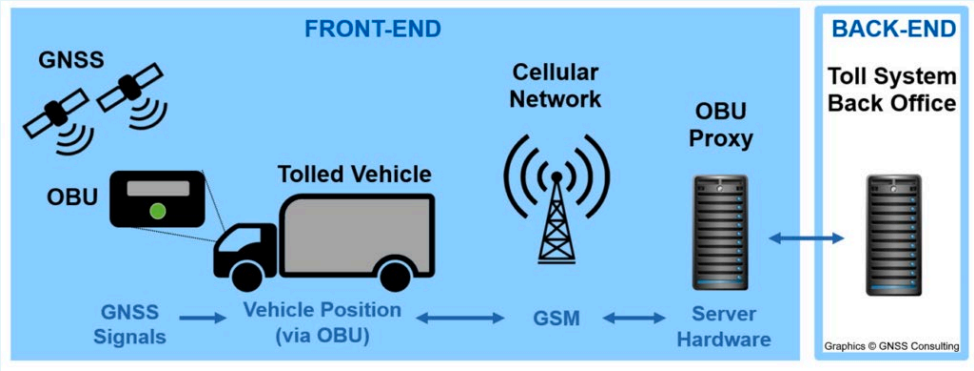
14. RADIO FREQUENCY IDENTIFICATION (RFID) TECHNOLOGY

- RFID technology refers to a wireless system comprising two components: **tags and readers.**
- **Reader** is a device that has one or more antennas that emit radio waves and receive signals back from the RFID tag. Readers can be mobile so that they can be carried by hand, or they can be mounted on a post or overhead.
- **RFID Tag** is embedded on the windscreens of the vehicles for transporters. It can store a range of information from one serial number to several pages of data. The tags use radio waves to communicate their identity and other information to nearby readers.



Satellite-based toll collection

- Central government has plans to implement satellite-based toll collection on highways in India in 2024.
- This will replace the **radio frequency identification-based FASTag system** that was rolled out in 2016 and made mandatory from January 2021.
- **Significance**: Efficiency in toll collection and barrier-free movement of vehicles.



Working Mechanism:

- **On-board unit:** Every vehicle registering for the Global Navigation Satellite System (GNSS) of toll collection will be equipped with an on-board unit (OBU) that will be linked to a constellation of satellites via a GPS receiver. The OBU transmits the vehicle's location and identification information to the toll collection system. The OBU will also be linked with a wallet from which the toll amount will be automatically deducted.
- **Satellite tracking:** Satellites track the movement of the vehicle and determine the distance travelled on tolled roads.
- **Toll calculation:** The toll collection system calculates the toll based on the actual length of the highway traversed by the vehicle and the vehicle's class (**E.g.,** car, truck).
- **Automatic payment:** Toll amount is automatically deducted from the driver's prepaid account or linked credit card.

15. FREE SPACE OPTICAL COMMUNICATION

- Free Space Optical (FSO) communication refers to the transmission of optical signals through free space, such as the atmosphere or vacuum, using line-of-sight (LOS) communication between transceivers.
- It is typically used for short-range communication links, such as within buildings or across relatively short distances.

ADVANTAGES

- FSO communication offers a high data rate to meet the tremendous increasing demand of broadband traffic mostly driven by Internet access and HDTV broadcasting services.
- Compared to fibre optics technology, FSO offers much more flexibility in designing optical network architectures at very high speeds, at tens and hundreds of Gbit/s rates.
- Both point-to-point, point-to-multipoint, multipoint-to-point, and multipoint-to-multipoint FSO communications are possible, depending on the different scenarios of establishing optical links.

LIMITATIONS

- However, FSO communication is affected by atmospheric effects (fog, rain, turbulence), which limits sensitivity and achievable data rates with acceptable BER (Bit Error Rate).

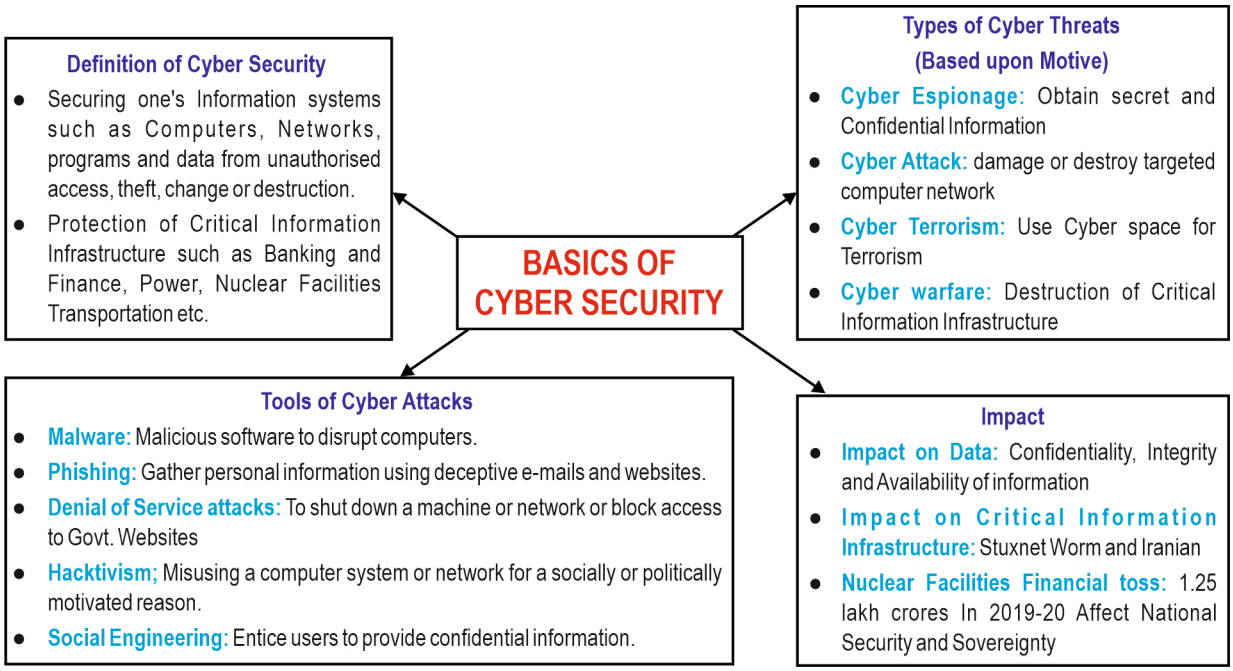
16. DEEP SPACE OPTICAL COMMUNICATION

- DSOC is NASA's first demonstration of optical communication beyond the Earth-Moon system. DSOC uses near-infrared signals to transmit data, instead of radio waves.
- It promises data rates at least 10 times faster than the current radio frequency communication.
- **Primary objective** is to enable high-data-rate communications offering the potential to transmit high-definition images, video streaming and increased scientific data volume during space missions.
- A recent demonstration of DSOC technology was done from NASA's Psyche spacecraft. The DSOC system on board Psyche successfully transmitted a 15-second ultra-high definition video from a distance of 31 million kilometres at a rate of 267 Mbps.
- This paves the way for future missions that will require high-bandwidth communications from deep space.

17. CYBER SECURITY THREATS

India has been victim to the Cyber-attacks number of times in the recent past:

- **2017:** WannaCry and Petya Ransomware
- **2018:** Aadhaar Software hacked and Aadhaar details of the people leaked online.



TOOLS OF CYBER ATTACKS

1. Malware: Malicious software to disrupt computers. It can include Virus, Spyware, Trojans etc.

Types of Malwares:

- **Virus**: Most common type of malware. It can replicate itself and spread to other computers.
- **Worm:** Malware that can self- replicate without a host program. Worms typically spread without any human interaction or directives from the malware authors.
- **Trojan**: Malicious program that is designed to appear as a legitimate program. Once activated following installation, trojans can execute their malicious functions.
- **Spyware:** Malware designed to collect information and data on users and observe their activity without users' knowledge. **E.g.,** Pegasus.
- **Ransomware**: Malicious software injected into the computer to limit the access of the system to the user and encrypt the data. Cyber criminals demand money/ cryptocurrency in lieu of an encryption key (that would unlock all the data and restore the access to the system). **E.g.,** *WannaCry Ransomware*, *Locky Ransomware* etc.

2. **Denial of Service attacks:** An attack meant to shut down a machine or network, making it inaccessible to its intended users.
3. **Crypto jacking**: Cryptocurrencies are created through a process called mining. To mine digital coins, miners need to use high-end processors that consume a lot of electricity. Crypto jacking is what some digital coin miners do to illegally gain access to many computers. The miners stealthily drop malware in an unsuspecting user's computer. This malware runs surreptitiously and turns devices into cryptocurrency-mining botnets. Unlike most other types of malwares, crypto-jacking scripts do not use the victim's data. But they drain the CPU's resources, which slows down the system, increases electricity usage, and causes irreparable damage to the hardware.
4. **Hacktivism:** Misusing a computer system or network for a socially or politically motivated reason. For example, the hacktivists can block access to Government's website, deface the government's website or unblock the sites which have been blocked by the Government.
5. **Social Engineering:** Manipulation and exploitation of human psychology to deceive individuals or gain unauthorised access to confidential information (passwords, bank information etc.) or clicking on malicious links. These attacks often exploit traits such as trust, helpfulness, curiosity, or fear. Common techniques used in social engineering attacks:

- **Impersonation**: Impersonating friends, relatives in distress to seek money.
- **Phishing:** Pretending to be legitimate entities, such as banks or organisations, to deceive individuals into revealing sensitive information like usernames, passwords, or credit card details. Typically done through fraudulent emails, messages, or websites that appear authentic.
- **Baiting:** Installing malware on pretext of enticing offers like free software upgrade.

6. **Advanced Persistent Threat:** Type of cyber-attack in which an unauthorised user gains access to a system or network and remains there for an extended period without being detected. They generally do not cause damage to company networks or hardware. Instead, they are focussed on stealing data

MALWARE-AS-A-SERVICE (MAAS)

- Type of cybercrime model where malware is offered for sale or rent by cyber criminals as a service to other hackers or malicious actors on the internet.
- MaaS operates in a similar way to legitimate Software as a Service (SaaS) models, where software (malware) is provided on a subscription or pay-per-use basis.
- These services typically are available on the dark web. They are purchased to carry out various malicious activities, such as stealing sensitive information, disrupting computer systems, or encrypting data and demanding a ransom to unlock it.

18. DARK PATTERNS

- Dark patterns are any practices or deceptive design patterns using user interfaces on any platform (website, mobile applications etc.) that are designed to mislead or trick users to do something they originally did not intend or want to do.
- The Central Consumer Protection Authority established under Section 10 of Consumer Protection Act, 2019, has classified them as 'unfair trade practice' and notified **'Guidelines for Prevention and Regulation of Dark Patterns, 2023'** to curb dark patterns across various platforms offering goods or services in India.
- The guidelines list 13 dark patterns, which include:

S. No.	Dark patterns	Definition
1.	False Urgency	Creates a sense of urgency or scarcity to pressure consumers into making a purchase or taking an action.

2.	Basket Sneaking	Add additional products or services to the shopping cart without user consent.
3.	Confirm Shaming	Involves guilt as a way to make consumers adhere. It criticises or attacks consumers for not conforming to a particular belief or viewpoint.
4.	Forced Action	Forcing consumers into taking an action they may not want to take, such as signing up for a service in order to access content.
5.	Subscription Trap	Makes it easy for consumers to sign up for a service but difficult for them to cancel it, often by hiding cancellation options or requiring multiple steps.
6.	Interface Interference	Make it difficult for consumers to take certain actions, such as cancelling a subscription or deleting an account.
7	Bait & Switch	Practice of advertising a particular outcome based on the user's action but deceptively serving an alternate outcome.
8.	Drip Pricing	Involves hiding additional costs from consumers until they are already committed to making a purchase.
9.	Disguised Advertisement	Advertisements that are designed to look like other types of content, such as news articles or user-generated content.
10.	Nagging	Refers to persistent, repetitive and annoyingly constant criticism, complaints, requests for action.
11.	Trick Question	Deliberate use of confusing or vague language like confusing wording, double negatives, or other similar tricks, to misguide or misdirect a user.
12.	SaaS Billing	Process of generating and collecting payments from consumers on a recurring basis in a software as a service (SaaS) business model by exploiting positive acquisition loops in recurring subscriptions to get money from users as surreptitiously as possible.
13.	Rogue Malwares	Using ransomware or scareware to mislead or trick users into believing there is a virus on their computer and aims to convince them to pay for a fake malware removal tool that actually installed malware on their computer.

19. END-TO-END ENCRYPTION

Encryption:

- Encryption is a way of protecting data from unauthorised access or tampering. It works by transforming the data into a secret code that only the intended recipient can decipher.
- There are two main types of encryption:
  - **Symmetric encryption** uses the same key to encrypt and decrypt the data.
  - **Asymmetric encryption** uses a pair of keys: one public and one private. The public key can be shared with anyone, but the private key must be kept secret.

End-to-End Encryption (E2EE):

- E2EE is a security measure used in communication systems to protect the confidentiality and privacy of data exchanged between users.
- It protects data as it is transferred between end locations, i.e., the sender and receiver can read any exchanged messages, while preventing unauthorised third parties, including service providers and government entities, from intercepting and reading the content.
- **Working:** E2EE generally utilises asymmetric cryptography/encryption, which in turn uses a pair of keys – public and private – to secure communications. The public key is used to encrypt data, while the private key decrypts it.

20. OPEN-SOURCE SOFTWARE

- Open-source software (OSS) is software that is distributed with its source code, making it available for use, modification, and distribution with its original rights. Examples: Linux, Mozilla Firefox, VLC media player, SugarCRM, etc.
- While the operating system of Apple's iPhones (iOS) is closed source, meaning it cannot be legally modified or reverse engineered, Google's Android operating system is open source.
- Many other solutions launched by the government including Digilocker, Diksha, Aarogya Setu, the Covid-19 vaccination platform CoWIN have also been built on top of open-source digital platforms.

ADVANTAGES OF OPEN-SOURCE SOFTWARE

- More affordable than proprietary counterparts and give increased personal control to creators and users alike.
- By harnessing crowdsourcing, open-source software allows developers to benefit from accelerated innovation, quicker development processes and having more success troubleshooting when problems arise.
- Spur growth of new technologies like 5G/6G, microprocessor technology, Artificial Intelligence, Internet of Things, by building indigenous technology capabilities.

21. ARTIFICIAL INTELLIGENCE

- Artificial Intelligence (AI) is the simulation of human intelligence processes by machines, especially computer systems.
- Machines can perform cognitive tasks like thinking, perceiving, learning, problem-solving and decision-making through technologies like natural language processing and artificial neural networks.
- **Natural Language Processing:** NLP involves the interaction between computers and humans using natural language. Through techniques like machine learning and deep learning, computers can understand, interpret, and generate human language in a way that is meaningful. NLP enables tasks such as language translation, sentiment analysis, text summarisation, question answering, and chatbot interactions.
- **Artificial Neural Network:** A computational model inspired by the structure and functioning of biological neural networks. It consists of interconnected nodes called artificial neurons or units, which are organised in layers. Each neuron takes input from the previous layer, performs a computation, and passes the output to the next layer. ANNs are used for various tasks like pattern recognition, classification, regression, and decision-making.

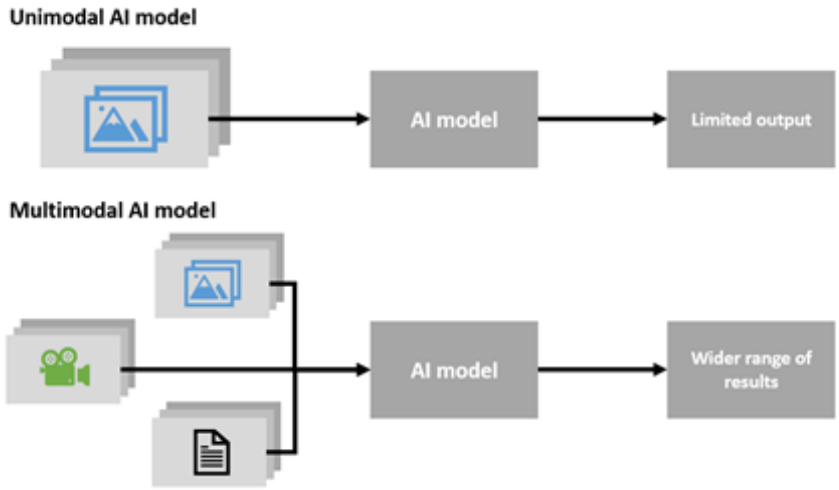
GENERATIVE AI

- Type of AI that involves creating new, original content or data (like text, images, music, code etc.) using machine-learning algorithms.
- Generative AI works by training a model on a large dataset and then using that model to generate new, previously unseen content. **E.g.,** DALL-E for image generation, ChatGPT for text generation.
- One of the most popular approaches to generative AI is the use of generative models, particularly generative adversarial networks (GANs).

- GAN is a class of AI algorithms that consist of two neural networks: generator and discriminator, that compete against each other.
  - The generator learns to create new samples (synthetic data) that resemble the training data.
  - The discriminator tries to distinguish between the generated samples and the real data.
  - This adversarial training process leads to the improvement of both networks over time, resulting in generation of increasingly realistic synthetic content. **E.g.,** Deepfakes.

UNIMODAL AI AND MULTIMODAL AI

- **Unimodal AI** refers to AI models that work with a single type of data input and output. In simpler terms, they specialise in one specific modality, either text, images, audio, or video.
- **Multimodal AI** refers to AI systems that can understand and process information from multiple sources, such as text, images, audio, video, etc. This integration and analysis of data from diverse formats allow for richer understanding and more accurate results. **E.g.,** Gemini



APPLICATIONS OF AI

- **Education:** Transform education by providing personalised learning experiences, intelligent tutoring systems, and adaptive educational content.
- **Healthcare:** Improve diagnostics (AI-enabled medical imaging), development of personalised treatments and discover new antibiotics, robots for surgical procedures.
- **Agriculture:** Crop yield prediction and forecast prices, AI-based sensors for spraying pesticides/herbicides, autonomous robots for harvesting crops, monitoring crop health for diagnosing pests/soil defects, nutrient deficiencies in soil etc.
- **Infrastructure:** Aid in the development of smart cities, improve safety by enabling intelligent infrastructure (self-driving cars) and optimising complex transportation hubs.
- **Data Analysis and Research**: Analyse vast amounts of data, identify patterns, and aid in scientific discoveries and data-driven decision-making.
- **Enhance National Security:** Detecting and responding to cyber threats, identifying vulnerabilities, and conducting cyber attacks.
- **Space exploration**: **E.g.,** Development of autonomous spacecraft, smart habitats.
- **Service delivery**: AI-powered chatbots and virtual assistants can enhance customer experiences by providing quick and accurate responses to inquiries, automating routine tasks, and personalising interactions.
- **Environmental sustainability**: Optimising energy consumption, facilitating smart grid management, enabling better decision-making for resource management.

Can a copyright be given to a content generated by AI?

- The **Indian Copyright Act, 1957**, grants exclusive rights to creators (authors, artists, etc.) over their original works for a specific duration.
- Using a copyrighted work (literary, artistic, musical, etc.) without the owner's permission, in a way that infringes their exclusive rights over it, constitutes copyright infringement.
- India does not have any specific litigation in the context of text and data mining by AI.
- In the Copyright Act of India, there is no way a non-human can be granted copyright protection. The Act currently recognises only human authors for copyright protection.

GLOBAL PARTNERSHIP ON AI (GPAI)

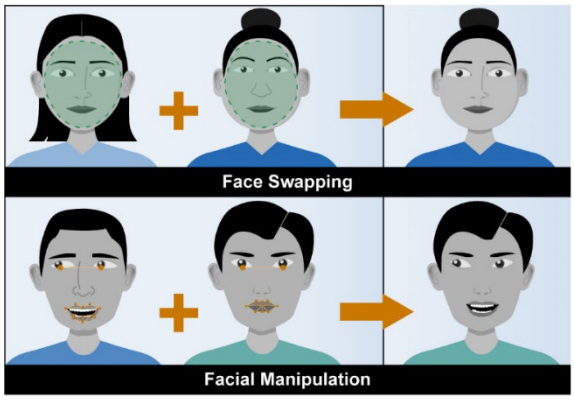
- A multi-stakeholder initiative which aims to bridge the gap between theory and practice on AI by supporting cutting-edge research and fostering international collaboration for responsible AI development.
- **Launched:** June 2020. India is a founding member of GPAI.
- **Members:** Presently, GPAI has 29 members, including Australia, Canada, France, Germany, India, United Kingdom, United States, European Union, among others.

New Delhi Declaration on AI:

- In December 2023, the New Delhi Declaration on AI was adopted to find a balance between innovation and the risks associated with AI systems.
- It promoted equitable access to critical resources for AI innovation including computing, high-quality diverse datasets, algorithms, software, testbeds, and other AI-relevant resources and human-centred use of AI.

22. DEEP FAKES

- Synthetic media (image, video, audio) that has been digitally created/altered to replace a person's face or body with that of another with a high potential to deceive or manipulate.
- Deepfakes are generated using powerful techniques from machine learning called generative adversarial network (GAN) and artificial intelligence.
- The technology can be utilised for malicious activities like scams, identity theft, financial fraud, pornography, election meddling, social engineering and automated disinformation attacks.



Source: GAO. | GAO-20-379SP

- The law currently being invoked to tackle deep fakes is the **Information Technology Act, 2000.** Under section 66D of the IT Act, it is a punishable offence to use computer resources to cheat by personation.
- **Information Technology Rules, 2021** prohibit hosting any content that impersonates another person and requires social media firms to take down artificially morphed images when alerted. All content reported to be fake or produced using deep fake has to be taken down by social media intermediary platforms within 24 hours of the receipt of such a complaint.

23. NEUROMORPHIC COMPUTING

- Neuromorphic Computing is an approach to computing that is inspired by the structure and function of the human brain.

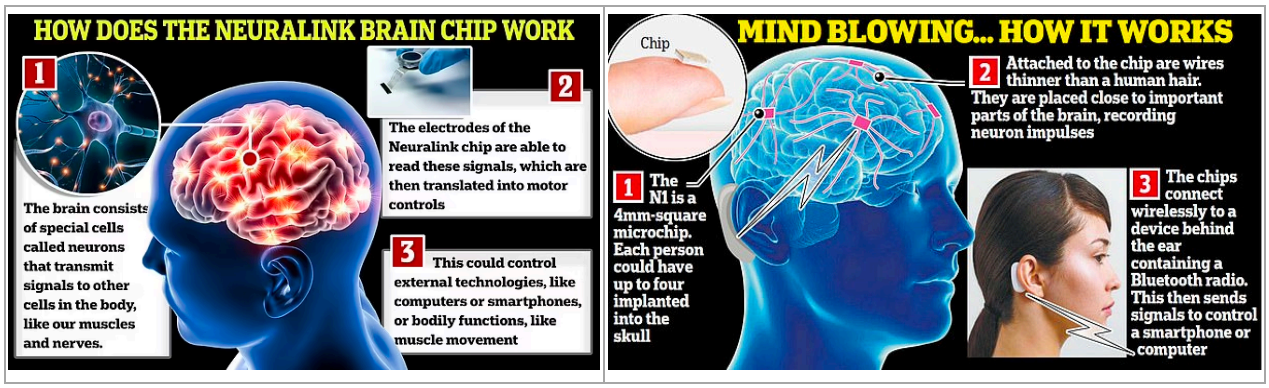
- The development of neuromorphic hardware aims at mimicking biological synapse that monitors and remembers the signal generated by the stimuli. (simply, aims to design computer systems that mimic how human brain processes information)

WORKING

- A neuromorphic computer/chip consists of Artificial Neural Networks composed of millions of artificial neurons (made from Silicon).
- These neurons pass signals to each other in layers, converting input into output through electric spikes or signals, based on the architecture of Spiking Neural Networks.
- This allows the machine (computer systems) to mimic the neuro-biological networks in the human brain and perform tasks efficiently such as visual recognition and data interpretation.

24. NEURALINK BRAIN CHIP IMPLANT

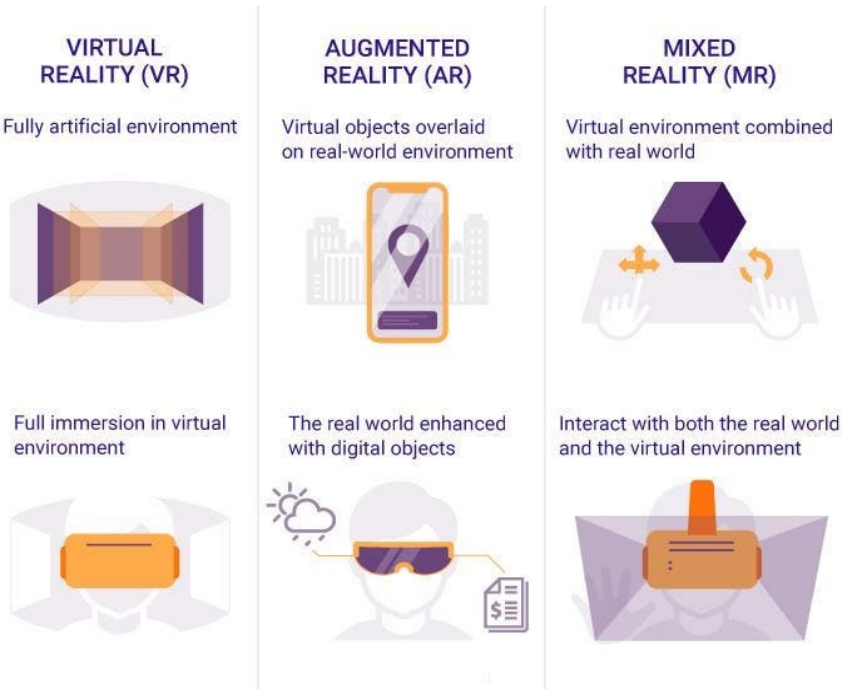
- As per the computer-brain interface company Neuralink, the first human has received a brain chip implant and is recovering well.
- Neuralink is working on linking the nervous system to computers, with efforts aimed at helping treat brain disorders, overcoming brain injuries, and other applications.
- **Aim:** To give people the ability to control a computer cursor or keyboard using their thoughts alone or "just by thinking".



25. IMMERSIVE TECHNOLOGIES

Extended reality (XR) is an umbrella term for the spectrum of immersive technologies that alter or add to our perception of the real world. This includes technologies like Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR).

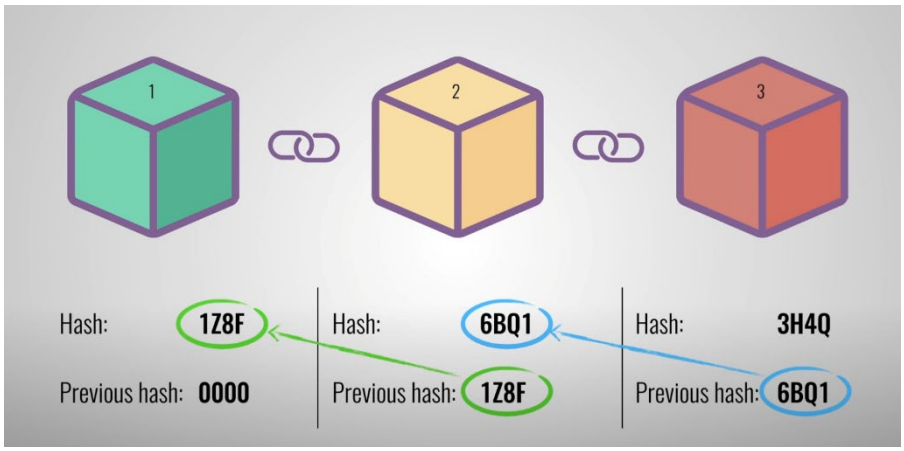
- **Augmented Reality (AR)**: It overlays digital elements onto the real world. AR does not replace the real world, but enhances it with virtual/digital information. Devices: Commonly accessed through smartphones, tablets, or special AR glasses. **E.g.,** Pokemon Go (Game)



- **Virtual Reality (VR)**: Creates a completely immersive simulated environment and cuts off the user from the physical environment/reality. VR replaces the user's entire field of view with a computer-generated virtual world. **Devices:** Requires dedicated VR headsets and motion controllers.
- **Mixed Reality (MR)**: MR combines elements of both VR and AR. MR places virtual objects in the real world and enables users to interact with them as if they were physically present. This is typically achieved using specialised headsets that incorporate sensors and cameras that scan the environment and track the user's movements, making digital objects appear to exist in the real world.

26. BLOCKCHAIN TECHNOLOGY

- Blockchain technology is a decentralised, distributed ledger that records transactions across a network (multiple computers) in a way that makes them tamper-resistant and transparent.
- At its core, a blockchain is a chain of blocks, where each block stores data or digital information. (**E.g.,** In the case of Bitcoin, a block stores a record of cryptocurrency transfer).
    - Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data.
    - Once a block is added to the chain, it is extremely difficult to alter, hence, ensuring the integrity of the data.
    - The transactions are verified and added to the block through a process called consensus (proof of stake), which involves a network of participants known as nodes, who collectively validate the transactions.



KEY FEATURES OF BLOCKCHAIN TECHNOLOGY

- **Decentralisation & transparency:** Blockchain operates on a peer-to-peer network, where each participant has a copy of the entire blockchain, ensuring transparency. All transactions recorded on a blockchain are visible to all participants in the network.
- **Security:** Blockchain technology utilises cryptography to secure transactions and control the transfer of assets. Each transaction is encrypted and linked to the previous transaction, forming a chain of blocks that cannot be easily altered.
- **Immutability:** Once a transaction is recorded on the blockchain, it is extremely difficult to change or delete. This immutability ensures the integrity of the data stored on the blockchain.
- **Smart Contracts:** Blockchain platforms often support the execution of smart contracts (self-executing contracts with predefined rules). Smart contracts automatically enforce the terms and conditions of an agreement, eliminating the need for intermediaries.

POTENTIAL APPLICATIONS OF BLOCKCHAIN

Originally introduced as the underlying technology behind the cryptocurrency Bitcoin, but its potential applications extend far beyond digital currencies.

- Transfer of land records (Property record management).
- Digital certificates management (Education, Death, Birth, Agreements, Sale Deeds)
- Pharmaceutical supply chain
- e-Notary service (Blockchain enabled e-Sign solution)
- Farm insurance
- Identity management

- Power distribution
- Duty payments
- Agriculture and other supply chains
- e-Voting
- Electronic Health Record Management
- Digital Evidence Management System
- Public Service Delivery
- IoT Device Management and Security
- Vehicle lifecycle administration
- Microfinance for Self-Help Groups

27. NON-FUNGIBLE TOKENS

- NFTs or non-fungible tokens are digital assets (often in the form of digital art, music, videos, or other digital content) based on blockchain technology.
- Each NFT is assigned a unique and unchangeable code stored on the blockchain, providing a clear record of ownership and verifying the authenticity of the associated digital asset.
- Each NFT is distinct and scarce and cannot be duplicated or forged. This uniqueness adds value to the digital asset.
- Many NFTs utilise smart contracts, self-executing contracts with the terms of the agreement directly written into code. These contracts automate processes like royalties, ensuring creators receive a percentage of future sales.

28. DECENTRALISED FINANCE (DeFi)

- An emerging concept that leverages blockchain technology to offer financial products and services without relying on traditional intermediaries like banks or brokerages.
- DeFi applications are built on blockchains and rely on smart contracts that automate financial transactions according to predetermined rules. This eliminates the need for a trusted third party.
- **DeFi offers a variety of financial services, including:**
  - Users can borrow or lend cryptocurrencies directly to each other.
  - Interest-bearing accounts where users can deposit their crypto assets and earn interest.
  - Peer-to-peer insurance products where users can pool funds to cover losses.

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5 CHAPTER FRONTIER TECHNOLOGIES

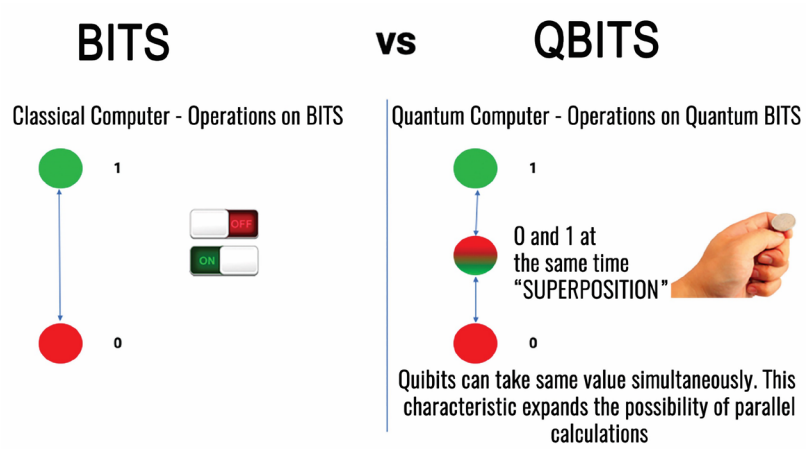
➔ QUANTUM TECHNOLOGIES

1. INTRODUCTION TO QUANTUM

Quantum Mechanics is a field of physics that describes the behaviour of matter and energy at the smallest scales, typically at the level of atoms and subatomic particles.

QUANTUM COMPUTERS AND QUBITS

- Quantum computers are machines that use the properties of quantum physics to store data and perform computations.
- While classical computers use bits as the basic unit of information, that is a two-state system that can represent either 0 or 1 at a time (they just act like a light bulb to represent ON/OFF), quantum computers use qubits which represent 0, 1 and an intermediate state (superposition of 0,1) in between.
- **A qubit can be:**
  - a particle — like an electron, photon (E.g., Linear optical quantum computing uses photons as qubits).
  - a collection/group of particles
  - any quantum system engineered to behave like a particle.
- Any particle that can be controlled and manipulated using quantum-mechanical phenomena can be used as a qubit. The information can be 'encoded' in some property of the particle (like an electron's spin) and then processed.
- The power of a quantum computer scales exponentially (2^N) with the number of qubits, unlike classical computers, which scale linearly with the number of bits.



- This enables quantum computers to perform complicated large-scale calculations out of the reach of the classical and even the best supercomputers.

2. QUANTUM PHENOMENON

Quantum Superposition:

- Qubits can simultaneously exist in more than one location or quantum state at one time while remaining as a single entity. Thus, superposition enables qubits to perform multiple operations simultaneously.

Quantum Entanglement:

- When two particles become entangled, the state of one particle becomes linked with the state of the other, regardless of the distance between them. This means that changes to the state of one particle instantaneously affects the state of the other.

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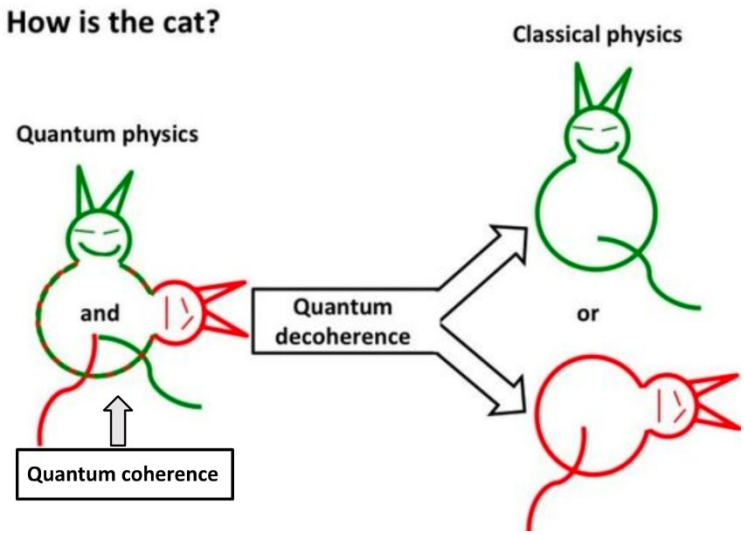
- Hence, measuring the state of one entangled particle instantly determines the state of its entangled partner, even if they are vast distances apart.
- So, entangled qubits in a quantum computer can be manipulated collectively, allowing for the parallel processing of information in a way that classical bits cannot achieve.



Quantum Coherence:

- Quantum mechanics allows qubits to exist in a superposition state, where they can be 0 and 1 simultaneously.
- Quantum coherence refers to the maintenance of the phase relationships between these superposed states, which is essential for performing calculations in quantum computers.

The Challenge:

- Qubits are very fragile and susceptible to decoherence (slight disturbances in the surroundings may result in a change of the quantum state of the particle and can result in a change of the information). Thus, maintaining quantum coherence is difficult.
- This fragility arises out of the interaction between qubit and their environment leading to decoherence.
- Decoherence can be caused by various factors, such as noise, heat, and measurement. It causes qubits to collapse into one of the two states and lose quantum information.
- Previously, quantum coherence could only be achieved at extremely low temperatures, around -196°C (liquid nitrogen temperature). This makes building practical quantum computers challenging.

Coherence at Room temperature:

- Recently, Researchers were able to achieve quantum coherence at room temperature by embedding a light-absorbing molecule called a chromophore within a metal-organic framework (MOF), using Zirconium as the metal component.
- The MOF's structure restricted the movement of the chromophore, minimising environmental disturbances. This allowed the chromophore to maintain quantum coherence for a brief period in the nanosecond range (billionths of a second) at room temperature.

Chromophore:

- A molecule in a given material that absorbs particular wavelengths of visible light, and emits colour as a result, and in doing so confers colour on the material.

Metal Organic Framework (MOF):

- A type of porous material that consists of a network of repeated molecular arrangements where the repeating structure has a metal atom or ion with organic molecules attached to its like tentacles. Each tentacle attaches to another metal atom and the structure repeats itself to make up the MOF.
- MOFs have various applications in fields such as gas storage, catalysis, and sensing, due to their high surface area, tunable structure, and functional properties.
- MOFs can also be used for quantum computing, as they can host qubits within their pores or on their surfaces.

Majorana Zero Modes

- Exotic quasiparticles (not fundamental particles like electrons) that arise in certain types of topological superconductors.
- They exhibit unique behaviour and possess topological degeneracy (inherent stability i.e, even if disturbed slightly, their overall quantum state remains unchanged, making them robust qubits for quantum computers).
- Traditional qubits (quantum bits) are prone to errors. However, Majorana zero modes offer a path to more stable and error-resistant qubits.

Quantum Supremacy:

- It is the point at which a quantum computer can complete a mathematical calculation that is beyond the reach of even the most powerful supercomputer.
- In 2019, Sycamore (Google's quantum computer) claimed 'supremacy' because it reportedly took 200 seconds to perform a calculation that the world's fastest supercomputer, Summit, would have taken 10,000 years to accomplish.

3. APPLICATIONS OF QUANTUM TECHNOLOGY

1. Quantum Computing:

- **Quantum Computers:** Building quantum computers to solve problems beyond the capabilities of classical and super computers.
- **Post-Quantum Cryptography**: Breaking current encryption methods and developing alternative cryptographic algorithms secure against attacks from quantum computers.

2. Quantum Simulation:

- **Drug Discovery:** Simulating complex molecules to design new drugs and materials with specific properties.
- **Materials Science:** New materials are being modelled for novel aeroplanes, automotive designs for better fuel efficiency, and aerodynamic properties.
- **Energy solutions:** Materials science simulating complex molecules to find new materials to develop safe and sustainable batteries and fuel cells.
- **Climate modelling:** Climate modelling enables meteorologists to better predict trajectories of hurricanes, winter storms, and other weather events.

3. Quantum Sensing:

- **Medical Imaging**: Developing highly sensitive MRI scanners for earlier disease detection and improved diagnostics.
- **Navigation Systems**: Creating next-generation navigation tools with exceptional precision and immunity to GPS disruption.
- **Weather forecasting:** Developing more accurate and long-term weather prediction models.
- **Materials Characterisation:** Analysing materials at the atomic level for a deeper understanding of their properties.

4. Quantum Communication

(i) Quantum Key Distribution

- QKD is a technology that uses the laws of quantum physics to distribute secure keys between two parties which prevent the decryption of data, and thus, ensure secure communication.
- QKD involves sending encrypted data as classical bits over networks, while the keys to decrypt the information are encoded and transmitted in a quantum state using qubits.

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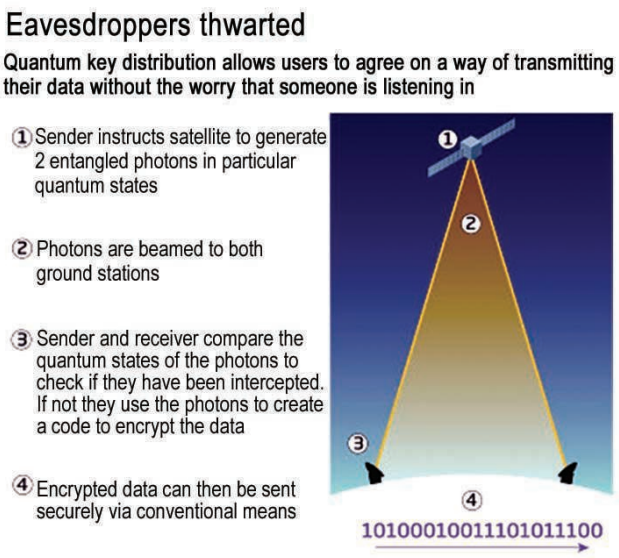
- A key feature of the technology is its ability to detect and mitigate interception. This is based on the fundamental law of quantum physics that observation itself disturbs the quantum state of a particle, i.e., if an eavesdropper tries to intercept the QKD signal, it will immediately change the signal's state. This makes the interception detectable and ensures any intercepted information is immediately discarded.
- QKD technology still faces some challenges, such as limited transmission distances (100-500 kms) due to decoherence and the high cost of specialised equipment.



(ii) Quantum Teleportation-based Communication

- Alternatively, a communication system can work by representing entire information using qubits of entangled photons instead of only the encryption key. The qubits may be instantaneously transferred owing to their entanglement.
- This instant transfer of "qubits" to send information is called "quantum teleportation".
- The entangled photons may also be used to send information through optical cables and received through a single-photon detector at the receiver end.

QUANTUM TELEPORTATION IN NEWS

NASA's quantum teleportation demonstration	NASA's jet propulsion laboratory has demonstrated 44 km teleportation of qubits of photons over a fibre-optic network and single-photon detectors.
Quantum Internet	• Future quantum internet is going to be built using communication links based on quantum teleportation. • Quantum internet would be able to transmit large volumes of data across immense distances at a rate that exceeds the speed of light. • It is said to be energy efficient because it does not involve transmission through electricity or light. • Quantum internet will be safe/tamper proof due to the interception-free nature of qubits.

4. NANOTECHNOLOGY

- Nanotechnology involves the manipulation and control of matter at the nanoscale, typically in the range of 1 to 100 nanometers. (1 nm = 10-9 metres)
- At the nanoscale, materials exhibit novel properties and behaviours that are different from their bulk counterparts.
- These properties arise due to increased surface area, quantum effects, and the interactions between atoms on the surface and those at the interface (where two different materials meet).
- Nanotechnology aims to harness these properties to develop new materials, devices, and applications with enhanced performance and functionality.

APPLICATIONS OF NANO TECHNOLOGY

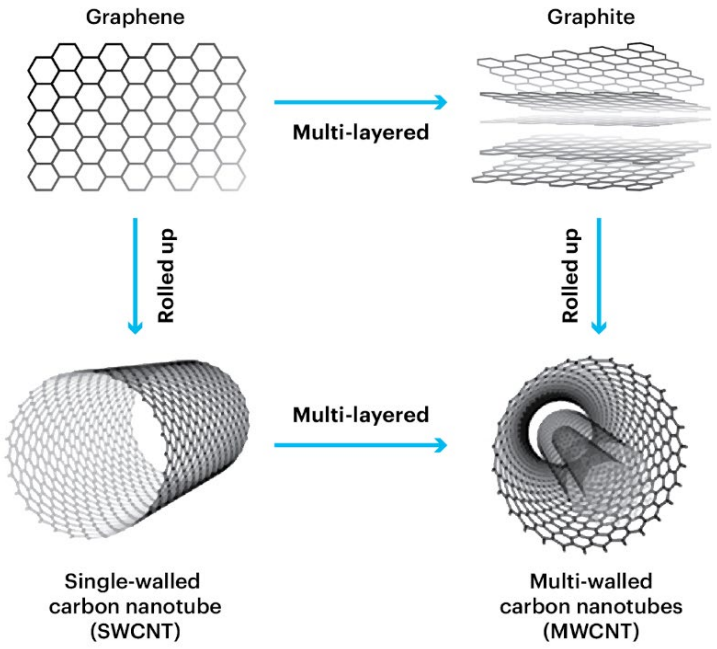
- **Medicine & Healthcare**: Drug delivery, bioimaging, diagnostics, antimicrobial coatings, cancer treatment.

- **Electronics**: Nanoelectronics, sensors, data storage devices, quantum dot displays.
- **Energy**: Solar cells, lithium-ion batteries, fuel additives, hydrogen generation and storage.
- **Automotive**: Fuel cells, lighter and stronger materials, advanced lubricants.
- **Aerospace**: Lighter and stronger composites, structural health monitoring.
- **Defence**: Lightweight soldier armour, surveillance, sensors, nano-coatings for equipment.
- **Environment:** Pollutant degradation, water treatment, nano-filtration, catalytic converters.
- **Agriculture**: Pesticides, fertilisers, pathogen detection, encapsulated agrochemicals.
- **Food & Packaging**: Antimicrobial films, nano-coatings with improved barrier properties, moisture control, and thermal stability.
- **Textiles**: Stain and wrinkle-resistant fabrics, lightweight protective clothing, moisture wicking.
- **Cosmetics**: UV protection in sunscreens, long-lasting colour pigments, anti-ageing creams.
- **Paints & Coatings**: Anti-corrosive coatings, thermal barrier coatings.

5. IMPORTANT NANOMATERIALAS

1. GRAPHENE

- An allotrope of carbon consisting of a single layer of Carbon atoms arranged in a two-dimensional hexagonal lattice.
- **Properties:**
  - Thinnest compound (one atom thick)
  - Lightest material known
  - Strongest material discovered (between 100-300 times stronger than steel) yet more flexible than rubber.
  - Best conductor of heat at room temperature and best conductor of electricity
  - Almost perfectly transparent as it absorbs only 2% of light.
  - Impermeable to gases, even those as light as hydrogen and helium.



Applications of Graphene:

- **Flexible Electronics**: Can be used in wearable electronics, flexible displays, electronic textiles, and bendable sensors.
- **Energy Storage**: Enhance performance and capacity of energy storage systems like supercapacitors and high-performance batteries.
- **Water purification**: Suitable for water filtration and desalination systems.
- **Bio-sensors:** To sense chemical and biological agents, explosives, radiation, and other hazardous substances.
- **Aerospace and Defence:** Develop lightweight, high-strength armour and ballistic protection. Have potential to absorb and dissipate electromagnetic waves, making it valuable for developing stealth coatings.

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- **Medical Applications:** Biosensing, bioimaging, targeted drug delivery, tissue engineering, phototherapy and cancer treatment. Has antibacterial properties.

2. CARBON NANOTUBES (CNTs)

- Graphene can be rolled up to form CNTs which are cylindrical in shape with diameter in nanoscale.
- **Properties:**
  - High tensile strength and light-weight
  - High electrical and thermal conductivity
  - Have large surface area and is chemically stable

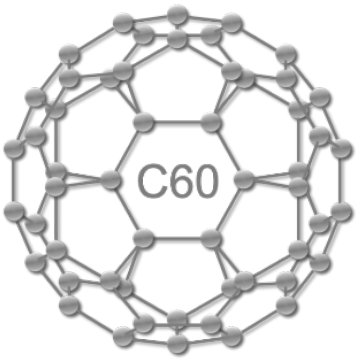
Applications of CNT:

- Applications in aerospace and automotive engineering.
- Electronic devices, such as transistors, high sensitivity sensors, solar cells, flexible electronics and touchscreens, organic light emitting diodes.
- Used in energy storage (electrodes for Lithium-Ion batteries, capacitors), drug storage and drug delivery.

Challenges:

- Impurities such as residual metal particles in CNTs.
- Processing & manufacturing of CNTs is challenging.

3. FULLERENE



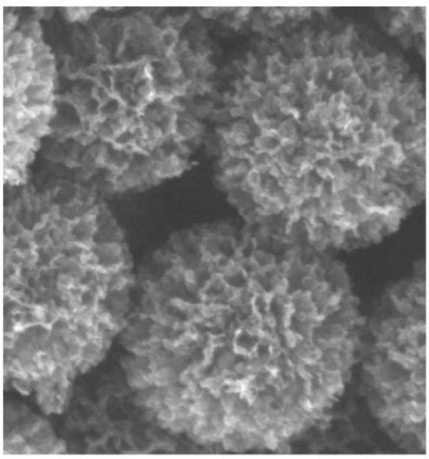
- Fullerene is a family of carbon allotropes that consists of cage-like or tubular structures.
- The most well-known fullerene is buckminsterfullerene (C60), which resembles a soccer ball with 60 carbon atoms forming pentagons and hexagons.
- Fullerenes, though not typically abundant, are found naturally in soot, volcanic eruptions, interstellar dust clouds and lightning strikes.

Applications of Fullerene:

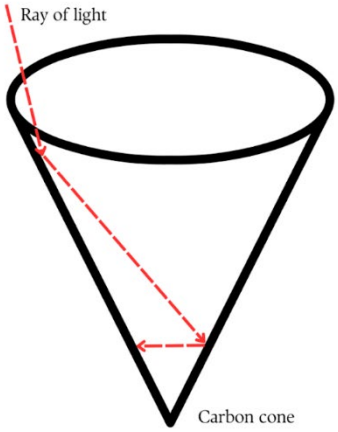
- **Electronics and Energy storage:** Can be used in organic photovoltaics (solar cells), organic light-emitting diodes and organic field-effect transistors.
- **Medicinal Chemistry:** Can act as antioxidants, scavenging free radicals, targeted drug delivery and imaging applications such as magnetic resonance imaging.
- **Catalysts:** Can act as catalyst supports in fuel cells and environmental remediation.
- **Water Purification**: Removal of pollutants and contaminants due to their adsorption and catalytic properties.

4. CARBON NANOFLORETS

- Unique nanostructure composed of carbon atoms arranged in a distinctive flower-like structure.
- They can absorb up to 87% of sunlight (infrared, visible, and ultraviolet light), and convert it into heat with exceptional efficiency, unlike traditional solar-thermal conversion materials that only absorb visible and ultraviolet light.
- Their cone-like shape minimises reflection allowing for maximum light absorption. Most of the light that falls on the material is reflected internally.
- **Applications:** Solar thermal applications such as water heating and desalination, heating homes, and sterilising surfaces in hospitals without relying on fossil fuels.



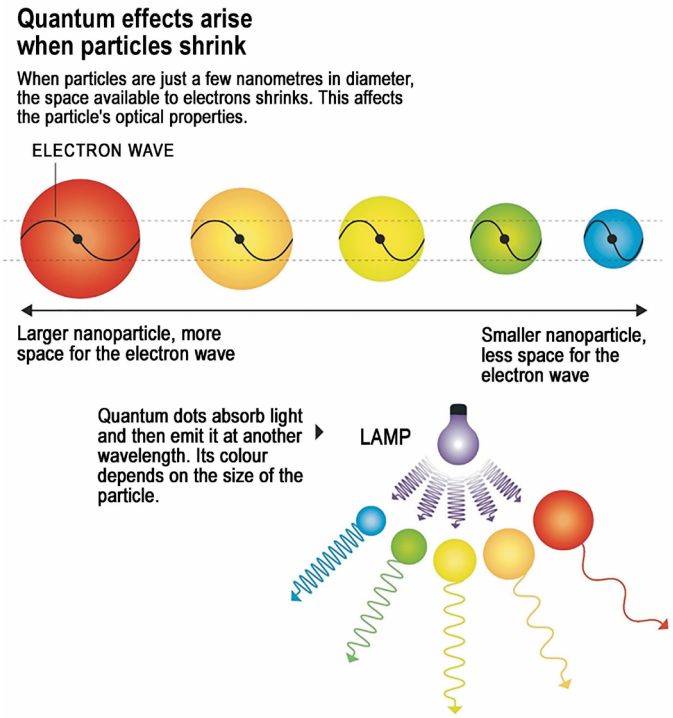
Carbon nanoflorets observed through a microscope. | Photo Credit: Ananya Sah



A simple schematic diagram showing the path of sunlight insight a carbon nanofloret. | Photo Credit: Sayantan Datta

5. QUANTUM DOTS (*NOBEL PRIZE IN CHEMISTRY 2023*)

- The 2023 Nobel Prize in Chemistry has been awarded to Alexei Ekimov, Louis Brus, and Moungi Bawendi for their work on Quantum dots.
- Quantum dots are tiny particles or nanocrystals of semiconducting material made from a semiconductor such as Silicon with a diameter in the range of 2–10 nm (10–50 atoms).
- They behave like artificial atoms, as they can have a fixed number of electrons in a confined space, leading to unique properties that are size-dependent. QDs exhibit special properties when they interact with light.
    - In general, the colour of any material depends on the wavelengths of the light spectrum absorbed or reflected by the material.
    - However, quantum dots made from the same material will re-emit/give out different colours of light depending on their size. (The biggest quantum dots produce the longest wavelengths, while the smallest dots make shorter wavelengths).



Applications of QDs:

- **Bioimaging**: QDs are 20 times brighter and 100 times more stable than traditional fluorescent dyes, are photostable and can be used in bioimaging.
- **Bio-sensors:** QD sensors can detect presence of pathogens in food or water, or monitor levels of pollutants in the environment.
- **Targeted Cancer treatment**: QDs exhibit specific opto-electronic properties which can be utilised for targeted cancer treatment. Because of their nano size; they possess large surface area ensuring higher drug loading capacity and can tag nanocarriers in biological systems.
- **Optical applications:** QLEDs are capable of emitting all colours depending on their size, thus, they provide high-definition, brighter and more colourful displays and efficient image sensors like CMOS sensors.
- **Flexible electronics:** Quantum-dot logic circuits layout building blocks for innovative devices, including printable electronics and flexible display screens.

6. Liquid Nano Urea

- IFFCO has entered a MoU with public sector fertiliser manufacturers National Fertilisers Limited and Rashtriya Chemicals and Fertilisers Ltd. for 'transfer of technology' aimed at increasing production of Liquid Nano Urea.
- Developed by IFFCO. India will be the first country to start commercial production of Liquid Nano Urea.
- Nanotechnology-based fertiliser contains Nano-scale nitrogen particles which have more surface area and number of particles, which make it more impactful.

Benefits of Nano Urea:

- As compared to conventional urea, uptake of Nano Urea is more than 80%. It is thus required in lesser amounts as compared to the conventional urea fertiliser to fulfil the plant's nitrogen requirement. Other benefits:
  - Cheaper than conventional urea
  - Easy to store
  - Reduced input costs to farmers
  - Easy to apply as Nano urea is directly sprayed on leaves (can be absorbed directly through the leaves' pores)
  - Reduced import of conventional urea saving precious foreign exchange.

7. NanoPtA

- A platinum-containing synthetic nanozyme that mimics the function of oxidases, natural enzymes that remove hydrogen from substrates in the presence of oxygen to form water.
- It can degrade pollutants in industrial wastewater by oxidising them in the presence of sunlight, reducing wastewater toxicity.
- It exhibits robustness and can withstand pH and temperature variations. It also exhibits impressive stability, lasting for up to 75 days at room temperature.
- It can oxidise neurotransmitters like dopamine and adrenaline, leading to a colour change in the solution, which can be used to measure their concentration. This holds potential for diagnosing neurodegenerative diseases like Parkinson's and Alzheimer's disease.

➔ MISCELLANEOUS

6. CRYOGENIC TECHNOLOGY

- Cryogenics is the study of the production and behaviour of materials at extremely low temperatures (below -150 degrees Celsius).
- The most common gases turned into liquid for cryogenics are Oxygen, Nitrogen, Hydrogen and Helium.

Potential Applications of Cryogenics:

- **Cryosurgery**: Cryogenic temperatures are used to kill unwanted or malignant tissues, such as cancer cells or moles.
- **Cryopreservation:** Preservation of organisms, tissue, and genetic material using cryopreservation. **E.g.**, Freezing of eggs and embryos for fertility preservation and research purposes, storage of vaccines, blood banking, food preservation.
- **Cryonics:** Cryopreservation of animals and humans with the goal of reviving them in the future.
- **Cryoelectronics:** Study of superconductivity, variable-range hopping, and other electronic phenomena at low temperature.
- **Cryoengines**: Rocket engine using cryogenic fuels, including liquid hydrogen and liquid oxygen.
- **Research:** Cryogenic technology is used in Nuclear magnetic resonance (NMR) to determine the chemical structure of a molecule.

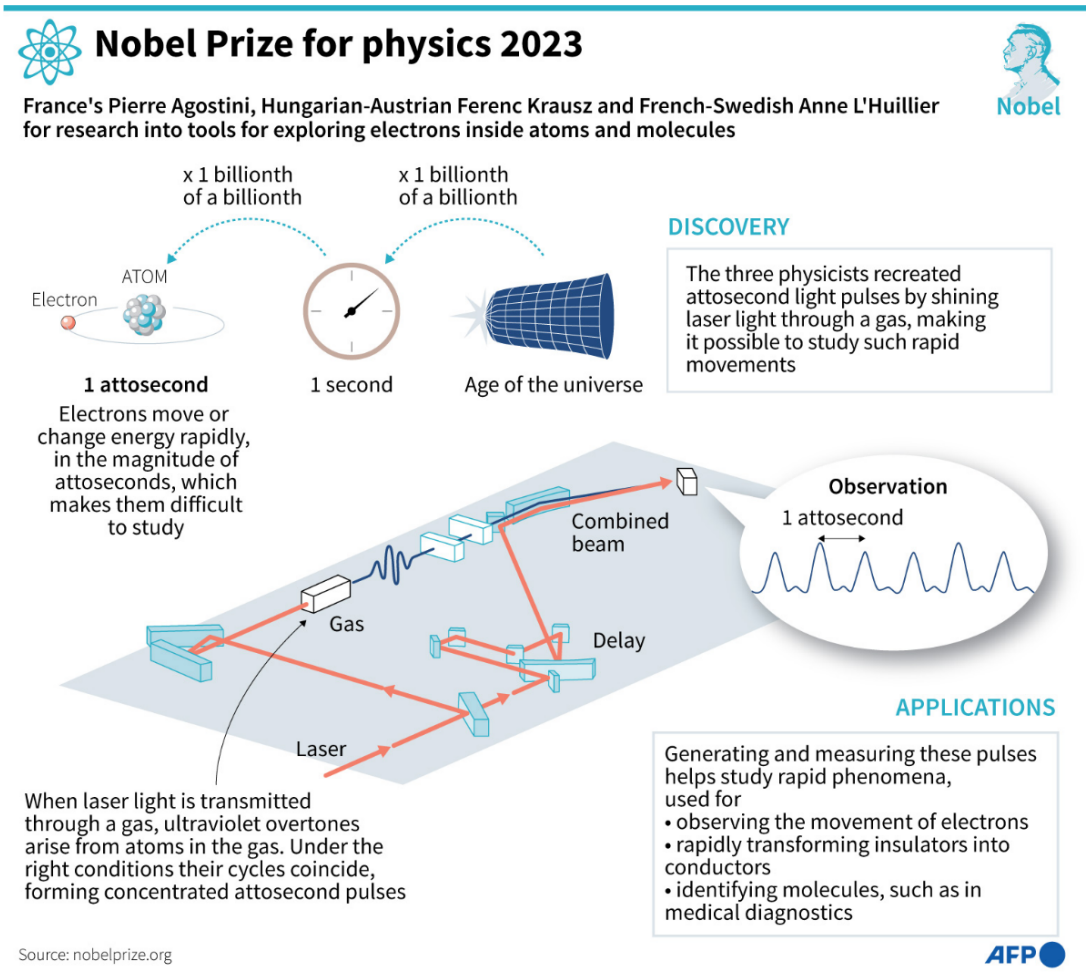
7. ATTOSECOND PULSES OF LIGHT (NOBEL PRIZE IN PHYSICS 2023)

- The 2023 Nobel Prize in Physics has been awarded to Pierre Agostini, Ferenc Krausz and Anne L'Huillier for experimental methods that generate attosecond pulses of light.

OBSERVING DYNAMICS AT THE SUBATOMIC LEVEL

- At atomic and subatomic levels, processes (movement of electrons, or energy dynamics) happen at an incredibly fast rate.
- To observe any process, the measurement must be made at a pace quicker than the rate of change.
  - **Femtosecond pulses** (10^{-15} seconds) enabled scientists to observe the processes happening at the **atomic or molecular level.**
  - **But at the sub-atomic level,** dynamics of sub-atomic particles happen even faster, at the level of attoseconds (10^{-18} seconds). **E.g.,** Dynamics of electrons are 100 to 1000 times faster than that of an atom. (Lower the inertia, faster the dynamics).
- The scientists devised experimental methods by mixing lights of different wavelengths to produce **attosecond pulses of light** (extremely short pulses of light that last 10^{-18} seconds).

These attosecond pulses can be used to observe electron movement within atoms and molecules, providing unprecedented insights into chemical reactions, energy transfer, and other fundamental processes.



POTENTIAL APPLICATIONS

- **Efficient electronics:** Observing the movement of electrons, and manipulating it to design more efficient electronic devices.
- **Advanced imaging:** New imaging methods with attosecond resolution, spectroscopy etc.

- **Medical diagnostics:** Attosecond pulses can be used to identify different molecules and study molecular-level changes in blood to identify diseases.

8. PIEZOELECTRIC EFFECT

- Piezoelectric effect is a phenomenon in which certain materials generate an electric charge in response to applied mechanical stress or pressure.
- The phenomenon can be observed in materials like quartz, topaz, tourmaline, ceramics such as lead zirconate titanate (PZT), and even in certain biological materials like bone and tendons.
- Some materials also display an inverse piezoelectric effect, where the application of an electric current induces a mechanical strain or deformation.
- **Applications:** Used in pressure sensors, accelerometers, acoustic devices, high voltage generators, electronic frequency generators, microbalances, inkjet printers, electronic stethoscopes.

9. RHODAMINE-B

- Rhodamine-B is a water soluble chemical compound or fluorescent xanthene dye which has various applications.
- It can cause serious environmental and health problems, including skin and eye irritation, stomach issues, breathing problems, organ damage, and an increased risk of cancer.'
- The chemical is considered substandard and unsafe under the Food Safety and Standards Act 2006.
- **Various applications include:**
  - Dyeing in textile, paper, paints, leathers etc., lends a vibrant pink hue.
  - Food dye (used in cotton candy to produce its iconic pink colour).
  - Used as a tracer dye, **E.g.,** to determine the rate and direction of water flow in rivers, lakes etc. Used to trace pollutants in water systems and indicate herbicide usage, or detect leaks in pipelines due to its high visibility and water solubility.
  - Rhodamine dyes exhibit fluorescence, and thus can be used in fluorescence microscopy, fluorescence correlation spectroscopy and ELISA (To detect the presence of specific molecules like proteins or antibodies).
  - Laser Dyes employed in scientific and medical lasers.

10. THALLIUM

- Thallium is a highly toxic metal that is an abundant element on the Earth's crust.
- It does not exist in free elemental form in nature, and exists in the form of ores with other elements, mostly potassium.
- Thallium compounds are tasteless, odourless, and colourless, which makes it particularly dangerous for human consumption.
- Thallium poisoning can occur through various routes, including ingestion, inhalation, or skin contact with thallium compounds.
- **Applications**:
  - Widely used in making various electronics, such as, photoresistor, rectifier, detectors in infrared devices and in gamma radiation detection devices.
  - Used in the pharmaceutical industry to make various drugs and medicines. Radioactive isotope Thallium-201 is used for nuclear medicine scan.

11. SLAG

- Slag is a by-product generated during manufacturing of pig iron and steel. Primarily, slag consists of calcium, magnesium, manganese and aluminium silicates and oxides in various combinations.

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- Among all the solid/liquid wastes, slag is generated at such large quantities that management of slag has become a critical component of steel production.
- **Potential Applications:**
  - Used mainly as road metal and bases, asphalt paving, track ballast, landfills and aggregate for concrete.
  - Used for soil conditioning as fertiliser and liming agent in agriculture due to presence of CaO content.
  - Used in making mineral wool for insulation purposes.
  - Barrier material remedy for waste sites where heavy metals tend to leach into the surrounding environment.
  - Used to filter and remove contaminants from water and treat acidic water discharges from abandoned mines.

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6 CHAPTER ENERGY TECHNOLOGY

1. INTRODUCTION TO ENERGY

There are many ways of looking energy. One way is to go back to the root word. Energy is derived from the words 'En' and 'Ergon': meaning 'in' and 'work'. Thus, energy is something that has work in it. Also 'energos' means 'activity.

DIFFERENT DIMENSIONS OF ENERGY

Energy characterizes life and non-life

- Energy is also one basis upon which life and non-life are characterised.
- The ability to make an 'effort' differentiates life and non-life.
- To make an effort, life requires energy. Thus, life is something that utilizes energy to do some work.
- In other words, energy is expended to do work. The rate at which the energy is expended is called 'power'.

Energy as the capacity to do work

- Another way of looking at energy is the state of orderliness and disorderliness in nature.
- Those things in nature, which have in them unused energy, are in a state of orderliness. Eg: Fuels which are energy stores are in a state of orderliness.
- Those things in nature that do not have unused energy are in a state of disorderliness. Eg: Heat that is released upon burning of fuel is in a state of disorderliness.
- Fancy names for orderliness and disorderliness are negentropy and entropy respectively.
- If left to itself orderliness in nature always decays into a state of disorderliness. (**2nd law of thermodynamics**)
- However, in the journey of moving from orderliness to disorderliness, we can extract some orderliness. This is what energy is and can be used to do work. That is why energy is the capacity to do work.
- **Illustration**: burning a fuel(orderliness) gives heat (disorderliness). A part of this heat (disorderliness) can be converted to mechanical motion of the turbine(orderliness). Note there is a limit to which you can reverse the process of orderliness changing to disorderliness. This is called the efficiency of any system.
- Thus, Sun is a store of orderliness, plants through photosynthesis take a part of this orderliness and store in the chemicals it makes (primarily carbon, hydrogen and oxygen). Animals use the energy store of plants to do some work and store some for later use. In all these systems major part of orderliness is lost. (plants can take only 0.5% of sunlight(orderliness) and store it in chemicals(starch) and animals can use only a part of this and so on)
- In short, the **amount of usable 'energy' goes on reducing** from **Sunlight→ Photosynthesis → Plants → Animals.**
- Further plants and animals when buried under earth's crust for millions of years become fossil fuels which are simply stores of energy that was stored in them long ago.
- These stores of energy can be used to do some work which is what we do when we burn coal or petrol.

→ FOSSILS AS ENERGY STORES

Fossils are simply store of orderliness that was saved by plants and animal millions of years ago and therefore source of energy. This energy is converted to heat (high-entropy) which in turn is converted to mechanical and electrical energy (low entropy) which will do work.

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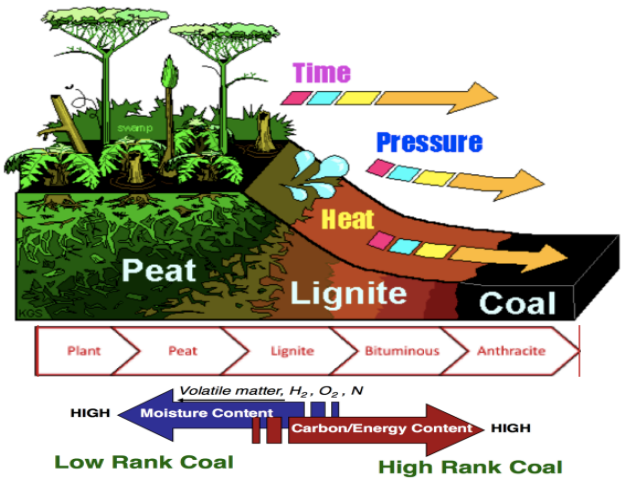
2. COALIFICATION

- Coal is simply old plants buried inside earth for millions of years to become a rock (sedimentary). The elemental composition of the plants, which includes carbon, hydrogen, and oxygen, transforms into coal over time. This transformation occurs in the absence of oxygen.
- With time, plant loses its oxygen and water content. The longer the coal is underground, the more concentrated the hydrocarbons become, resulting in a higher quality fuel.
- Accordingly, coal is classified peat, lignite, bituminous, and anthracite, with anthracite being the highest quality and most valuable type of coal. See table below for details.



Plant	Peat	Lignite	Sub-bituminous	Bituminous	Anthracite	
Carbon Content		25-35	35-45%	45-85	85-96	Increasing Heating Value
Moisture				High	Low	Decreasing Moisture Content
Ash		10-40%	<10%	3-12%	10-20%	
				Soft Coal	Hard Coal	
				Most commonly found Used for power generation	Formed in Mountains Used mainly for manufacturing Coke Low smoke content Burns slowly	
Sulphur				0.7-4%	<1%	

COMPOSITION

- Coal or any hydrocarbon is primarily made of carbon, hydrogen oxygen. In addition, since they are just old plant matter, they should contain some nitrogen, sulphur and phosphorous. (remember all life is made of CNOS majorly)
- In addition, there is some moisture, heavy elements as they are buried deep.
- Carbon, hydrogen and oxygen are all combustible. Meaning when they mix with oxygen, they release some heat. This is the heat we are all interested in to do work in the powerplant.
- Note that even oxygen is combustible, but the proportion is so low we don't bother.

- Note its carbon and hydrogen that decides the amount of heat we can generate. If you look at chemical composition, it is C137H97O9NS for bituminous coal and C240H90O4NS for anthracite. (You don't need to remember the numbers its only for you to know why anthracite is better)

BURNING AND COMBUSTION

- What do mean by burning and combustion?
- Burning of any fuel simply means you are adding heat to break the bonds between carbon and hydrogen.
- Once you do that you add oxygen(air) in order for carbon and hydrogen to combine with. This gives oxides of carbon and hydrogen and in the process give out heat. (you always add heat to break the bonds and you always get heat when bonds are made)

BURNING OF COAL: STEPS

- Coal when burnt, 1st thing that comes out is water. As dug from the ground coal has some amount of moisture.
- At slightly above 1000C (boiling point of water) causes water to evaporate leading to loss of weight.
- The left-over dry coal is further heated but now in the absence of air (we don't want burning). The matter that comes out is called volatile matter.
- Note that volatile matter is also hydrocarbon (aromatic rings) that evaporates when heated in the absence of oxygen.
- The left-over coal is called fixed carbon which is what we "burn" in coal plants.
- The carbon content now ranges from 50% to about 95%.
- Now we burn this fixed carbon coal in presence of oxygen to derive useful heat.
- After all carbon and hydrogen is 'burnt', the left-over non-combustible solid matter is called ash.
- Ash is simply left-over incombustible solid made of inorganic contents. This is the main useless and hence undesirable thing in solid fuels in general. (more on this later)

PROCESS OF BURNING

- In coal-fired plant fuel is coal and source of oxygen is air
- Complete combustion (allow all coal to burn in air)
- Coal + Oxygen -----> Carbon dioxide + other gases (mixture is called flue gas)
- 1 gram of Carbon -----> 3.6 gram of CO_2 and 9 gm of N_2
- Incomplete combustion (don't allow all coal to burn by restricting the supply of air)
- Carbon + Oxygen -----> Carbon Monoxide (if you add more air it can 'combust')
- 1 gram of Carbon ----> 4.5 g of CO and 5.5 g of N_2

CHALLENGES RELATED TO BURNING OF COAL

Thermal pollution

- The efficiency of coal-fired power plants is around 35%, meaning only 35% heat that is generated out of coal-burning is usable. Rest will go out to the atmosphere. In other words, for every 1000 MW of power produced 1500 MW of heat is wasted.

Carbon Emissions

- 1 gm of carbon burnt produces 3.5 g of CO_2. A coal plant that produces 1GW of electricity emits 1 ton of carbon dioxide every 2 seconds.
- Solution: Carbon Capture and Storage

Air pollutants

Three potential pollutants are formed when coal is burnt; sulphur oxides, nitrogen oxides and fly ash.

Nitrogen

- Normally nitrogen is very stable and burns only at high temperatures. At high temperatures when nitrogen reacts with oxygen it forms oxides of nitrogen. This is very harmful as it acts as nuclei for fine dust causing PM pollution.
- **Solution:** Remove nitrogen, reduce temperature of combustion

Sulphur

- Sulphur is of special interest again because it is a potential air pollutant. In addition, oxides of sulphur act as condensation nuclei during cloud formation leading to acid rain.
- Solution: desulphurization

Ash, mainly fly ash

- Left-over solid inorganic matter after burning of coal. (highest is bituminous)
- It can be collected at the bottom from where it can be removed.
- However, the problem is when the turbulent stream of gases in the boiler sweeps some of the ash out of the boiler along with flue gas. This is called *fly ash*.
- A 2016 report by IIT Kanpur says about 37% of PM 10 and 26% of PM 2.5 is caused by fly ash from coal plants.

> **India's fly ash problem needs government intervention**
>
> An IIT-Kanpur study on Delhi revealed fly ash as one of the major contributors to particulate matter (PM) contributing around 37% and 26% of...
>
> 27-Jun-2021

Coke (Carbon + Ash)

- Solid carbonaceous residue derived from low-ash, low-sulfur bituminous coal from which the volatile constituents are driven off by baking in an oven without oxygen at temperatures as high as 1,000 °C so that the fixed carbon & residual ash are fused together.
- Coke is used as a fuel & as a reducing agent in smelting iron ore in a blast furnace.
- Coke from coal is grey, hard, & porous & has a heating value of 29.6 MJ/kg
- Byproducts of this conversion of coal to coke include coal tar, ammonia, light oils, and "coal-gas".

3. WAYS TO CLEAN COAL

FLY ASH

ELECTROSTATIC PRECIPITATORS

- Fly Ash at exhaust can be dealt with using electrostatic precipitators. Simply charge metal plates to high voltage. The negatively charged plate will attract the particles and remove them from flue gas.
- Bottom ash
- The ash so collected are usually mixed with water and left to ponds nearby. But the problem with this is
  - In wet season the soluble contents of ash seeps into the ground and pollutes ground water.
  - In dry season, ash ponds dry up and ash flies off as fly ash.
- **Solution:**
  - Use bottom ash to make bricks.

FLUE-GAS DESULPHURISATION

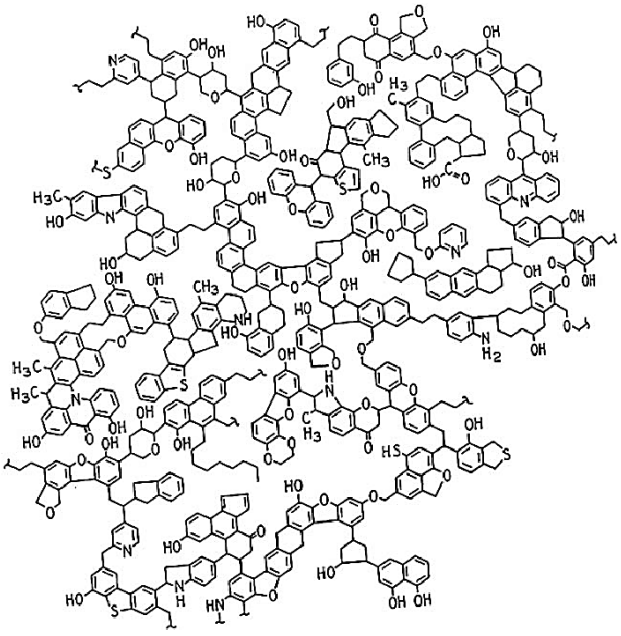
- Sulphur dioxide is acidic in nature, thus spray the exhaust gas(flue gas) with limestone/soap or anything that is basic in nature (sodium hydroxide, lime, sodium sulfite, ammonia).
- In 2015, Ministry of Environment, Forest and Climate Change issued notification to regulate emissions from coal-based power plants and set deadline of 2017 for flue-gas desulphurisation.

- However, the deadlines have been missed repeatedly leading to pushing of deadlines to 2024 for coal plants near Delhi, 2026 for other coal plants.

4. COAL CONVERSIONS

NEED FOR COAL CONVERSION

- Coal is basically a complex molecule that is made of long chains of hydrocarbons arranged in the form of rings. (see figure).
- As a result, it takes a lot of heat to burn coal and in-turn lot of heat is released when carbon in coal oxidizes with air.
- As a result, the temperature in a coal power plant is extremely high which leads to two problems a) thermal pollution and b) oxides of nitrogen are formed. (remember otherwise stable nitrogen, oxidizes at very high temperatures)
- In addition, burning of coal as in case of any solid fuel leaves solid residue like ash.
- In order to tackle all these issues coal conversion is resorted to.
- Coal conversion simply means converting combustible solids (coal) to combustible liquids or combustible gases.
- Accordingly, coal conversions include liquefaction and gasification.



5. GASIFICATION OF COAL

- While the goal of combustion is to produce the maximum amount of heat possible by oxidizing all the combustible material, the goal of gasification is to convert most of the combustible solids into combustible gases such as carbon monoxide, hydrogen, and methane.
- See how this works.

COAL GAS/PRODUCER GAS

- Burn coal with air: complete combustion ----> CO_2
- Burn coal with controlled oxygen: incomplete combustion ----> [CO + N_2]. This is called coal gas or producer gas.

India's first coal gasification based fertiliser plant on track

Outbreak of Covid-19 pandemic notwithstanding, India's first coal gasification-based fertiliser plant at Talcher is on schedule.

Published: 10th January 2021 04:35 AM | Last Updated: 10th January 2021 08:51 AM

Advantage

- Fly Ash is absent.
- Less NO_x formation due to low temperature of incomplete burning
- Carbon sequestration is easy (easy to remove nitrogen from flue gas as compared to oxides of nitrogen)

SYN GAS

- Alternately burn Coal with Steam -----> CO + H_2 (Synthesis Gas/Syngas)
- Aptly this is called steam reforming.
- You can make variety of things using Syngas like Methanol, Hydrogen, Methane (methanation).
- Syngas can be used to make **ammonia-based fertilizer.**

- N2(g) + 3 H2(g) -----> 2 NH3(g)

Advantage

- Reduced CO2 emissions.
- Syngas is combustible.
- NOx is not formed.
- Fly Ash is absent.


India to divert 100mn t coal to gasification projects

Published date: 01 September 2020

Share:

India is aiming to convert 100mn t of thermal coal into synthetic natural gas and chemical products in the coming decade, as part of its broader push to promote cleaner sources of energy.

Syngas can be used to make methane in a process called **Methanation/ Hydrogasification**

- $CO+3H_2$----->$CH_4 + H_2O$

Advantage:

- CH4 is combustible.
- CO2 is not produced.

6. LIQUEFACTION OF COAL

- In liquefaction the trick is to break the long chains of hydrocarbon rings and add hydrogen at high pressure.
- Depending on the type of coal used we get various coal liquids like gas oil, gasoline, kerosene.
- Note that the main difference between coal and petroleum products is the size of hydrocarbon molecule. (coal is long chain with 140-250 carbon atoms, petrol has 4-10, diesel has 8-14)
- The main advantage is low-quality coal is easy to liquify.

Advantage

- Heating value is doubled (because C-H ratio is increased)
- CO2 emissions are reduced.
- Fly Ash is absent.
- Since Indian coal is low in sulphur, methanol when used in vehicles can reduce SOX and NOX emissions and hence low PM pollution,

METHANOL

- Another approach to make liquid fuel is compress the syn gas obtained from gasification process. The mixture of CO and H2 is adjusted in its pressure and temperature to form methanol. (CH3OH)
- CO(g) + 2 H_2(g) ----> CH_3OH(l)
- Methanol is also called wood alcohol. (More on methanol in Gas-to-liquid alternative under transportation fuels)

7. COAL BURNING AND CCUS: COMBINATION TO COMBAT CLIMATE CHANGE

- By burning fossil fuels, we are essentially taking out carbon buried under the earth surface and putting it in the atmosphere. This has increased CO2 content in the atmosphere by more than 415 ppm (parts per million) as of 2020.
- And this is ever-increasing at the rate of 2 ppm.


Carbon capture and coal gasification can be a game changer for India

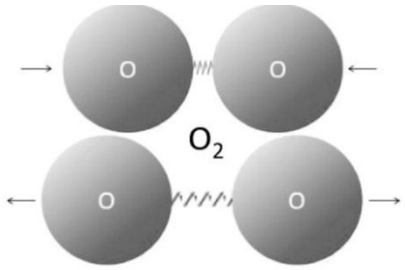
Gasification with CCUS needs to be engineered and applied in a way which preserves the economics, growth, quality, and scale of operation of the industrial economy

Atanu Mukherjee • Mar 12, 2019, 03.24 PM IST

- Coal, being carbon-heavy (150-240 carbon atoms), should always accompany CCUS technologies to achieve net-zero emissions. (see news headlines in the recent times)

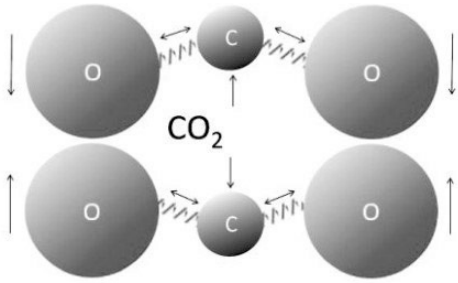
GREENHOUSE EFFECT

- Anything that has a temperature vibrates. In fact at the molecular level temperature is simply how fast the molecules are shaking (kinetic energy).
- When temperature is zero the molecules are simply not shaking. This is absolute zero or 0 Kelvin.
- Further atoms of molecules shake differently. Molecules made of 2 atoms like O2 or N2 shake due to stretching to-and-fro. (see figure)
- On the other hand molecules with 3 or more atoms (like CO2, CH4) shake due to stretching and bending.



Oxygen: stretching vibrations only

- Further the shaking due to bending matches the frequency of infrared radiation. (which is also vibration really)
- Because frequencies of visible light from the sun don't match the shaking of atmospheric gases (O2 and N2), or the GHGs, light passes through our atmosphere without being absorbed.
- However, since the frequency of infrared radiation from earth surface matches the bending-vibration of the GHGs, they interact with GHGs.
- This interaction shakes the GHG molecules thereby warming these molecules.
- The vigorously shaking GHG molecules then shakes the surrounding air molecules thereby increasing its temperature.



Carbon dioxide: stretching and bending vibrations

GHGs capable of trapping the heat include

- CO_2: Most significant
- CH_4: Methane: More potent as it traps more heat.
- Other GHGs include nitrous oxide(N_2O), ozone (O), chlorofluorocarbons, water vapour.

8. CCUS TECHNOLOGIES: CARBON CAPTURE UTILIZATION AND STORAGE

- In January 2018 IPCC said the world should emit not more than 420 gigatonnes of carbon dioxide to have a 67% chance of avoiding a rise of 1.5 degrees.
- Today that figure is down to less than 350 gigatonnes and global emissions are running at around 40 gigatonnes each year.
- This means we need to achieve zero global emissions(net-zero) by 2030–35 to keep total heating below 1.5 degrees, and 2040–50 for a 2-degree target.

NITI Aayog releases study report on 'Carbon Capture, Utilisation, and Storage (CCUS) Policy Framework and its Deployment Mechanism in India'

Posted On: 29 NOV 2022 8:59PM by PIB Delhi

- Thus, low-carbon future essentially includes, as its important component, CCUS technologies which essentially reverses the process of taking the underground carbon (fossils) and putting it into atmosphere (in the form of CO_2).
- In simple terms CCUS involves capturing the CO_2 that is released in burning of fossils, compressing, liquefying, and storing underground.
- Alternately CCUS includes converting CO2-forming fuels and converting them into chemicals that form less CO2. Examples include coal-to-products like syngas, producer gas, methanol, di-methyl ether etc.

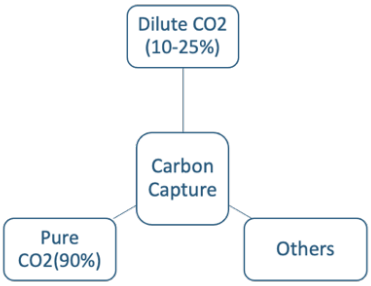
- CCUS is going to be an important component in hard-to-abate (CO2) sectors like power plants, petroleum refineries, fertilizers, cement, steel industries, etc

9. CARBON CAPTURE

- The flue gas that comes out of coal-fired power plants is mixture of gases.
- It typically constitutes carbon dioxide (~10%), nitrogen (70-80%), oxygen (1-10%), water vapor, Sulphur dioxide, NOx including nitrogen dioxide and nitrogen monoxide.
- Essentially flue gas is very dilute CO2.
- While we treat SOX and NOX using the processes described above, to arrest, capturing and storing carbon dioxide is a big challenge.
- Now this is because the principal component of flue gas is nitrogen. The 'effort'/'cost'(basically energy) used in capturing and storing flue gas goes higher if we dint purify it.
- Thus, carbon capture is all about purifying flue gas to separate CO2 and Nitrogen.
- Note the nitrogen so separated can be allowed to mix in atmosphere as it is stable and thus safe. It is the oxides of nitrogen that is a problem which we have already dealt with. (anyway air is majorly composed of Nitrogen)
- Thus, carbon capture is really a misnomer, it should have been called carbon purification/ flue gas purification.
- There are different strategies for carbon purification. These include,
  1. Post-combustion
  2. Pre-combustion
  3. Oxy-fuel combustion

10. POST-COMBUSTION CARBON CAPTURE

- As the name suggests the separation of CO_2 and nitrogen is done after the combustion of fuel.
- In other words, under post-combustion carbon capture, we simply treating the flue gas to get purified CO_2.
- The simplest way of doing this is to stream the flue gas, at the exhaust, into a solution containing ammonia salts.
- While the CO_2 in flue gas reacts with the ammonia, the nitrogen floats upwards. You have separated CO2 and nitrogen.
- Now CO_2 dissolved in ammonia solution should be extracted.
- This can be done by passing very hot steam through the solution which heats the solution and drives off pure CO_2. The CO_2 is then compressed, liquefied, and sent to underground storage.



Advantage

- Retrofitting is possible.

Disadvantage

- The very hot steam needed to separate CO2 from dissolved ammonia solution requires energy.
- The energy required to do this is about 25% of the energy produced in a coal plant.
- Thus, post-combustion method reduces the efficiency of coal plants from 34% to 25%.
- Expensive

11. PRE-COMBUSTION CARBON CAPTURE

- Here the trick is to convert combustible solids to combustible gases (same as gasification we discussed above).
- Thus, these plants are also called integrated gasification combined cycle (IGCC) power plants.
- This can be done either through steam reforming or through controlled oxygen combustion.

- In both these processes coal is converted to carbon monoxide.
- The carbon monoxide so obtained is treated again with hot steam before combustion.
- The water molecules in the steam splits into hydrogen and oxygen.
- The hydrogen from steam and from coal are mixed and the gas is burnt.
- The oxygen reacts with the CO to form CO2, which is then easily separated, compressed, liquefied, and pumped underground.

Advantage

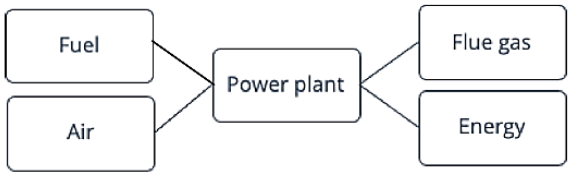
- Reduces efficiency of coal plant by 15% compared to 25% in post-combustion technique.

Disadvantage

- Expensive

12. OXY-FUEL COMBUSTION

- Now we know the input in powerplants are fuel and oxygen and output is energy and flue gas. The concern, from carbon emissions point of view, is the nitrogen in the flue gas. And the source of this nitrogen is the air in the input.
- So, one way is to purify the air before combustion to remove nitrogen.
- We are now left with oxygen which is what we need for combustion.
- Since we are purifying air at source before combustion the technique is called oxy-fuel combustion.



- In order to purify air, it has to be chilled to -200°c at which point it becomes a liquid.
- This liquid air is then gradually warmed until the nitrogen boils off, leaving nearly pure liquid oxygen.

13. CARBON STORAGE

- Now that we have dealt with the purification part or carbon capture part, we need to find a place to store the captured CO_2.
- Normally the CO_2 so captured is compressed, liquified and pumped to the place where it is stored.
- Various strategies to store CO2 include

14. GEOSEQUESTRATION

- Pressurize the CO2 and put it beneath the earth surface. There are different strategies depending on where below the earth surface you pump and store the CO2.

15. ENHANCED OIL RECOVERY (EOR)

- Under this technique carbon dioxide is reinjected into depleted gas and oil fields. These oil and gas wells have some un-extracted oil and gas left deep below which was not commercially viable to extract.
- The injected-CO2 provides extra pressure, helping to push more of the oil and gas from below.

Advantage:

- Getting oil and gas out of the process is an economic incentive.

Disadvantage:

- Extracting hydrocarbon through carbon capture and storage is paradoxical.

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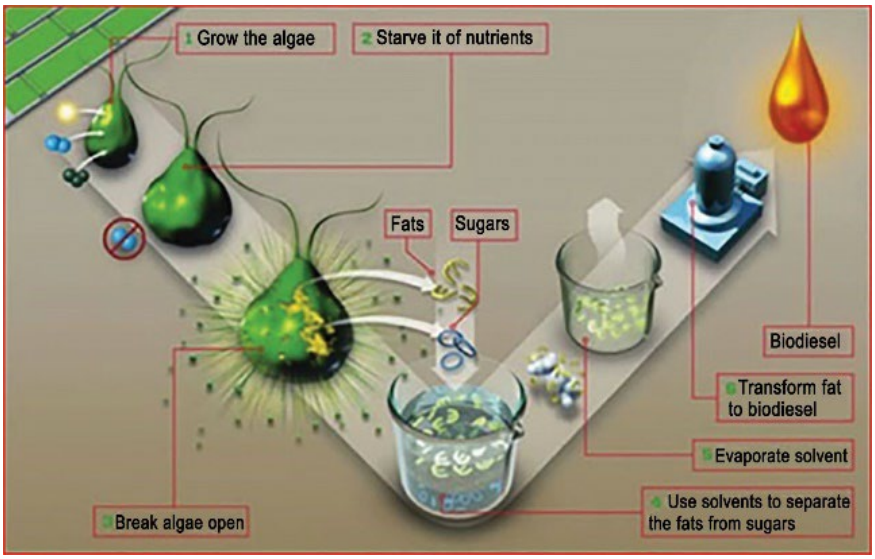
16. SALINE AQUIFERS

- Brine or salty water sits in some rocks which are porous in nature. Since the water has too much salt here it not useful for drinking or irrigation, you don't lose anything by storing the unwanted gas.
- CO2, so injected will dissolve in the water, forming carbonic acid which then combines with minerals in the rock to form stable carbonates, locking up the carbon dioxide forever.

17. DIRECT CAPTURE BY ALGAE

Additionally, CO_2 can be directly captured just like what happens in nature. There are 3 strategies to directly capture CO_2.

ALGAE



- While most plants are very inefficient in photosynthesis (only 0.5% of sunlight is captured), algae have very high photosynthetic efficiency capable of growing very fast capturing the CO2 from atmosphere.
- The flue gases from power plant can be bubbled through water and algae.
- Algae extracts large amounts of the carbon dioxide to feed their growth and very little is left to emit to the open air.
- The so grown algae can be used as input for producing biodiesel (like vegetable oils).

Advantage

- Biodiesel has no sulphur thus produce no SOX emissions.
- Algae-based biodiesel represents net-zero fuel as the CO2 at the exhaust out of biodiesel-run vehicle is nothing but CO2 captured by algae from the atmosphere.

18. CARBON CAPTURE IN SOILS AND VEGETATION

CHARCOAL OR BIOCHAR

- Charcoal or Biochar is made by partially burning wood or plant matter like coconut husk. It consists of extremely stable and pure carbon.
- Essentially burning wood partially involves restricting the air flow thereby depriving oxygen supply and thus keeping the temperature low.
- The unburnt charcoal can store carbon for centuries.
- Thus, if we make charcoal from wood and then dig it into the soil, we are sequestering carbon from the atmosphere.
- When mixed with soil biochar can significantly improve fertility of the soil as biochar is highly porous which enables it to retain nutrients and encourages growth of beneficial microfungi.

19. CARBON SINKS

Soil and forests act as the most efficient sinks of carbon from atmosphere.

SOIL

- Soils are the storehouse of carbon. It holds twice as much carbon as does atmosphere and about 1 trillion tons more than the world's plants do.
- Carbon cycle broadly involves movement of carbon in various forms from soil to air to plant and vice-versa.
- The amount of carbon flowing in and out of soils in the natural cycle is about 10-20 times the volume put in the atmosphere by the burning of fossil fuels.
- The effect of global warming is that it speeds up rate of chemical reaction leading to carbon emissions from soil at a faster rate. (above 250 C soil carbon losses are rapid)
- In addition, land-use change has led to degradation of soil.
- Industrial meat requires heavily fed cattle which consume 35% of world's cereal.
- Growing crops for fuels (biofuel) are yet another source of soil degradation.

Following are the farming practices that help soil restore and retain carbon

ZERO-TILL FARMING

- Basic principle is that ploughing is counterproductive because it reduces the carbon content in soil. So, disturb the soil as little as possible.
- Under this technique we plant the seeds along with fertilizer in a row.
- As soon as the main crop is harvested, a second crop is planted as a cover for the soil preventing erosion.
- This cover crop acts as manure when they are dead
- This acts as a rich source of organic material that earthworms can use to improve the quality of the lower soil.
- The following year, no fertilizers are used. Instead the seeds are planted through this green manure.
- Besides varying the 2nd crop regularly prevents the accumulation of pests and diseases.

Disadvantage

- The only problem is in the absence of ploughing, weed growth cannot be arrested. (basic purpose of ploughing)
- Thus, either we have to use large amounts of herbicide to control weed growth or grow GM crops.

FOREST

- Wood is approximately 50% carbon.
- When forest is lost for wood and this wood is burnt carbon is put in the atmosphere
- Deforestation accounts for more than 15% carbon emissions.
- Wood is largely used as cooking fuel. The solution therefore is alternative cooking fuel.
- Alternative cooking techniques include solar cookers and biogas collectors. This is the reason India has stepped up efforts to produce compressed biogas.

COMPRESSED BIOGAS

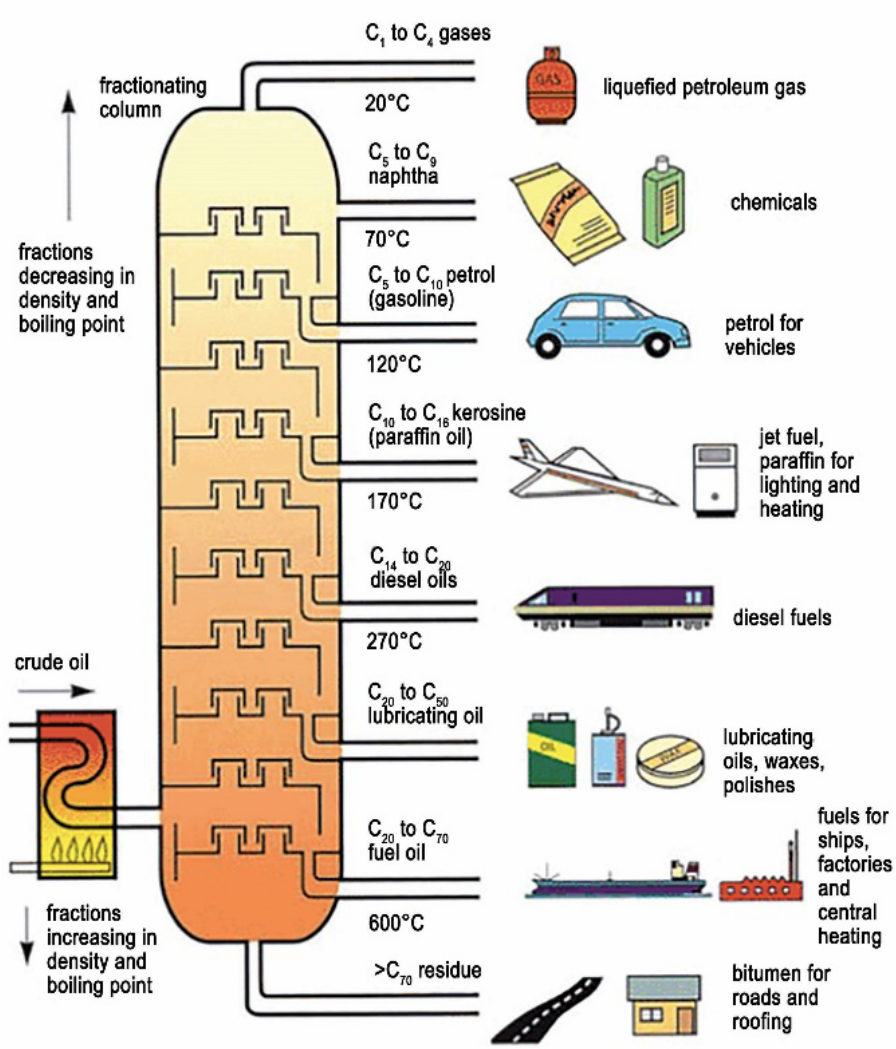
- Input (feedstock) can be any organic waste including agri-waste, rotten human and animal waste that essentially gives off methane (Bio-CNG)
- The recent budget has earmarked Rs 10,000 crore under the **GOBAR-Dhan scheme** (Galvanizing Organic Bio-Agro Resources- Dhan) for setting up 500 new 'waste to wealth' plants.
- Around 200 compressed bio-gas plants and 300 community and cluster-based plants are planned to be set up.
- Bio-CNG, in purified form (98% methane) can be used as both cooking and transportation fuel.
- Only thing is it pressurised to around 250-300 bar.
- SATAT (Sustainable Alternatives Towards Affordable Transportation) also envisages setting up if CBG plants to produce and supply CBG to oil and gas marketing companies.

20. ENERGY IN TRANSPORTATION

PETROLEUM AS THE ENERGY SOURCE

What is Petroleum?

- Petroleum is derived from the words 'petra' and 'oleum' meaning rock oil.
- Animal biomass buried under earth crust for millions of years under high pressure in the absence of oxygen led to the formation of sedimentary rock with complex hydrocarbons. This we call petroleum. Majorly it constitutes crude oil and natural gas.



CRUDE OIL

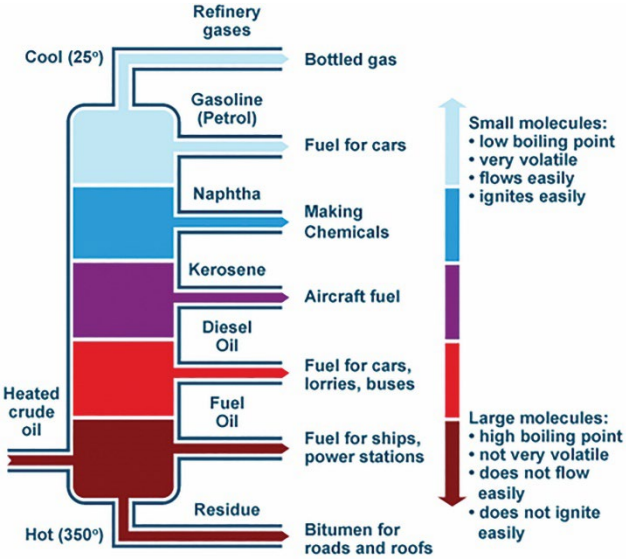
- Crude oil is a complex mixture of hydrocarbons.
- The different constituents of the crude oil mixture is simply different hydrocarbons with varying number of carbon atoms.
- This gives them varying densities and thus have different boiling points.
- Note: The basic factor that determines boiling temperatures of different components is the amount of carbon they have.
- Higher the carbon content higher the density higher the boiling temperature.

SEPARATING THE CRUDE: FRACTIONAL DISTILLATION

- The different components of crude oil mixture with different densities boil at different temperatures.
- Thus, in order to separate crude, we heat the mixture to about 6000 Celsius which boils the entire mixture.
- This vapour mixture is then made to pass through a fractional distillation column which is maintained at different temperatures at different levels. (lower to higher from top to bottom)
- Depending on their respective densities the constituents condense upon cooling down at different levels thereby separating itself from the mixture.
- Thus, those hydrocarbons with high boiling point condenses low in the column and those with lower boiling point condense at the top.
- Further higher the carbon atoms the fuel is found in solid form.
- Hydrocarbons with 1 to 4 carbon atoms are gases at room temp. Eg: Methane, Ethane, Propane and Butane.
- These components do not condense and thus are pressurised at 5 bar to make LPG.
- Hydrocarbons with 5 carbon atoms to 14 carbon atoms are found in liquid form. Eg: Petrol, kerosene, diesel.
- Hydrocarbons with more than 16 carbon atoms are normally found in solid form.

Click here for INDEX

- Note that since all the components are essentially hydrocarbons, they all are combustible. Only difference is they combust at varying temperature.
- More the amount of carbon atoms more difficult it is to break the bonds and thus at higher temperatures they burn. For instance, petrol can burn very easily as compared to lubricant oil.



COMPONENTS OF CRUDE OIL

Table and figures above and below provide a snapshot of components of crude oil, their properties and their application.

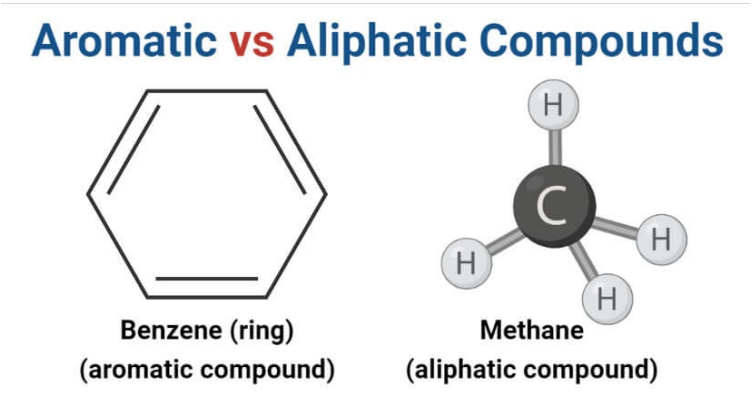
Typical Products

Products	Proportion	Boiling Point in degree Celsius	Application	Carbon Atoms
LPG	4%	Below 30	Cooking Fuel/ Transportation	Propane and Butane (C3-C4)
Naptha		70	Used in gasoline and Chemicals	
Petrol	47%	100-150	Used in gasoline	C7 to C9
Kerosene (Paraffin Oil)	10%	170	Used as Jet Fuel and Heating and Lighting oil	C10 to C16
Diesel	23%	270-350	Transportation	C14 to C 20
Lubricating Oil		>350	Engine Oil, Polish, Wax	C20 to C50
Fuel Oil		600	Industrial Heating	
Asphalt/Bitumen(liquid asphalt)	3%	Residue	Tar for roads, sound absorbers	>C70

BASICS ON HYDROCARBONS

Straight chain and closed rings

- The classification of hydrocarbons in general depend on how the carbon atoms have arranged themselves.
- This decides their chemical and physical properties.



Aliphatic compounds

- Carbon atoms in aliphatic are arranged in straight chain manner (open). Further aliphatic are classified based on how the carbon atoms are bonded with one another. (single or double bonds). This is important in all organic matter because single bonds are very hard to break and thus make stable compounds (saturated). Double bonds on the other hand are easy to break and thus make unstable compounds (unsaturated).

Aromatics and Naphthalene

- These are hydrocarbons where carbon atoms are arranged in closed rings. Again, depending on single or double bonds they are classified into naphthalene and aromatics respectively. Eg: Benzene (details are not important for future civil servants).
- Note that aromatics from any source react with sunlight and moisture in atmosphere to form ozone at the ground level which is a pollutant.

COMPOSITION OF CRUDE OIL

- Crude oil has primarily hydrocarbons, but also some non-hydrocarbon component.
- **Hydrocarbons**
- Crude oil majorly contains saturated straight chain hydrocarbons called paraffins. Examples include C1 to C4 in the form of gases (methane, ethane, propane and butane) and C5 to C10 in the form of liquids, common examples including kerosene, petrol, diesel etc.
- In minor amounts it contains closed ringed double bonded hydrocarbons which are volatiles like benzene. (which is unstable and therefore a pollutant)
- The major difference between coal and oil & gas is the C-H ratio (no of hydrogen for every carbon**). It is the C-H ratio that decides the amount of energy you can get out of a fuel (very important for you to appreciate the nature of fuels).** So, methane (4 hydrogen for every carbon) will have higher energy compared to propane (C3H6: 2 hydrogen for every carbon).

Carbon	83-87%
Hydrogen	10-14% (up to 5.5% in coal)
Nitrogen	0.1-2%
Oxygen	0.1-1.5%
Sulfur	0.5-6%
Metals	<1000 ppm

Non-Hydrocarbons

- Sulphur, Nitrogen, Oxygen, Metals. Table above gives you rough composition of crude oil components.

CHARACTERISTICS OF FUEL FOR TRANSPORTATION

Amount of energy

- The major difference between coal and oil & gas is the C-H ratio (no of hydrogen for every carbon**). It is the C-H ratio that decides the amount of energy you can get out of a fuel (very important for you to appreciate the nature of fuels).** So, methane (4 hydrogen for every carbon) will have higher energy compared to propane (C3H6: 2 hydrogen for every carbon).

Energy density

- Most important characteristic that decides the suitability and favorability of a fuel in transportation is energy density. Energy density is simply how much energy is there in every gram of fuel.
- Table below gives you an idea. (not important to remember but important to compare)

Coal	6 Cal/gm
Gasoline	10 Cal/gm
Natural gas	13
Hydrogen	26
U-235	20 million

Energy in volume

- In addition, for automobiles, how much fuel can a box of 1cm x 1cm x 1cm hold become very important. (this is the factor that determines the size of the tank).
- This is simply an indicator of how much fuel is there in 1 litre at atmospheric pressure. Table gives you an idea.

Petrol	740 g
Diesel	840 g
Hydrogen	71 g

- This means you can only fill 71 grams of hydrogen in 1 litre bottle.
- If you want to fill more, you need to compress it as a compressed gas or even liquify it which will require high pressure.

Knocking and Octane Number

- Knocking is an important property of any internal combustion engine.
- Petrol or diesel are not a homogenous mixture of fuel. It is a mixture of hydrocarbons (C7-C9 for petrol, C14 to C 20 for diesel) which have different boiling points.
- As a result, some components of the fuel burn faster than others resulting in a lag in complete combustion of fuel.
- This lag leads to shock waves in the engine cylinder causing a damage to the piston. This is called knocking.
- Simple solution is we need to homogenize the fuel. This is done by using fuel with higher octane number (simply more C8 hydrocarbon).
- Usually this is expressed as the percentage of Octane (91-94 etc.)

COMBUSTION IN IC ENGINES

- Combustion includes breaking of bonds between carbon and hydrogen and allowing them combine with oxygen in air resulting in liberation of energy in the form of heat in the combustion chamber of the engine. This heat pushes the piston which runs the crank shaft and thence to rotating of the wheels.
- **Air-fuel ratio**
- Hydrocarbons burn when air:fuel ratio is between 7:1 to 30:1
- In IC engines air-fuel ratio is maintained at 15:1
- If air-fuel mixture is more: Lean (In this case fuel is not completely burnt giving rise to more CO but it gives more mileage)
- If air-fuel mixture is low: Rich (In this case fuel is completely burnt thereby give more power output)

21. CHALLENGES IN BURNING TRANSPORTATION FUELS

EMISSIONS FROM IC ENGINES

Source of Emission

- When combustion takes place inside the combustion chamber the fuel and air is mixing to form oxides. As they combine pollutants are emitted.
- Air consists of 79% of nitrogen - Nitrogen does not participate in combustion and thus whatever comes in will go out of the exhaust.
- CO_2 and H_2O will be produced because you are burning hydrocarbons.
- Rest is pollutants. This concentration is about 1%.

Regulated and Unregulated Emissions

Emissions are classified into 2 types

- Regulated Emissions

- These are in large concentration.
- Emissions are very perceptible, and you immediately feel the discomfort.
- These include NOx, PM, CO, hydrocarbons.
- Carbon Monoxide more in petrol emission.
- Long-term exposure to CO prevents oxygen transfer in the blood because hemoglobin attracts CO more readily. When hemoglobin reacts with CO it produces carboxy hemoglobin which is very stable.
- Hydrocarbon emissions are main problem in petrol engines.
- NOX emissions are more prevalent in diesel engines. Can cause lung tissue damage, eye irritation because NOX reacts with water to cause nitric acid.
- PM is more prevalent in diesel engine. They harm the respiratory tracts.
- Unregulated Emissions
- These are emission in low concentrations and are not perceptible. But long-term is very fatal.
- These include formaldehyde, BTX (Benzene, Toluene, Xylene), Aldehydes, SO2, CO2, Methane, Poly-Cyclic Aromatic HC and Nitro PAHC.

How do you deal with Emissions?

Engine Design

- Engine is designed to produce certain concentrations of emissions by calibrating the combustion at various speeds and load which varies with urban/rural road for example. This is called engine tuning.
- Further optimize the combustion in order to get more heat output and thereby increasing efficiency.
- This is done by the way fuel-air mixture is delivered to the engine.
- Increase the number of valves: Earlier it used to be 1 intel 1 outlet not we have 2 inlet 2 outlet under 4-valve. This makes gas exchange more efficient.
- Increase the pressure at which fuel is injected: Higher the injection pressure smaller will be the droplet size of the fuel. Smaller will be the droplet size better will be the mixing of fuel and air. This will lead to increased efficiency of combustion thereby reducing the pollutant emissions.

EMISSION REDUCTION STRATEGY FOR NOX AND PM

EGR + Soot Trap

- Exhaust Gas Recirculation is basically done in order to reduce NOx emissions.
- Problem: Once EGR is done this produces lot of particulates. This is tackled by deploying soot traps.
- This will meet Euro 4 or Euro 5

Exhaust After-treatment

- NOx reduction is the goal using some strategy to treat the exhaust gases. 2 main technologies include
- **SCR (Selective Catalytic Reduction)**
- Here we use urea which is broken into ammonia and H2O. Ammonia reacts with NOx to produce nitrogen and water.
- **Lean NOx trap system**
- As a result of NOx treatment strategies, you can burn the fuel at high temperatures which reduces the PM formation.
- Using combination of EGR + Trap + Exhaust after-Treatment we can meet BS 6 criteria.

Note: For **after-treatment technologies to work** we need to **low-sulphur fuel (10-15ppm)** because sulphur kills the catalysts like plutonium, rhodium etc. which are used in SCR technology.

Sulphur

- In addition to killing the catalysts, sulphur is responsible for PM formation.
- Crude oil has in it sulphur is 2 forms hydrogen sulphide and sulphur in free form.
- This sulphur upon being heated reacts with oxygen to forms oxides of sulphur, SO2 and SO3.

- The oxides of sulphur react with moisture in the engine to form H2SO4 vapours which leads to formation of sulphates which act as the nuclie for PM formation.
- Thus, we need to reduce the sulphur in the fuel to arrest PM pollution.
- But sulphur provides lubricity to the fuel. So, if we reduce sulphur, we need to add lubricants to the fuel.

22. INDIA'S STRATEGY OF EMISSION CONTROL: BHARAT STAGE NORMS

- Set up by CPCB in 2000.
- It primarily regulates IC engine emissions particularly from vehicles.
- They are based on Euro regulations.
- Though we started some regulations in 1992, we implemented for 2 and 3-wheelers only around 2000.
- Requirement was lean-fuel ratio and electronic ignition.
- Changeover to 4 stroke
- Use of catalytic converter to reduce NOx.
- Fuel Injection system.
- From 20th April 2020 Bharat Stage 6 is being implemented which makes it mandatory to use PM traps and NOX catalytic convertors.
- Currently in India we have emission norms for vehicles (2, 3, 4 wheelers, heavy duty engines, diesel construction machinery, diesel agricultural tractors(TREM norms), generator sets)
- However, we do not have emission norms for locomotives as of now.
- With pressure from various quarters including NGT, locomotive emission norms are on the anvil and will soon be implemented.

BHARAT STAGE 6

BS-VI vehicles

- Vehicular emission (NOx, SO2, CO2 and particulate matter) is a major contributor to the worsening air quality of Indian cities.
- Bharat Stage VI (BS VI) is an emission standard that will induce technology in the vehicles to reduce pollutant emissions.
- The vehicles will mandatorily include OBD (On-board diagnostics) which will and monitor the pollution caused by the vehicle in real time.
- The BS-VI vehicles use selective catalytic reduction technology which substantially reduces particulate matter emission.(remember in order for this to work we need to use low-sulphur fuel)

BS-6 emission norms

- Petrol vehicles will have to effect a 25% reduction in their NOx, or nitrogen oxide emissions.
- Diesel engines will have to reduce their
- HC+NOx (hydrocarbon + nitrogen oxides) by 43%,
- NOx levels by 68%
- Particulate matter levels by 82%.

Advantages of using BS-6 fuel and vehicles

- NOx emission will come down by approximately 25% for the petrol engine and 68% for the diesel engines.
- BS-6 grade fuel contains 10 parts per million (ppm) of sulphur as against 50 ppm in BS-4 fuels.
- The BS-6 fuel would result in 10-20 per cent reduction in particulate emission when used in BS-4 or lesser grade engines.

- The Octane number for petrol engines has improved from 88 in BS-2 to 91 as required under BS-6 emission norms.
- However full benefits will be realized when the automakers start manufacturing BS 6 grade engines in their vehicles.
- The PM emission will see a substantial decrease of 80% in diesel engines.

→ALTERNATIVE FUELS IN TRANSPORTATION

- Looking for alternative fuels in transportation has multiple incentives for India as below.
- Reducing import dependence for crude
- Reducing carbon emissions
- Reducing air pollution
- In this section we will be looking at alternative fuels from fossil sources. In the next section we will talk about biofuels.

23. GASEOUS ALTERNATIVES

- From solid to liquid to gaseous fuels, the fuels become cleaner in the increasing order.
- However, energy density decreases in that order.
- Characteristics
- Combustion efficiency is increase. (Proportion of usable heat is more)
- Cleaner combustion in the absence of residues and pollutants
- Easy to transport. The challenge is to compress it in fuel pumps and tanks.
- However, the problem with gaseous fuels is higher NOx emission due to high temperature of combustion.

24. NATURAL GAS

- Natural gas is primarily a mixture of lightweight alkanes (aliphatic: straight-chain hydrocarbons). see table
- Typically, C3, C4, and C5 hydrocarbons are removed before the gas is transported.
- In addition, natural gas coming out of the reservoir contains about 9% which is reduced to 2% before being shipped onshore.
- Here again carbon capture technology mentioned above is employed to remove CO2.
- Thus, natural gas that is commercially available is a mixture of methane and ethane.
- The propane and butanes removed from natural gas are usually liquefied under pressure and packed as liquefied petroleum gases (LPG).

Hydrocarbon	Proportion
Methane	80-95
Ethane	5-10
Propane, Butane, Pentane etc.	<5

SOURCE OF NATURAL GAS

- Natural Gas occurs in nature in the following forms

Gas Wells

- Bombay high, Assam's Digboi, KG basin, Rajasthan (Jaiselmer), Tripura.
- Largest gas fields are located in Iran, Central Asia and Russia. This is why the interest in TAPI (Turkmenistan, Afghanistan, Pakistan, India)

Diluted in Oil: Petroleum

- Petroleum wells are those in which liquid petroleum comes out and the top part is gas.

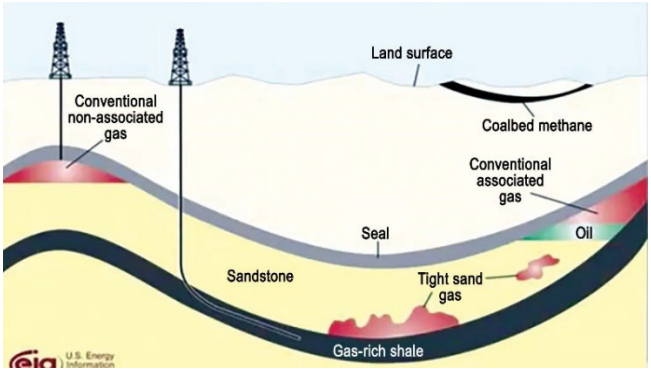
Diluted in Water: Gas hydrates

- Gas hydrates are natural gas is diluted in water.
- Hydrates are water and gas molecules present in crystalline form.
- Normally they are in the form of ice in permafrost or sea floor which when heated releases methane.
- Gas hydrates are present all over the coast.

Diluted in rocks: Coal-bed methane

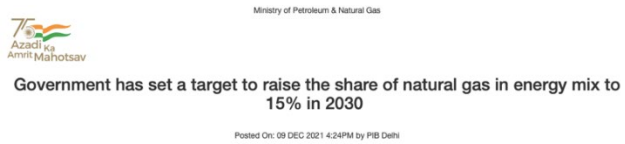
- Found in coal seams where hard coal deposits have methane absorbed in it under high pressure.
- Mining involves reducing the pressure of coal bed and releasing the trapped gases.

Natural Gas: Storage, Transport and Use



- Since natural gas contains some amount of propane and butane, we remove them.
- This is because, being heavier and denser, propane and butane liquifies at low pressure of 5 bar and can be used as cooking fuel.
- The pressure in your LPG cylinders is around 12 bar to keep it liquid inside the cylinder. This is done to get high energy per volume.
- On the other hand, its major component methane is lighter and hence needs to be compressed or liquified in order to be used in vehicles.
- Accordingly, we make Compressed Natural Gas or Liquified Natural Gas. (more on this in a bit)

India's push for gas-run economy


Ministry of Petroleum & Natural Gas

Azadi Ka Amrit Mahotsav

Government has set a target to raise the share of natural gas in energy mix to 15% in 2030

Posted On: 09 DEC 2021 4:24PM by PIB Delhi

- India has been taking a number of steps to leapfrog into gas-run economy in the near future.
- Currently the share of natural gas in India's energy basket is 6.7% compared to 23% worldwide.
- This India wants to increase to 15% by 2030.


A gas-based economy is what India needs today: PM Narendra Modi

He said these infrastructure projects would strengthen gas connectivity in eastern India and improve both ease of doing business of living.

- Accordingly, India has taken the following steps:
  1. Expansion of National Gas Grid to about 35,000 Km from current 17,000 Km.
  2. Expansion of city gas distribution network to cover 96% of India's population and 86% of its geographic area.
  3. Setting up of LNG Terminals.

25. CNG

- Methane, being lighter, is compressed at high pressure (around 225 bar) in the vehicle tanks to get a workable energy-density. This limits the size of the tank making it suitable for light-commercial vehicles like cars, auto-rickshaw etc.
- Thus, CNG vehicles have low range and are suitable only for intra-city travel.

NATURAL GAS ALTERNATIVE IN TRANSPORTATION

- While CNG continues to grow rapidly in India, the next logical step is to step up LNG production to replace diesel in heavy-load trucks.

CNG IN TRANSPORT FLEET

CNG makes inroads in India's auto sector

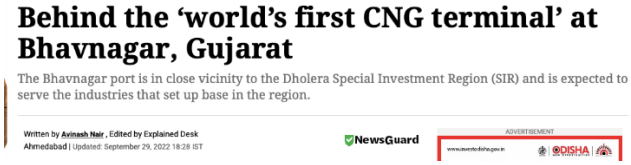
The LCV segment saw its CNG and electric marketshares rise in FY 22

By Brian de Souza 27 Apr 2022 34274 Views

- In 2022, annual sales of CNG vehicles in the passenger segment more than doubled.
- 49% of the light commercial vehicles sold in 2022 were CNG-powered.
- India plans to increase the number of CNG stations to 10000 by 2030 from current 4,500.

WORLD'S 1ST CNG TERMINAL

- India is setting up the world's 1st CNG in Bhavnagar, Gujarat.



Behind the 'world's first CNG terminal' at Bhavnagar, Gujarat

The Bhavnagar port is in close vicinity to the Dholera Special Investment Region (SIR) and is expected to serve the industries that set up base in the region.

Written by Avinash Nair, Edited by Explained Desk
Ahmedabad | Updated: September 29, 2022 18:28 IST

NewsGuard

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Advantage of CNG as alternative

- No sulphur emissions.
- No unregulated emissions like benzene.
- Low carbon emissions. (1 unit of natural gas produces half the emission as compared to 1 unit of coal)
- No PM pollution.

Challenge

- NOX emissions will be higher due to higher temperature of combustion.

26. LIQUID ALTERNATIVES

- Liquid fuels can be alcohols or hydrocarbons. While hydrocarbon liquids are diesel and petrol, alcohol-based fuels are methanol and ethanol.
- Besides alternative liquid hydrocarbons include LNG, LPG, Dimethyl ether, liquid hydrogen (suitable only in rockets).

GAS-TO-LIQUIDS: HYDROCARBON-BASED ALTERNATIVES

- As you have already seen, hydrocarbons in the gaseous form are small chain molecules like C1, C2, C3 and C4 (methane, ethane, propane and butane)
- While gas is voluminous, its density is too small.
- Therefore, to transport and use gas either we need to pump it at high pressure, or we need to liquify it.
- Gas-to-liquid alternatives involve this conversion of gas to liquid fuels. (like LNG)
- When we are liquifying gas what we are really doing is only fusing small chain gas molecules into long-chain ones. This is fancily called polymerizing.

- This will increase the boiling point and eventually become liquid.
- Basically, **by polymerizing hydrocarbon gas molecules to liquid, we are only making diesel.**

Advantage

- Higher energy density
- Ease of transport and storage
- Zero sulphur emissions
- Zero aromatics (no closed-rings remember?!)
- Low NOx as compared to gaseous fuels.

27. LNG (GAS-TO-LIQUID ALTERNATIVE)

- Alternately, we can liquify methane in order to achieve higher energy density.
- However, at normal atmospheric pressure methane liquifies at very low temperature of about -1700C because it has a low Boiling Point about -1600C.
- Thus, in order to transport we need cryogenics which is not feasible for 2-wheelers and 4-wheelers.
- However, LNG, with its higher energy density, occupies three times less space than CNG.
- Thus. it is suitable for long-haul transport like trucks provided they are fitted with cryogenic tanks.

LNG in transport fleet

Indian trucking will drive into gas age with 50 LNG stations

SANJAY DUTTA / TNN / Nov 19, 2020, 22:55 IST

- LNG is the best bet to replace heavy-duty diesel-based trucks.
- India has more than 10 million trucks, of which the government expects at least a million to run on LNG by 2035.
- India has planned to build 1,000 LNG stations in next 3 years along major highways, industrial corridors and mining areas.

28. LPG

- As we have seen gaseous components of petroleum separation include methane, ethane, propane and butane. While methane and ethane are used in the form of gas (natural gas), the heavier gaseous hydrocarbons are liquified to form what is called liquified petroleum gas.
- This is because heavier gases like propane and butane liquify when compressed become liquid at lower pressures of around 5 bar.
- This is why your LPG cooking cylinders are maintained at low pressure of 12 bar to hold enough fuels.
- LPG is a better alternative than LNG in transportation as it can be liquified at lower pressure and thus suitable even for 2, 3 and 4 wheeler segments.
- Only constraint has been lack of supply and thus LPG use is restricted as cooking fuel.

29. METHANOL

- Another approach to make liquid fuel is compress the syn gas obtained from gasification process. (remember syn gas is produced by burning any hydrocarbon, be it fossil or biofuel, with steam)
- The mixture of CO and H2 is adjusted in its pressure and temperature to form methanol. (CH3OH)
- $CO(g) + 2\ H_2(g)$ ----> $CH_3OH(l)$
- Methanol is also called wood alcohol.

Advantage

- Methanol can directly be used in IC engines or even converted to petrol using a zeolite catalyst.

- Note that methanol can be produced from any hydrocarbon not just coal including natural gas, biomass, and even captured carbon dioxide. Only thing you need to adjust the amount of hydrogen.

Coal ministry to focus on coal gasification to produce methanol, fertilisers over 3 years

During the gasification process, oxygen and water molecules oxidize the coal and produce syngas - a gaseous mixture of carbon dioxide (CO2), carbon monoxide (CO), water vapour (H2O), and molecular hydrogen (H2)

Anshul Joshi • ETEnergyWorld • Updated: March 11, 2020, 11:22 IST

Significance of Methanol

- Methanol cars are becoming common especially in China where coal is in abundance.
- Methanol can also be used in fuel-cells and thus could drive the EV revolution.
- India by adopting Methanol can reduce its import dependence on oil and at the same time have a cheaper fuel (at least 30% cheaper than any available fuel)
- Niti-Aayog is set to come out with a roadmap for transition to Methanol Economy.

30. DME: DI-METHYL ETHER

- The most significant thing about **DME is that it is liquid at room temperature.**
- To make DME all you need to do is to take 2 molecules of methanol and remove water from it.
- $CH_3OH + CH_3OH \rightarrow CH_3-O-CH_3 + H_2O$

Advantage

- Liquid at room temperature
- Liquifies at 5 bar and thus easily stored.
- Better for NOx reduction
- Low CO_2 emissions owning to high H-C ratio.

31. HYDROGEN

WHY HYDROGEN?

- A general trend towards development of better fuels is hydrogen-rich fuels.
- This means more of hydrogen in the fuel and less of carbon or more hydrogen to every carbon atom. Eg: Natural gas 4 hydrogen to every carbon as opposed to very little hydrogen in coal.
- This is because just like carbon, hydrogen is also combustible, i.e. it mixes with oxygen in the air and gives heat.
- In addition, moving from a solid to a liquid and then finally to a gaseous state energy carrier.

NATURE OF HYDROGEN

Hydrogen as an energy carrier

- It is important to understand that all fuels we have seen so far are energy carriers.
- Hydrogen is the best energy carrier as there are no harmful impact (read carbon emissions)
- This is because hydrogen is not freely available on earth, but it is in abundance in the form of in water and hydrocarbons.
- However, to extract hydrogen from water or hydrocarbons you need to expend energy and the energy spent in extracting hydrogen is much more than the amount of energy the so-extracted hydrogen gives out. This is why hydrogen is energy carrier and not an energy source. (in fact all fuels we have seen are energy carriers)

Combustible nature

- Hydrogen is highly combustible i.e. it mixes readily with oxygen to produce heat.

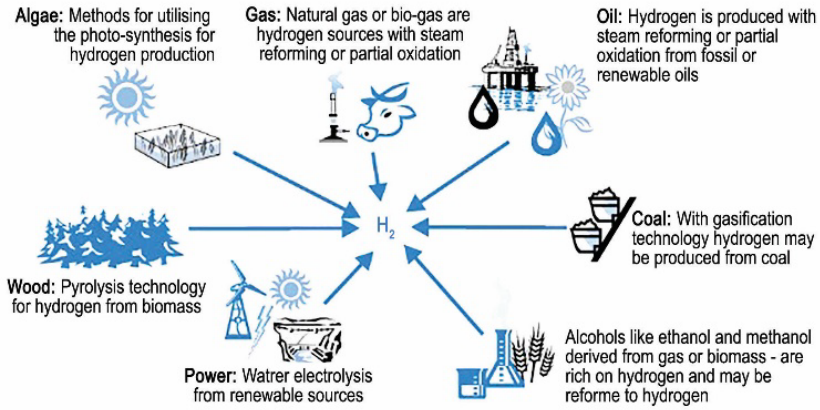
High energy density per gram

- Further the amount of energy out of this process is about 3 times higher than that you get when you burn petrol. (26 Kcal/gm for hydrogen compared to 10 Kcal/gm for gasoline).

Extremely low density per volume

- However, the problem with hydrogen is that it has low density, meaning the amount of hydrogen mass you can hold in 1 liter is about 71 grams.
- That means the tank size at normal temperature and pressure to hold hydrogen is very big.
- In other words, though the fuel itself is lightweight the tank size and therefore the weight of the tank goes higher.
- This puts a limitation on hydrogen being used as a fuel in private transport.
- Thus, hydrogen is suitable for large vehicles like buses which requires a limited range but can hold a large tank.
- This requires hydrogen to compressed at high pressure. Alternately you can liquify hydrogen by compressing and taking away heat.

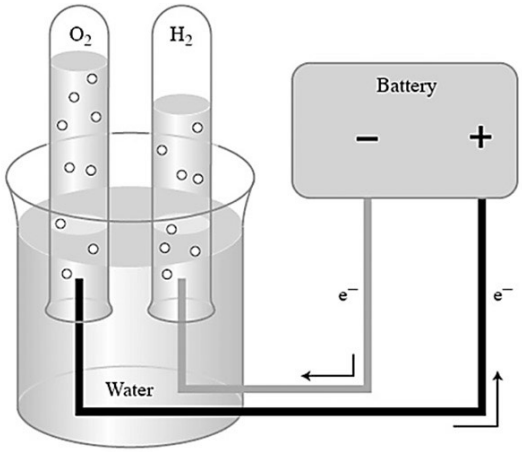
HOW TO MAKE?



- You can't mine hydrogen. There is virtually no hydrogen gas (or liquid) in the environment.
- But there's lots of hydrogen in water and in fossil fuels (hydrocarbons)-but not "free" hydrogen, the molecule H2.
- That's what we want for the hydrogen economy.
- Two major sources of hydrogen on earth are water and hydrocarbons
- From hydrocarbons
- Take any hydrocarbon and treat it with steam we get syn gas which is a source of hydrogen.
- Any hydrocarbon+H2O→ CO+H2
- Hydrocarbon could be either fossil or biofuel or even organic waste.
- However, hydrocarbon source of hydrogen is again a problem because the left over carbon has to go to atmosphere.
- This makes it dirty. That's why hydrogen from these sources is colour coded with 'dirty' colours like grey, blue, black etc.

NATIONAL GREEN HYDROGEN MISSION

- Budget 2021-22 proposed the National Hydrogen Mission to make India the hub of green hydrogen production.
- In Feb 2022 the National Green Hydrogen Policy was formulated.
- In 2023, the cabinet approved Rs.19,744 crore towards other Mission components.



ELECTROLYSIS OF WATER

- Pass electricity through water, it will split it into its constituent Hydrogen and oxygen.
- Process where electricity is used to make a chemical change that wouldn't happen otherwise.
- In a normal situation oxygen pulls electrons and hydrogen pushes its electron.
- In case of electrolysis, water is split into hydrogen and oxygen and for this to happen hydrogen has to gain electron and oxygen has to lose electron which is the opposite to what happen normally.
- This requires energy which is what electricity gives.
- So, take a battery use the energy to pull the electrons out of oxygen and push it towards hydrogen.
- If the electricity you use to split water comes from renewable source, it gives you green hydrogen, the cleanest source of hydrogen.

HOW TO USE HYDROGEN?

- Burn it in directly IC engine, blend it with another gaseous fuel or use it in fuel cell.
- Hydrogen being combustible can be used directly in IC engine. However, the efficiency is very low, hardly 25-30%.
- Alternately we blend hydrogen with natural gas. This is what is called H-CNG.

Advantages of HCNG

- The energy density increases.
- Carbon emissions are reduced.
- Low NOx emissions
- No sulphur emissions

32. FUEL CELLS: BEST WAY TO USE ENERGY FROM HYDROGEN

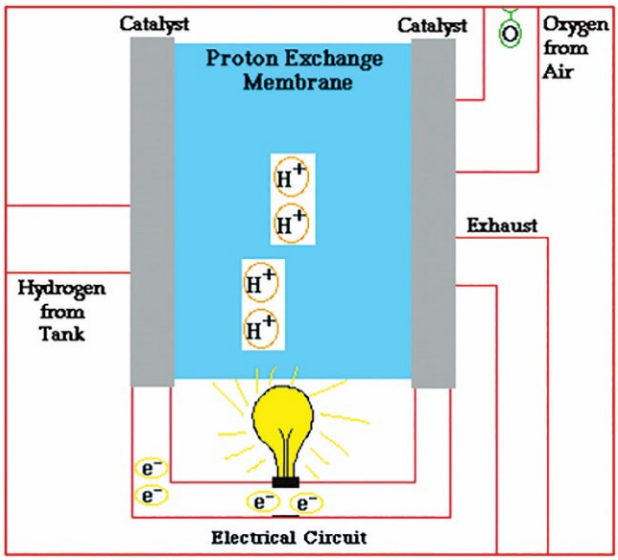
- The best way to use the energy from hydrogen is fuel cells.
- The main advantage of using hydrogen in a fuel cell over using as a fuel is the increase in efficiency which is around 60% for solid-oxide fuel cell and around 50% for PEM fuel cell. (heat energy is a poor form of energy compared to electric energy)
- Before you read about fuel cells do read the section on batteries below.

PRINCIPLE BEHIND FUEL CELLS

- Fuel cell is just electrolysis in reverse. Meaning in a fuel cell you pump hydrogen and oxygen which combines to form water, in the process you can derive electricity.

HOW DOES IT WORK?

- You pump hydrogen on one side and separate it into its constituent ion and electron.
- Make the electrons to pass through a wire and you have electricity.
- In addition, we use an electrolyte which is simply a membrane that allows ions to pass through and not electrons to pass through.
- The separation of hydrogen into its constituent electron and hydrogen ion is brought about by a platinum catalyst. The challenge is its high cost.
- Finally, when ions and electrons recombine the resultant hydrogen is mixed with oxygen to produce water. This produces heat which is a deciding factor in choosing the fuel cell. **(operating temperature of fuel cell)**

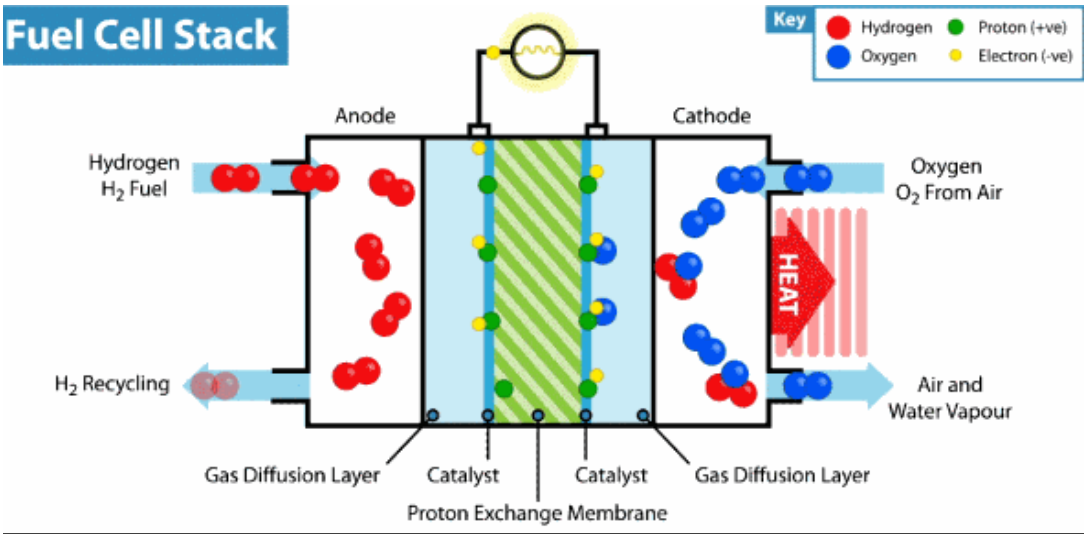


TYPES OF FUEL CELLS

- Please note that the only fuel cells that are feasible for use in automobile are the ones which have manageable operating temperatures.
- Following are the fuels cells that are relevant for use in electric vehicles.

PROTON-EXCHANGE MEMBRANE FUEL CELL

- The example we have taken to illustrate the working of fuel cell above are called proton-exchange fuel cell.



SOLID OXIDE OR METHANE FUEL CELLS

- Alternately we can use methane or even ethanol out of which you can derive hydrogen inside the fuel cell itself.
- However operating temperatures are high upon formation of water (around 200 degree celsius).
- Due to high operating temperature, we can use solid electrolyte, typically a meta oxide. Thus, the name.
- Having solid electrolyte is important for use in consumer electronics.
- However, one disadvantage of such fuel cell is that the solid electrolyte used are typically rare earth elements. (eg: cerium, gadolinium, yttrium called YSZ)
- These are expensive and also environmentally harmful)

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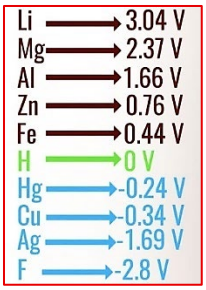
33. BATTERIES AND FUEL CELLS

PRINCIPLE

- Batteries or fuel cells are devices that derive electricity out of a chemical reaction that happens.
- The chemical reaction is simply pulling out electrons from something and making it travel along a metallic wire producing electricity. The thing about electron is once you pull it out of something it needs a place to go.
- The terminals from where electrons are pulled out and sent to are called electrodes.
- The terminal from where electrons are pulled out are called anode and those where electrons are sent to are called cathode.
- The chemical reaction that leads to pulling out of electrons is called oxidation and that that leads to dumping of electrons is called reduction.
- So typically, oxidation happens at anode and reduction happens at cathode. In the process of electron going from anode to cathode, the energy is flow of electrons (electricity) is captured.

HOW DOES BATTERY STORE ENERGY?

- Battery is a device where energy is stored for use later.
- So, in order to store energy, you need an energy source.
- The process of storing energy in a battery is what you know as charging the battery. Similarly, the process of using the energy is discharging of battery.
- Charging and Discharging the battery
- Here you pump energy from an outside source to take electrons of out some chemical from where it does not want to come and send it to another chemical where it does not want to go. Once you do this the electrons want to run back to its original place.
- This is like sending electrons uphill(charging) and allowing the electrons roll back downhill by itself (discharging).

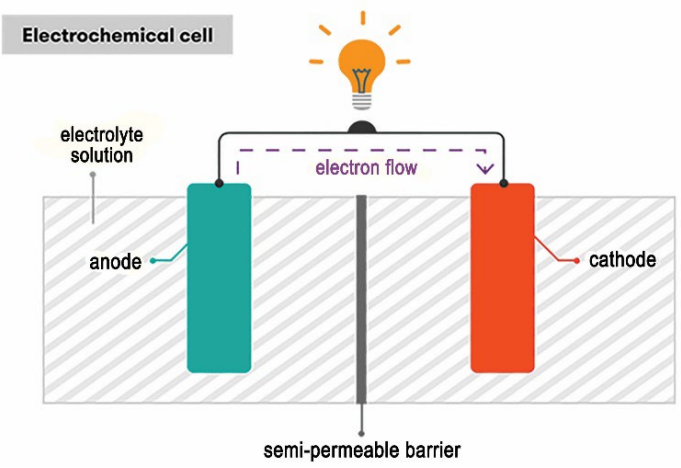


What chemicals to use?

- Everything depends on element's affinity (likeability) for electrons. Simply elements which like electrons and those that do not like electrons.
- The likeability for electrons decides the electrochemical potential of that element.
- Electrochemical potential is simply how readily an element wants to lose or gain electrons.
- Higher the electrochemical potential the element wants to readily lose electron, lower the electrochemical potential it wants to gain electrons.

WORKING OF A BATTERY

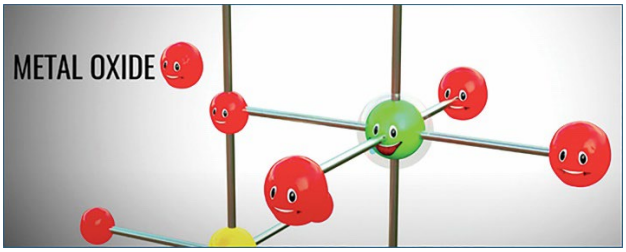
- The trick is to take 2 different metals with different electro-potential so that one wants to gain, and one wants to lose electron.
- Eg: Zinc and Copper.
- As it is evident from the table, Zinc wants to give electron and Copper wants take it. (that's why Zinc is anode and Copper is cathode)
- So, if you somehow give a path for these electrons moving from Zn to Cu, you will have derived electricity.
- When all the electrons have come to Cu, you can no longer derive electricity.
- So, you have to forcefully pull electrons out of Cu (cathode) and put it back at Zn (anode). This is charging.
- Once you have forcefully pulled out all electrons from Cu and have put it back at Zn, you can again rely on the natural flow of electrons from Zn to Cu to derive electricity. This is discharging.
- One last thing is about the electrolyte. An electrolyte is like a semi-permeable membrane for electrons and ions. It allows the ions to pass through them but not electrons.
- **Putting all the pieces together**



- In a battery a chemical reaction takes place where you are separating electrons and ions from the anode material.
- Once separated you make 2 different paths for these electrons and ions to move. For electrons you connect the anode to a metallic wire and for ions you dip the anode in electrolyte.
- Electrons will move towards cathode along the wire and ions move towards cathode along the semi-permeable electrolyte.
- Electrons movement through the wire gives you electricity.

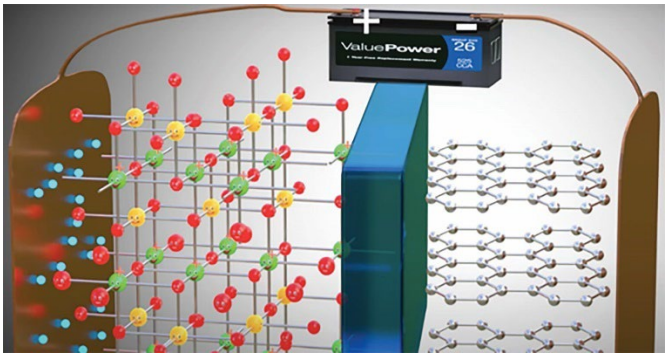
34. LITHIUM-ION BATTERY

PRINCIPLE



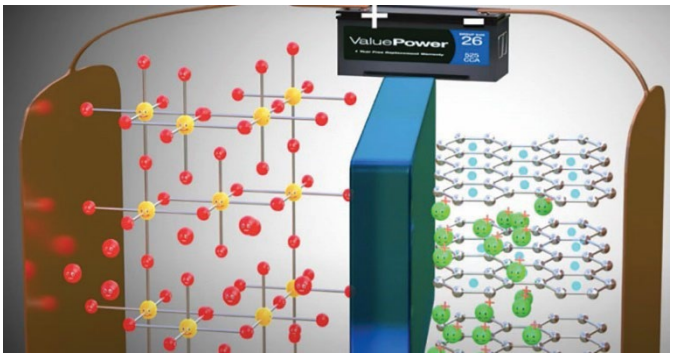
- Lithium, as you can see in the table above, has the highest electrochemical potential.
- It wants to lose electrons readily which makes it very reactive. That's why you don't get lithium in free form.
- However, when mixed with metal oxide lithium sits very stably.
- Thus, if we use this ability of lithium to be very unstable by itself to becoming very stable in metal oxide, we can derive electricity. This is what happens in a Li-ion battery.

WORKING OF A LI-ION BATTERY

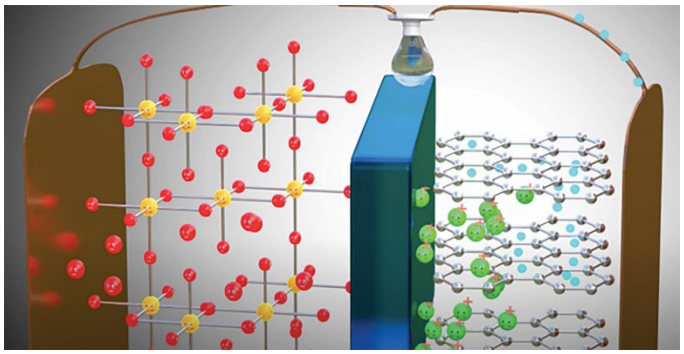


- Lithium is mixed in metal oxide (typically cobalt, nickel, or manganese)) is used as cathode.
- Graphite is use as a place to hold Li-ions which becomes an anode.

- As we have seen Lithium in metal oxide is very stable.



- In Li-ion battery we separate Lithium from metal oxide by pulling out its constituent electrons and ion forcefully by applying energy.
- The electrons and ions of Lithium are then given separate paths namely a metallic wire and an electrolyte.



- This is called charging as it required external energy to separate electrons and Li-ions from Lithium metal oxide.
- The li-ions moving through electrolyte and electrons moving through the wire then recombine at anode which is graphite.
- Once all the electrons and ions are pulled out the battery is completely charged.
- The lithium ions and electrons that is sitting between graphite sheets are unstable and wants to go back to metal oxide. If we again give separate paths to electrons and ions we can derive electricity.
- Thus Li-ion battery is used to store energy by shuttling lithium ions back and forth between the anode(Li-ion in graphite) and cathode(Lithium in metal oxide).

ADVANTAGE OF LI-ION BATTERIES

- **Light weight**
  - Lithium being lightest metal.
- **High Energy Density**
  - Lithium having highest electrochemical potential has very high energy density.
  - A typical automobile lead-acid battery weighs 6 kilograms more to store the same amount of energy than a lithium-ion battery.
  - In consumer electronics like mobile, laptops, camera etc I kilogram of Nickle cadmium batteries stores typically 60 to 70 watt-hours.
  - A typical lithium-ion battery can store 150 watt-hours of electricity in 1 kilogram of battery.
- **Minimum losses**
  - A lithium-ion battery pack loses only about 5 percent of its charge per month, compared to a 20 percent loss per month for Ni-Cd batteries.
- **Low Maintenance**
  - Lithium-ion batteries can handle hundreds of charge/discharge cycles.

DISADVANTAGES

- **Faster discharge**
  - While quick discharge is an advantage in electric vehicle and consumer electronics applications, it is not suitable to store energy for longer than 4 hours.
  - Thus, it is **not suitable for grid-level storage** which is necessary for renewable energy like solar which suffer from intermittency problem.
- **Ageing**
  - Li-ion batteries suffer from ageing at room temperature. Therefore, in a consumer electronic, batteries need to be partially charged for longer life.
- **Transportation**
  - Another disadvantage of li-ion batteries is that there can be certain restrictions placed on their transportation, especially by air to protect against short circuits.
- **Cost**
  - Lithium-ion batteries are around 40% more costly to manufacture than Nickel cadmium cells owing to high cost of lithium refining, cobalt and nickel.

35. ALTERNATIVES

SODIUM-SULPHUR

Advantage

- Sodium-Sulphur can be recharged 4500 times compared to 500 times of Lead-acid and Li-ion batteries.
- Further Lithium is way more costly than sodium. 10 times more per kilo.

Limitation

- Problem is Sodium used in these batteries need to be in liquid state and that happens at high temperatures of 350 degree Celsius. So, Sodium-Sulphur cannot be used in laptops and mobile phones.
- Price per charge-discharge cycles is high.

FUEL CELL V/S BATTERY

FUEL CELL	BATTERY
Not an energy storage device in the strict sense. It produces electricity as long as the fuel is supplied	Energy storage device
Longer life	Shorter life as chemical is degraded during charge-discharge cycle t.
Lower efficiency as compared to battery: around 50-60%	Efficiency is high: around 80-90%
Requires less time to refuel fuel cell based electric vehicles as you directly pump hydrogen in the tanks.	Requires more time for recharging

MICROBIAL FUEL CELL

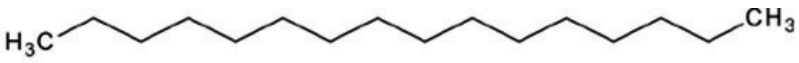
- It uses an organic electrolyte instead of inorganic ones in the above case.
- In other words, anaerobic oxidation of organic substances such as acetate, glucose, lactate, ethanol by microbes.

36. BIOFUELS

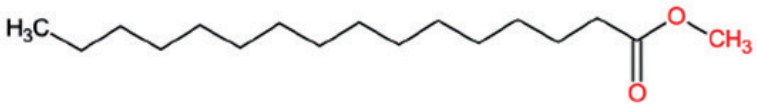
NATURE OF BIOFUELS

Biofuel: a net-negative pathway

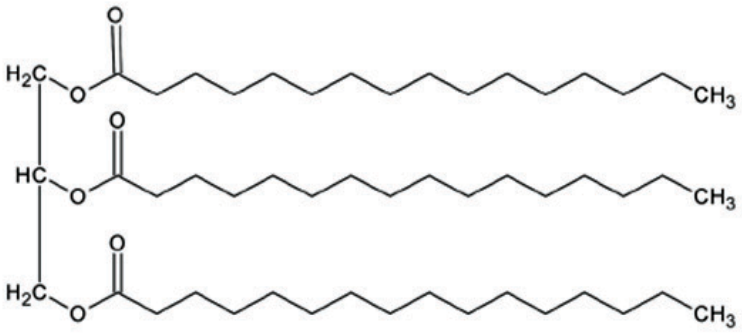
- Biofuels are way to take out CO2 from the landmass above the surface of the earth and putting it back in atmosphere.
- This is unlike fossils where you are taking carbon stock from below the surface and putting it in atmosphere increasing its concentration.
- Besides the amount of CO2 you are putting by burning 1 kg of biomass is much lesser than the amount of CO2 the plants used to make 1 kg of plant biomass. (plants convert only 0.5% of photosynthesis to biomass)
- Thus, biofuels are net-negative in terms of carbon emissions.



(a) Petroleum diesel



(b) Biodiesel



(c) Vegetable oil or Triglyceride

As hydrocarbon: Biofuel v/s fossil

- Biofuel is small ring hydrocarbons with **lots of oxygen and benzene rings. (not suitable remember)**
- Fossil as we have seen is just biomass buried for millions of years under low oxygen conditions.
- Besides biomass is long polymers of sugar molecules.
- So, if we somehow remove oxygen and break the polymer, we can get biofuels.

Biomass as energy store

- Further biomass is basically solar energy trapped in the form of chemicals that make up the living beings.

BIOMASS COMPOSITION

- C 50%
- O 40%
- H 5 %
- N 1%(From protein)
- P 0.5% (From protein)

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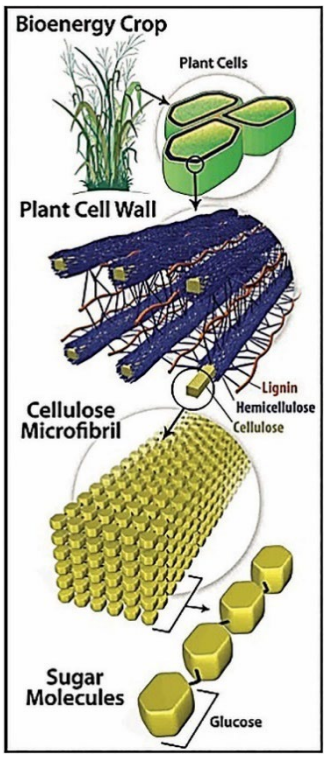
BIOMASS CONSTITUENTS

- Primarily made of sugar polymers with lots O_2 and closed ring hydrocarbons. (half the plant biomass is fundamentally sugar)
- Plant cells are made up of cell walls that gives a protective layer to help plants stand tall.
- The cell wall is made of microfibrils of **cellulose** which is basically sugar polymer. (1/2 of cell wall)
- At later stages there is an additional protective layer in the form of hard cover in trees which is called **lignin**.
- Lignin is plastic-like. It is not degradable, has lots of aromatics.



CLASSIFICATION OF BIOFUELS

- For the sake of simplicity think of plant biomass in terms of edible and non-edible part.
- The edible part of plant like fruits, vegetables, grains etc are usually made simple sugar, starch.
- The other edible part is seeds that have edible oils.
- The non-edible part of biomass on the other hand is made of cellulose, hemi-cellulose and lignin.

ENERGY FROM BIOFUELS

- There are 3 pathways to derive energy out of biofuels:
  1. Burn them
  2. Make alcohols like ethanol and methanol
  3. Make biodiesel
  4. Make biogas

Burning of biofuels

- Burning solid biofuel will leave solid ash residue which is not desirable. Eg: Cow dung, wood etc
- So, we need to gasify or liquify biomass.

Liquifying biofuels

- Liquifying biofuels again include 2 pathways
  1. Make alcohols: ethanol and methanol: fermentation
  2. Make biodiesel: From vegetable oils: transesterification

Gasifying biofuels

- Biogas: Bio-methanation
- Biohydrogen: from syngas

→ALCOHOLS: ETHANOL AND METHANOL

- Alcohols are best alternatives to petrol.
- You can directly replace petrol with ethanol or methanol in IC engines or alternately you may blend it with petrol. (Ethanol blending upto 20% by 2030 is the target)

How are they made?

Fermentation

- Alcohols are made by fermentation of sugars by microorganisms.
- Depending on the microorganism used and sugar source you get different alcohols.

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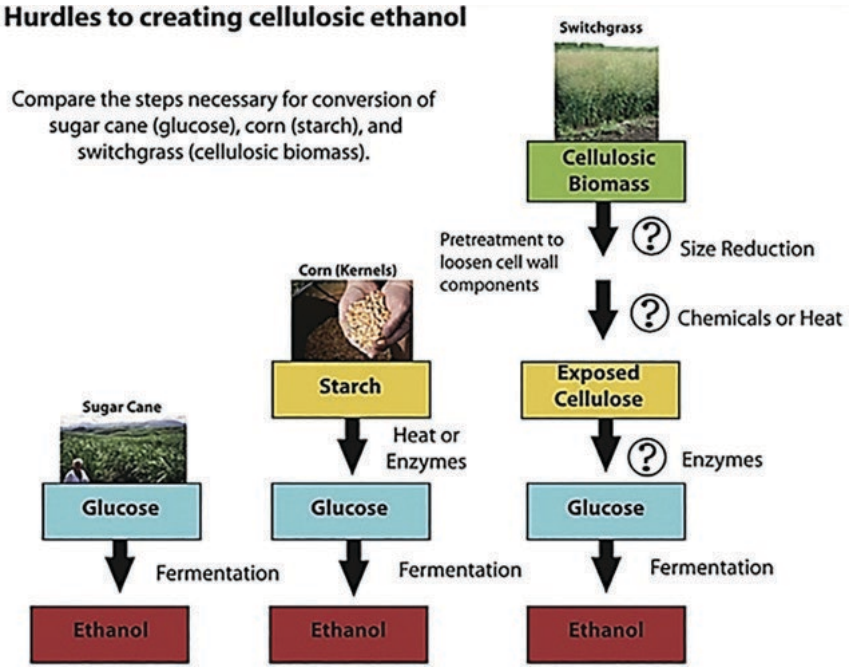
37. ETHANOL

- Most commonly formed alcohol through fermentation is ethanol.
- Fermentation is simply breaking down of sugar molecules in the absence of oxygen at the cellular level or in other words anerobic cellular respiration to produce ethanol. (For detailed discission on fermentation see the optional section below)



Which microorganisms produce ethanol?

- Microorganisms capable of producing ethanol include yeast, some species of bacteria, fungi and some species of micro algae.

Feedstock

Edible part

- Ethanol can be made from both edible parts and non-edible cellulosic biomass.
- Edible sources include sugarcane, corn, and other starch-based crops (sugar beets, rice, wheat, potatoes)

Non-edible part

- The cellulosic matter from plant biomass are basically complex sugar molecules.
- Thus, they have to be broken down into simple sugar in order to be fermented into alcohols.
- In order to break them down hydrolysis is done in other words treatment with water. These simple sugars can then be used for fermentation by microbes to produce ethanol.
- However, lignin is made of phenols and not sugars. Thus, they cannot be converted into alcohols.

Advantage

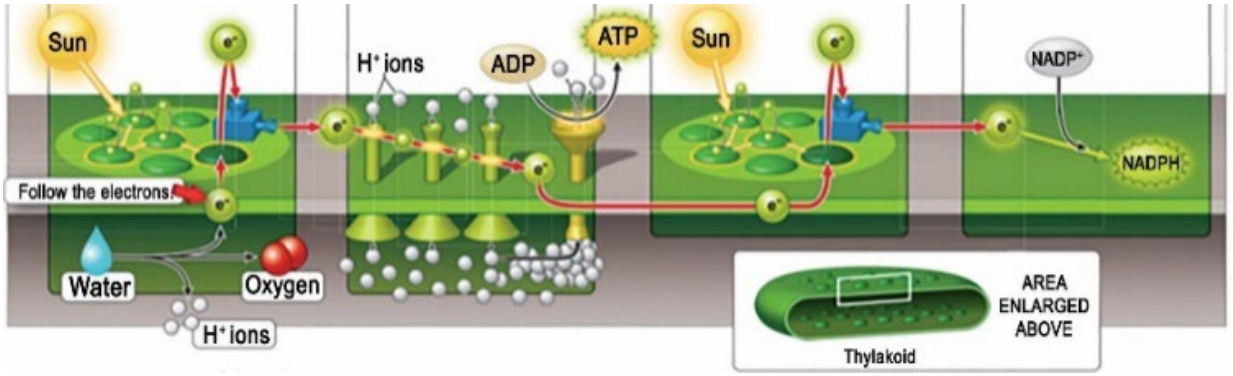
- No SOX emissions
- Can be used as a substitute for petrol in SI engines
- Low carbon emissions (biofuels are net negative)
- Low NOx emissions

38. METHANOL

- Although methanol can also be made through fermentation, it is rare.
- This is because it is produced in small amounts as by-products during fermentation of certain bacteria and fungi species.
- Thus, the commonly used pathway to make methanol is producing syngas. (discussed in alternate fuels: Gas-to-liquid section)

→OPTIONAL SECTION

PHOTOSYNTHESIS AND CELLULAR RESPIRATION: THE UNIVERSAL ENERGY PATHWAY



Photosynthesis: building the energy stores

- Plants have simply collected energy from sunlight and stored it in sugar molecules through the process of photosynthesis.
- Under photosynthesis, photoreceptors in plants called chlorophyll absorb sunlight. When light falls on chlorophyll it excites electrons in the chlorophyll. This is how energy from sunlight is captured.
- The excited electron then carries this energy and transports it to different parts of the plant body and stores. (follow the path of electron in the figure)
- The energy carried by the electrons is stored in a kind of rechargeable batteries in plants called ATP molecules. (future civil servants need not know the details of this molecule)
- These rechargeable batteries called ATP are stored in the sugar molecules of plant biomass built by plants.
- To do this, plants use CO2 and H2O in the atmosphere.

Cellular respiration: using the energy stores

- Ultimately all living organisms access energy through the process of cellular respiration.
- The process of utilizing the energy contained in food is called cellular respiration.
- Cellular respiration is just a way of taking in energy stored in the sugar molecules to run life activities.
- The food we eat is first digested or broken into simple sugars and carried in the bloodstream which carries the energy-rich sugar to all the cells of the body.
- The cells in turn use the energy in the sugar to form the rechargeable batteries ATP in the cells which then acts as drivers of life activity. Once done CO2 is released.
- Again, it is the electrons that carry energy.
- Once all the energy is delivered to ATP the electron needs a place to go. For this all living beings have electron acceptors.
- Oxygen is the most common electron acceptor. That's why we breathe oxygen.
- Finally, after oxygen receives electrons, it combines with hydrogen to form water completing the process of cellular respiration.
- Thus, for cellular respiration we need glucose and oxygen.
- $C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$ + energy (needed for life activities)

Cellular respiration in low oxygen condition

- When we are doing strenuous job like running or swimming, we need more energy. This energy is got from breaking down of glycogen (storehouse of glucose in our body) that is stored in the liver.
- However, there is not enough oxygen to accept electrons. Thus, cellular respiration comes to a halt.
- Alternately humans use pyruvate molecules (broken sugar) as electron acceptor instead of oxygen.
- When pyruvate accepts electron, it forms lactic acid instead of H2O.

Fermentation: cellular respiration in the absence of oxygen

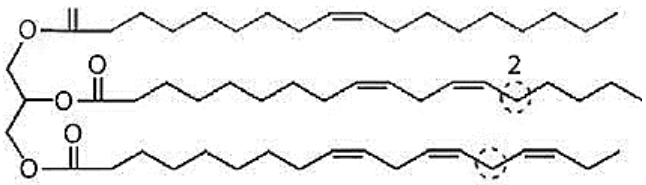
- Yeasts like humans also breakdown their food using oxygen.
- In the absence of oxygen, they produce alcohols that we drink.

- In yeasts after breaking down of glucose into pyruvate. After this the pyruvate is converted into acetaldehyde which acts as electron acceptor in the absence of oxygen.
- When acetaldehyde accepts electron, it forms ethanol.
- This anerobic respiration is called fermentation.

39. BIODIESEL: FROM TRANSESTERIFICATION

WHAT IS BIODIESEL?

- Oils from oilseeds are basically straight chain hydrocarbons but long ones.
- This is the only difference between biodiesel and diesel.
- If we take vegetable oil and break its long hydrocarbon straight chain into 1/3rd, 1/3rd, 1/3rd you get biodiesel.
- Biodiesel can directly replace diesel in diesel-IC engines.
- The resultant product, i.e, biodiesel is called ester.
- That's why the process of breaking long straight chain hydrocarbons into short chains is called transesterification.
- Breaking can be done by following ways:
  - Heat it: Pyrolysis
  - Apply pressure: Cracking
  - Replace double bonds with hydrogen: Hydrogenation



Feedstock

- Any oil seed can be used to extract oil. However, better option is to use non-edible oil seeds.
- There are more than 200 variety of oil seeds that can be used to produce biodiesel.
- Some common examples include rice bran, sal, neem, mahua, karanja, castor, linseed, jatropha, honge, rubber seed etc.

Advantages

Fuel	Energy density] (in MJ/ kg)
Ethanol	24-25
Peirol	43-44
Biodiesel	40-41
Diesel	45.5

- High energy density
- Low energy input
- Nitrogen-fixation
- No Sulphur
- No aromatics

A CASE FOR BIODIESEL

- India uses 5 times more diesel than petrol, so an alternative for diesel is more important than that for petrol.
- De-sulphurisation of diesel is cost intensive.
- Rural development: growing oilseed-based crops for biodiesel will augment farmer's income.
- Converting degraded land
- Improves soil fertility as most oilseed-crops are leguminous crops which helps in nitrogen fixation.

40. BIOFUELS: GENERATIONS

- Biofuels are classified into different generations based on the strategy adopted to derive energy from biomass.
- Accordingly, there are 4 generations of biofuels.

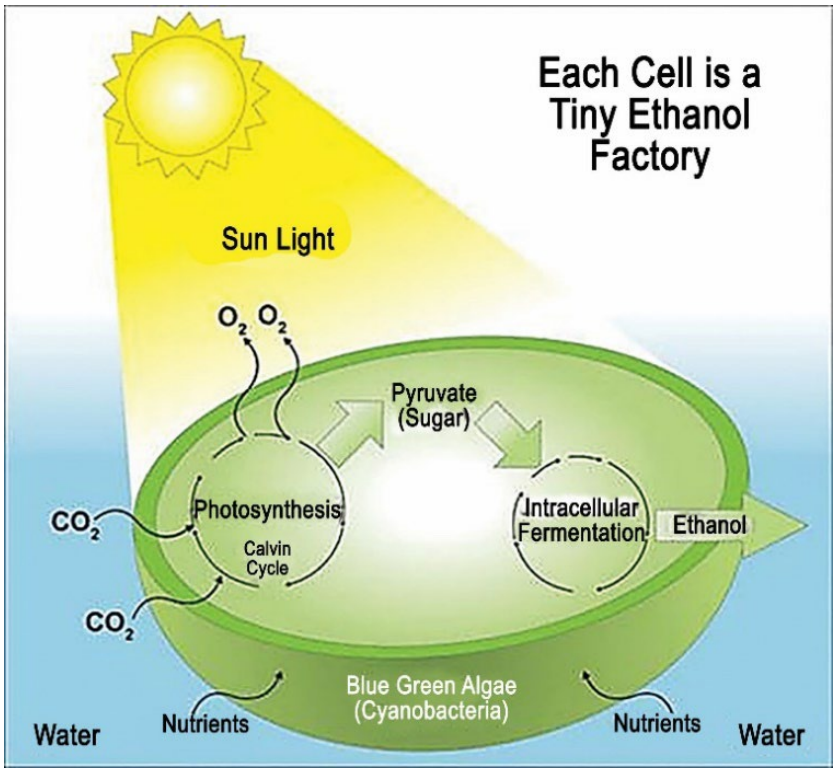
1ST GENERATION (MOSTLY EDIBLE SOURCE)

- Biofuels derived from edible source.
- Includes both starch-based ethanol and biodiesel (made from edible vegetable oil)
- Sugarcane, corn, and other starch-based crops (sugar beets, rice, wheat, potatoes)
- Oilseeds include rape-seed, sunflower seed, soybeans, palm seeds, rice bran etc.
- Non-edible source Jatropha in India

2ND GENERATION (CELLULOSIC BIOFUEL)

- Non-edible feedstocks like grasses, leaves etc
- Ligno-cellulosic: Mostly wood
- Agricultural waste including rice husk, corn stalks etc

3RD GENERATION (MOSTLY ALGAL BIOMASS-BASED)



Biofuels from high-photosynthetic efficiency organisms like algae.

- Feed-stock include:
  - Macro-algae
  - Micro-algae
  - Aquatic plants (water hyacinth)
- While most plants are very inefficient in photosynthesis (only 0.5% of sunlight is captured), algae have very high photosynthetic efficiency capable of growing very fast capturing the CO2 from atmosphere.
- Algae extracts large amounts of the carbon dioxide to feed their growth and very little is left to emit to the open air.
- The so grown algae can be used as input for producing both ethanol and biodiesel.

Advantages

- Fastest photosynthesis
- Do not need arable land
- CO2 sequestration (CO2 source can be coal-based power plants too, see section on Direct capture under CCUS technologies)
- Lipids (can be used for biodiesel) and protein source (single-cell protein source)

LIQUID TREE: LIQUID 3.0

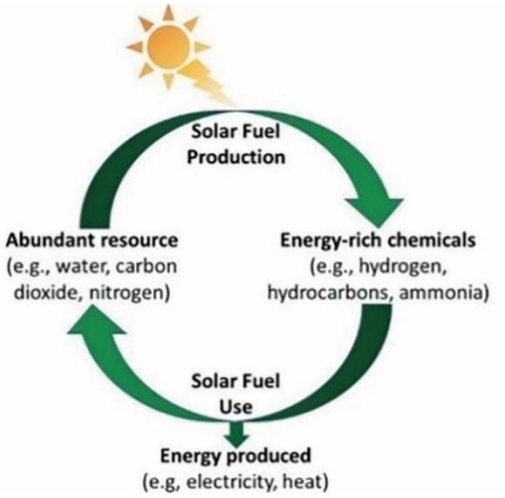
- Recently in Serbia scientists have created such a photo-bioreactor using algae to capture CO2 from the atmosphere.
- It contains 600 litres of water and works by using microalgae to bind carbon dioxide and produce pure oxygen through photosynthesis, in addition to producing biofuels.

NOTE ON METHANOGENS

- Additionally, there are organisms called Methanogens which capture sunlight to produce methane.

4TH GENERATION BIOFUELS: SOLAR FUELS: ARTIFICIAL LEAF AND PHOTOSHEETS

- This is application of synthetic biology to make biofuels.
- The approach includes mimic the biological process of photosynthesis to make energy-rich fuels. (Artificial photosynthesis)
- Currently there are two types of technologies performing artificial photosynthesis namely artificial leaf which produces syngas and photosheet technology which produces formic acid.
- Artificial leaf is a silicon-device powered by sunlight which produces synthesis gas (SynGas) by capturing CO2 form atmosphere or flue gas from power plants.
- While artificial leaf is a cleaner way to produce syngas their main limitation is its produces gas and takes an extra effort to store it in the form of liquid.
- Photosheet technology on the other hand produces formic acid which is stored as a liquid fuel.



41. GASIFYING BIOFUELS: BIOMETHANATION AND CBG

- Always remember the best way to biomass for energy production is to somehow extract only methane out of it and leave the rest for plant use.
- To gasify biomass is to copy what happens in a cow's stomach.
- Unlike humans, cow breaks down cellulosic biomass in its digestive process called anaerobic digestion.
- Cows have in its digestive system a large fermentation chamber filled with billions of microbes like bacteria and protozoa.
- The food that enters the fermentation chamber is broken down by these microbes, in the absence of oxygen, producing methane in its burps and fart. Mimic this process using bio-digesters you get biogas.
- Biogas is a mixture of methane, CO2 and hydrogen sulphide. So you need to separate CH4 before using it.
- Once separated compress methane to store it and transport it. This process is called bio-methanation.
- Feedstock can be agriculture waste which is mostly cellulosic biomass, cattle dung, sugarcane press mud, municipal wet waste etc.

42. SATAT

- In 2018 Sustainable Alternative Towards Affordable Transportation (SATAT) initiative was introduced to promote CBG as an alternative to CNG.
- Target is to produce 15 million tonnes of gas aiming to reduce CNG use by 40%. (CNG is imported)
- Particularly useful in states like Punjab, Haryana and Uttar Pradesh which are infamous for stubble-burning.

→ RENEWABLES

43. SOLAR ENERGY

NATURE OF SOLAR ENERGY

Ultimate source

- Solar energy represents the ultimate source of all energy on earth.
- All energy sources we have seen so far is simply energy from sun that was captured, be it in the form of ATP in plant biomass or energy in hydrocarbons in fossils.
- However, the amount of energy plant biomass or fossils have captured is a small proportion of energy from the sun.
- Thus, if we can find ways to access energy from the sun directly, we can increase the energy captured.

Intermittent nature

India working on an 'Energy Storage' policy

2 min read . Updated: 12 Oct 2021, 08:05 AM IST

Livemint

- Besides since energy from the sun is accessible only during the day, solar energy, like other renewable sources, suffer from what is called as intermittency problem.
- As a result, an essential component of renewable energy including solar energy is energy storage.
- This is why India is mooting an Energy Storage Policy towards large-scale integration of renewable energy to the grid.

Decentralised source

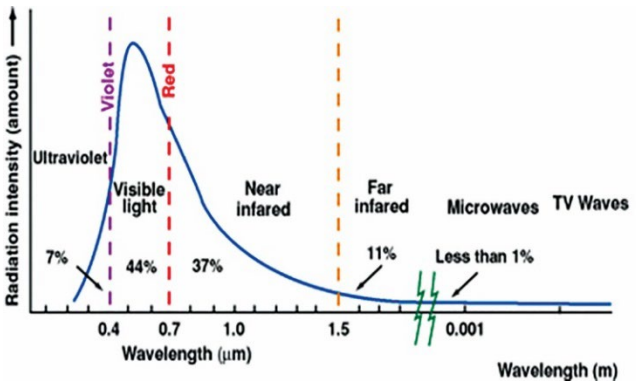
- Solar energy represents decentralized energy source as sunlight represents distributed energy resource.
- This said, India's share of decentralized renewable energy is meagre 6% of the total renewable energy capacity.
- The low share of decentralized solar energy, about 6.5 GW as against the target of 40GW, is the main reason for missing the target of 175GW of RE by 2022.

> India established a lofty goal to install 175 GW of renewable energy capacity by the year 2022, with 100 GW coming from solar, 60 GW from wind, 10 GW from biopower, and 5 GW coming from small hydropower
>
> *Status in India*

44. PATHWAYS OF CAPTURING ENERGY FROM THE SUN

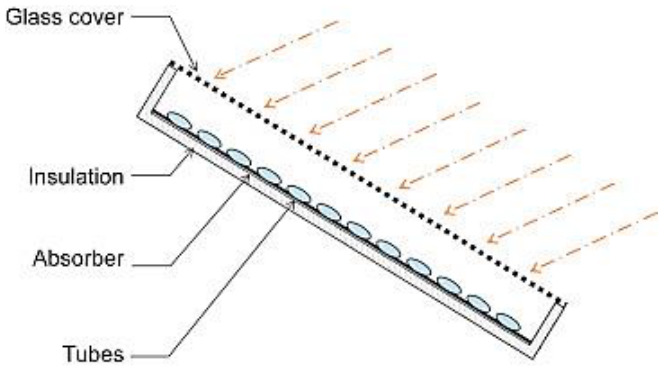
There are different ways to capture energy from the sun including:

- Solar thermal
- Solar concentrators
- Solar PV cells



45. SOLAR THERMAL

- The basic principle behind solar thermal is the green house effect. It is way to capture sun's energy in the form of heat.
- Since heat is low quality energy it has limited applications and thus suitable only for domestic applications like solar water heaters, solar pumps etc.



PRINCIPLE: GREENHOUSE EFFECT

- Solar energy is an admixture of various electromagnetic radiation with visible light constituting the maximum proportion. See figure for sun's emission spectrum.
- Thus, in order to gain maximum from sunlight we need to capture visible light from the sun.
- In order to do this, we use the principle of greenhouse effect demonstrated by glass.
- Glass is transparent to visible light and opaque to infrared light.
- So, glass cover is used in the top layer to allow visible light and block the infrared from the sun.
- This visible light is made to fall on a metal plate coated black which absorbs most of the visible light. (absorber in the figure)
- As a result of absorption of energy, the black metal emits infrared radiation which cannot pass through the glass cover.
- Thus, energy from visible light is trapped between glass cover and metal plate.
- This energy is in the form of heat (convection current) which can be carried by water or air.
- Besides the direction of the set up should be such that it should be able maximize the sun's rays incident on it.

- In northern hemisphere, it should be inclined at an angle equal to the latitude and south-facing.

Advantage

- The efficiency of solar thermal can reach upto 60%.

Disadvantage

- It is suitable for domestic applications as it cannot be scalable. (water is heated upto 60-70 degree celsius)

46. SOLAR CONCENTRATORS

- In applications where you need temperatures above the boiling point of water you use solar concentrators.

- Solar concentrators use a bunch of mirrors in such a way to focus all the incoming solar energy at one point from where it can be collected and carried.
- Solar towers are an example of solar concentrators.
- At the top of the tower is a sodium salt which can hold heat for longer time thereby increasing the amount of heat that can be captured.

Advantage

- You can heat the salt and keep it for later use when there is no sunlight.
- Efficiency is as high as 50%.

Disadvantage

- Capital cost is high as mirrors are expensive.
- High land requirement: 1.5 hectare per mega watt.

SOLAR TOWERS IN INDIA

- Bhadla solar park in Jodhpur Rajasthan. (biggest plant in the world)

47. SOLAR PV CELLS

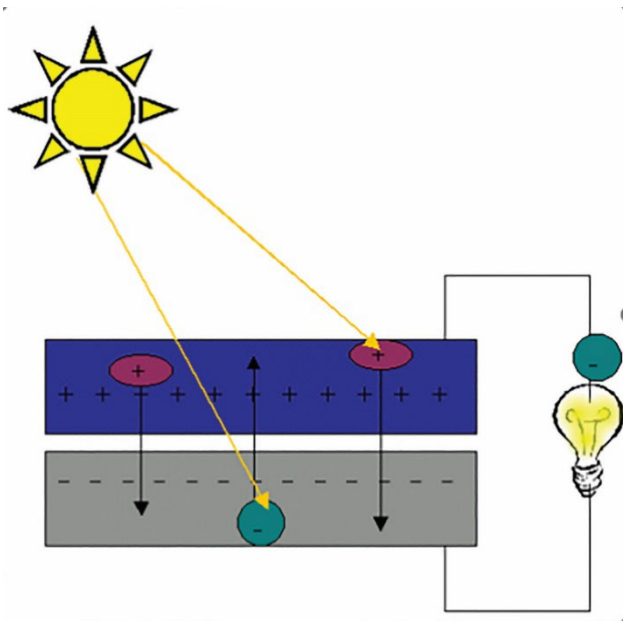
- Solar PV is the mainstay of solar energy particularly with decreasing cost of PV cells in the recent times.
- Photo voltaic cell is an example of photodetector devices which work on the basis of photoelectric effect.
- It is a way of directly using sunlight to produce electricity.

PHOTOELECTRIC EFFECT

- Photoelectric effect, 1st demonstrated by Einstein, relies on the interaction of photons and electrons and their behaviour during interaction.
- Flash a beam of light on to some material like metal it will knock-off electrons, collect these electrons at an electrode. Connect the electrode to a wire and there you have electricity.

WORKING OF PV CELLS

- A photovoltaic panel creates electricity when a photon hits the silicon surface and pushes an electron out of the top layer of the silicon and across an electrical junction inside the panel.
- The movement of this electron creates a useful voltage. When wires are connected to produce a circuit, this voltage means that current will flow, eventually taking the displaced electron back to the top layer.
- Solar cells work best in strong sunlight but will also generate some power on an overcast day from the diffused light that gets through the clouds.
- **Nature of electrical energy from PV cells**
- **DC current**



TYPES OF PV CELLS

1. 1st gen: Single crystal PV cells
2. 2nd Gen: Thin-film PV cells
3. 3rd Gen: Perovskites

1st generation PV cells

- These are basically silicon-based.
- Single crystal silicon: have the highest efficiency, around 20-25%, high-cost manufacturing
- Amorphous silicon (powdered): efficiency is 5%, used in calculators

2nd generation PV cells: Polycrystalline PV cells

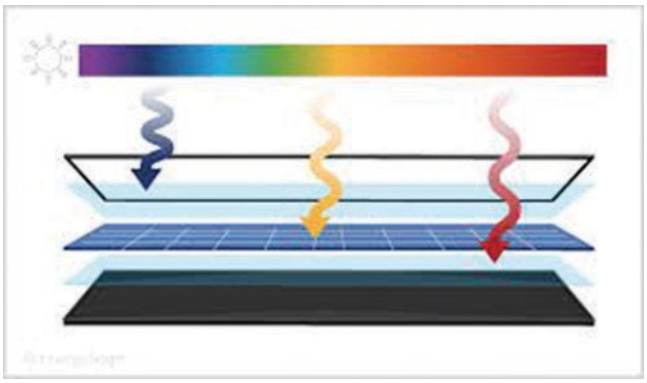
Cadmium Telluride

- CdTe can be deposited on thin sheets. So you can make flexible PV panels.
- CdTe absorbs sunlight readily to release electrons. So thin sheets can be made.
- Efficiency ~ 15%
- Disadvantage is cadmium is highly toxic.
- Tellurium is not available as it is a rare earth metal. It is found in under-water ridges.

CIGS: Copper Indium Gallium Selenide

Advantage:

- Similar to CdTe, it can absorb sunlight readily. Besides it is not toxic like CdTe.
- Disadvantage: Indium is in short supply



Multi-Junction PVs: Gallium-Arsenic, Indium, germanium

- Layers of semiconductor and metal
- Main advantage is high efficiency because different materials absorb different wavelengths from the sun.

3rd generation PV cells

Perovskites

- The main advantage of perovskites is they can used to make PV paints which can be painted on conformal surfaces like cars.
- Very recently organic-perovskite solar cells have reached efficiency of a record-breaking 24%

48. ENERGY STORAGE

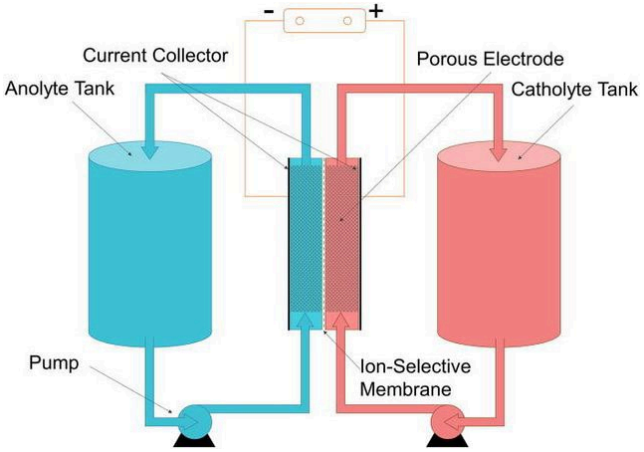
- Notwithstanding the advantages, Renewables have a peculiar problem called intermittency problem which means it is not available round the clock.
- Thus, energy storage becomes an important component of renewable shift.
- The most important energy storage strategy is batteries.

49. GRID-LEVEL BATTERY STORAGE: FLOW BATTERIES

(For basic principle on batteries and types of see section on batteries)

- The batteries we have discussed in the battery section including Li-ion batteries are not suitable to store energy for longer time.
- The energy storage at the grid level requires us to store energy atleast for 8 hours (night).
- The alternative suitable for grid-level storage is flow batteries.

50. FLOW BATTERIES



- The basic difference between conventional batteries and flow batteries is that while in convectional batteries we derived chemical energy of the electrodes, in flow batteries the energy is derived out of the flow of electrolytes.
- A flow battery uses two electrolyte solutions separated by a membrane to store electrical energy.
- A flow battery consists of two tanks - one for the positively charged electrolyte solution (called the catholyte) and one for the negatively charged electrolyte solution (called the anolyte).
- During charging the catholyte and anolyte flow on opposite sides of the membrane which is like going uphill.
- During discharge, the process is reversed. The catholyte and anolyte flow back into their respective tanks, and the electrical energy that was stored in the battery is released to power a device or a system.

Advantage

- Flow batteries are unique in their scalability which makes them suitable for grid-level storage.

51. SUPER CAPACITORS

Principle

- A capacitor is a device that stores electric charges thereby electric energy
- It is a set of two metal surfaces separated by an electric insulator.
- Put positive electric charge on one plate, negative on the other, and the combination can store energy for a long time, much longer than batteries can.
- Add more electric charge on the plate and you store more energy, but you also raise the voltage.
- The trick for storing energy in capacitors is making the insulator very thin, so that you can have lots of energy per unit volume while keeping the voltage low.
- These high energy-density capacitors are called supercapacitors or ultracapacitors.

Advantages

- Since capacitors don't depend on chemical reactions, they can release their energy extremely quickly thus suitable for EVs
- Not subject to degradation with use and time.
- Because they can be charged so quickly, supercapacitors can be used to improve the efficiency of regenerative braking; they absorb the energy in charges and release it when needed.

Disadvantage

- Supercapacitors can store about 1/3rd the energy of a same-weight lithium-ion batteries.
- Costs 3 times more than Li-ion batteries.

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7 CHAPTER DEFENCE TECHNOLOGY

1. MISSILES OF INDIA

CRUISE MISSILE AND BALLISTIC MISSILE

CRUISE MISSILE	BALLISTIC MISSILE
A cruise missile is guided towards a preset land-based target using a navigation system.	A ballistic missile is generally a projectile shot up in the atmosphere.
Cruise missiles are known for low altitude flight and high mobility and hence the name.	Ballistic missiles are launched outside the atmosphere where its warheads detach and hit the target. (uses gravity of earth and thus traces a parabolic path and hence the name)
Cruise missiles have short ranges of 300 to 1000 km. Brahmos – 290 to 450 km Nirbhay – 700 to 1000	Ballistic missile have long ranges up to 1000 km (ICBMs) Agni V – 5000 km
Easy to intercept because of high terminal speeds.	Difficult to intercept due to high terminal speeds of 5000 m/s
High precision due to navigation system	Low precision
Cheaper and thus suitable for firing conventional warheads	Expensive and thus suitable for firing nuclear warheads.

2. SHORT-RANGE BALLISTIC MISSILE

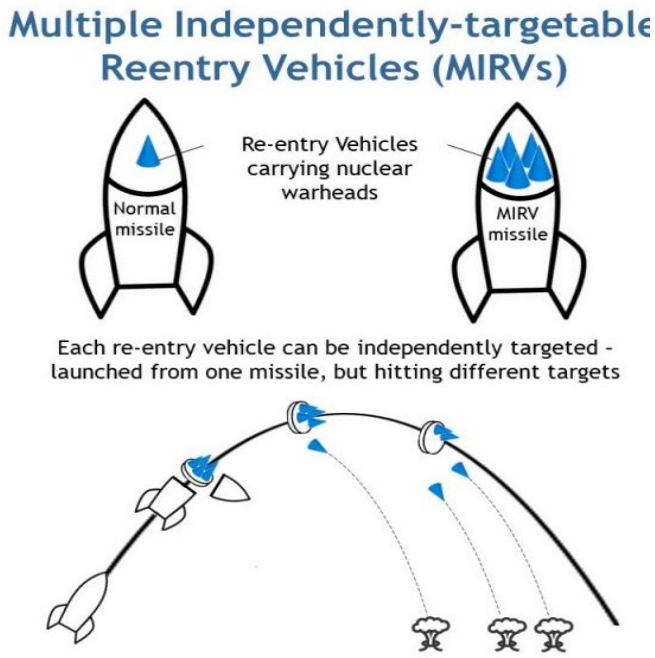
NAME	RANGE	WEAPON PAYLOAD	CHARACTERISTICS
PRITHVI-I	150 KM	1000kg	Short range surface-to-surface tactical ballistic missile
PRITHVI-II	350 KM	500Kg	Air Force Version
PRITHVI-III	350 KM	1000kg	
DHANUSH	350 KM	1000Kg	Naval Version of Prithvi I and Prithvi II class missiles
SHAURYA	600-700 KM	1000 Kg	• Hypersonic Canister-launched • Both conventional and nuclear warheads
PRAHAAR	150 KM	250 Kg	• To replace Prithvi I • Weapons: High explosives, cluster munition, strategic nuclear weapon
AGNI-I	700–900 KM	1000 Kg	• Single stage solid fuelled

			• Nuclear capable missile

3. INTERMEDIATE-RANGE BALLISTIC MISSILE

NAME	RANGE	WEAPON PAYLOAD	CHARACTERISTICS
AGNI-II	2000-3000 Km	1000Kg	Two and a half stage, solid fuelled missile with
AGNI-III	3200 Km	2000-2500 Kg	2-stage solid propulsion system
AGNI-IV	3500 Km	1000 Kg	2-stage missile powered by solid propellant

4. INTER-CONTINENTAL BALLISTIC MISSILE

NAME	RANGE	WEAPON PAYLOAD	CHARACTERISTICS
AGNI-V	**>5000 Km**	1500 Kg	3-10 Multiple Independently Targetable Reentry Vehicle (MIRV) warheads 
AGNI-VI	8,000–10,000 km (Under development)	1000 Kg	MIRV warheads
SURYA	10000 Km (Under development)	3000 Kg	MIRV warheads

5. SUBMARINE-LAUNCHED BALLISTIC MISSILE

NAME	RANGE	WEAPON PAYLOAD	CHARACTERISTICS
K-15 Sagarika	750 km	500 Kg	• Replica of land based Shaurya Missile.

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			• K-15 Missile gets help from Indian Regional Navigation Satellite System. • The K-series missiles are much faster than Agni Missiles
K-4	3500 Km	1000 Kg	• Nuclear-capable underwater missile • Meant for Arihant class submarines. • It is a solid-fuelled missile launched underwater capable of withstanding 50N of water pressure. • Submarine version of Agni 3. (Agni 3 – 17 m K-4 – 10 m)
K5 (Under development)	5000 Km		
K6 (Under development)	6000 Km		

6. CRUISE MISSILES

NAME	RANGE	WEAPON PAYLOAD	CHARACTERISTICS
Nirbhay: Subsonic Cruise Missile	750-1000 Km	500 Kg	• Long range subsonic cruise missile. • 1st indigenously developed long range cruise missile flying at low altitudes. • It will arm the army, the navy and the air force. • **Speed**: Subsonic speeds of 0.7 mach. (speed of sound) • **Range**: Long range of 700 to 1000 km. • Can fly at tree-top altitudes as low as 10 m. (now tested for 5 m) • Capable of delivering nuclear warheads of 200-300 kg. • 2-stage solid fuelled cruise missile. • As a result it has terrain-hugging capability and sea-skimming capability and thus go undetected by enemy radars.
Brahmos: Supersonic Cruise Missile	290 Km	300 kg	• Joint venture missile between India and Russia. • **Speed**: Top speed of 2.8 Mach (speed of sound). • **Range**: After India became a full member of the MTCR export control regime, the range of BrahMos has increased from 300 km to 450 km. • Fire and forget principle of operation • Capable of being launched from land, water and air. **BRAHMOS NG** Low weight Air-launched version capable of being carried by Light Combat Aircraft, Tejas LCA
Brahmos II: Hypersonic	290 Km	300 Kg	6 Mach

7. SHORT-RANGE SURFACE-TO-AIR MISSILES

NAME	RANGE	WEAPON PAYLOAD	CHARACTERISTICS
TRISHUL	**9 – 12 Km**	**5 Kg**	• Short range low-level surface-to-air missile
AKASH	**30 Km**	**50 Kg**	• Supersonic speed: Mach 2.5. • Medium range surface-to-air missile • Part of Air-defence system • It can simultaneously engage multiple targets in Group Mode or Autonomous Mode. • It has built in Electronic Counter Counter Measures (ECCM) features. • Indigenous seeker technology.

MAITRI (QRSAM)	**25–30 km**	**10 Kg**	• Developed by DRDO in collaboration with BEL and Bharat Dynamics Ltd.
			• Most effective in combating low flying Aerial targets faced by forward tactical battlefield area formations like
			  ○ Attack helicopters
			  ○ UAVs
			  ○ Armed drones
			  ○ Subsonic Cruise missiles
			• QRSAM is part of India's air defence system.
			• Capable of striking targets on-the-move.
			• It can strike targets at various altitudes from 30m to 6km.
			• It has a speed of 700-800 metres per second
			• RF seeker (Radio Frequency) as a part of terminal guidance to hit the target.
			• It has a truck-mounted canister.
			• It is capable of multiple-target engagement.
			• It is light-weight, has high-mobility and shorter-reaction time compared to Akash Air Defence Surface-to-Air Missiles.
			• It is equipped with electronic counter measures against the aircraft jammers to deceive enemy radar.

REVATI	**25–30 km**	**10 Kg**	**(Naval-Version of Maitri)**
ROHINI	**25–30 km**	**10 Kg**	**(Air Force-Version of Maitri)**
BARAK-8	**70-100 Km**	**60 Kg**	• Indian-Israeli Medium Range Surface-to-Air-Missile • Part of naval air defence system To be used aboard INS Vikrant (under construction) • maximum speed of Mach 2
IGLA-S	**Maximum range of 6km, altitude of 3km**		• Russia's Very Short Range Air Defence Systems (VSHORAD) • Man-Portable Shoulder launched Air Defence System • It can aim at enemy targets using • Infrared signature • Laser targeting • Remote-controlled targeting

8. AIR-TO-AIR MISSILE

NAME	CHARACTERISTICS
ASTRA	• It is a BvRAAM (Beyond Visual Range Air to Air Missile). • 1st air to air missile developed by India. • Capable of engaging targets at varying range and altitudes. • Both short range targets at a distance of 20 km and long range targets up to a distance of 80-110 km.

9. ANTI-TANK GUIDED MISSILE

NAME	RANGE	WEAPON PAYLOAD	CHARACTERISTICS
NAG	3-7 Km	8 kg	• 3rd generation anti-tank missile, best in its class for Indian conditions. • Fire and forget capability. • Imaging Infrared(IIR) guidance with day and night capability • Weight - 48 Kg and therefore fired from a BMP-2 vehicle called **Namica(Nag Missile Carrier)** **DIFFERENT VARIANTS** 1. Mounted on an infantry combat vehicle: NAMICA (Nag Missile Carrier) 2. Man Portable shoulder carried 3. HeliNa: (Helicopter-launched Nag) Rudra Helicopter, Dhruv and LCH.
HELINA	7 Km	8 Kg	Helicopter-launched Nag
SPIKE			• Israeli 4th generation anti-tank guided missile. • Fire-and-forget capability • Available in man-portable, vehicle-launched, and helicopter-launched variants. • Change the target mid-flight as a result of dual-seeker. • Kill-probability of 95% • Better than Nag because Nag is facing seeker issues especially if the temperature of the target is high.
MILAN			• It is an anti tank guided missile for the Army. To be acquired from France.
SPICE 2000			• Israeli guided bombs for the Indian Air Force.

➔ INDIA'S MISSILE DEFENCE SYSTEMS

10. BALLISTIC MISSILE DEFENCE SYSTEM

- 2-tier missile defence system
- Aimed at intercepting aerial threat from ballistic missiles that have ranges up to 5000 km at altitudes both outside (exo) and inside (endo) the atmosphere
- **1st layer: Endo**
  - The single stage solid rocket-propelled **Advanced Air Defence (AAD) low-altitude interceptor** missile. (**Ashwin**)

- The AAD interceptor missile is primarily designed to intercept enemy missiles in the endo-atmosphere at altitudes of 20-40 kilometres.

- **2nd layer: Exo**
  - Prithvi Air Defense Vehicle known as Pradyumna Ballistic Missile Interceptor is designed to destroy missiles with ranges 300-2000 km at exo-atmosphere (about 80 km altitude).
  - For higher altitudes up to 150 km, Agni-V-based ballistic interceptors would be used. (because of 5000 km range)

11. MULTI-LAYERED AIR DEFENCE SYSTEM: S-400

- India has signed a deal with Russia to acquire the S-400 Triumf multi-layered air defence system.
- S-400 is known as Russia's most advanced long-range surface-to-air missile defence system.
- The S-400 layered defence system can intercept all types of aerial targets including aircraft, unmanned aerial vehicles (UAV), and ballistic and cruise missiles up to the range of 400 km, at an altitude of up to 30 km.
- Capable of firing three types of missiles to create a layered defence.
- **Note**: USA had offered **THAAD** and **Patriot** as alternatives to S-400 to India.
- **Iron Dome**: Israeli SHORT-RANGE AIR DEFENCE System.

12. BARAK-8 LONG AND MEDIUM RANGE SAM

- Medium-range surface-to-air missile system being developed jointly by India and Israel.
- It will have an interception range of 70-100 km.
- Part of naval air defence system To be used aboard INS Vikrant (under construction)
- Maximum speed of Mach 2.

13. AKASH MEDIUM-RANGE SURFACE TO AIR MISSILE SYSTEM

- India has 2 regiments of the indigenous Akash systems which are capable of multi-target engagement.
- It can strike targets up to a range of 25 km and altitude of 18,000m.

14. MULTI-LAYERED AIR DEFENCE SYSTEM FOR DELHI

- India is developing a multi-layered air defence system for its cities besides air defence systems for tactical battle areas.
- 1st layer: 2-tier Ballistic Missile Defence System
- 2nd Layer: S-400 layered defence system
- 3rd Layer: Barak-8 long and medium range SAM
- 4th Layer: Akash medium-range surface to air missile system

15. HYPERSONIC MISSILES

- Travels at Mach 5 or higher (more than one mile per second)
- They typically consist of a Supersonic Combustion Ramjet or Scramjet propulsion system to enable such high speeds.
- Scramjet engine collects oxygen from the atmosphere as it is travelling and mixes the oxygen with its hydrogen fuel, creating the combustion needed for hypersonic travel.
- India is developing a **Hypersonic Technology Demonstrator Vehicle (HSTDV)**.

- It is an unmanned scramjet (allowing supersonic combustion) demonstration vehicle that can cruise to a speed of mach 6 (or six times the speed of sound) and rise up to an altitude of 32 km in 20 seconds. It has been developed by DRDO.
- There are 2 types of Hypersonic Weapon Delivery Systems
  1. Hypersonic Cruise Missiles (HCM)
  2. Hypersonic Glide Vehicle (HGV)

SIGNIFICANCE

- They are a mix of the speed of a ballistic missile and manoeuvring capabilities of a cruise missile.
- While cruise missiles achieve speeds of 550 miles per hour, the hypersonic missiles aircrafts can reach speeds more than 3500 miles per hour.
- Capable of penetrating any anti missile defence system currently available that are designed to intercept cruise and ballistic missiles.
- Specifically designed for increased survivability against modern ballistic missile defence systems.

16. IMPORTANT HYPERSONIC MISSILES

Only the USA, Russia and China have hypersonic missiles.

USA: Possesses hypersonic missiles, but specific details are classified.

Russia:

- **Avangard**: Nuclear-capable hypersonic boost-glide vehicle (Mach 20, 6000+ km range).
- **Kinzhal:** Nuclear-capable air-launched ballistic missile (Mach 10, 2000+ km range).
- **China:**
  - **Starry Sky 2:** Hypersonic glide vehicle utilising waverider technology. It is known as waverider for its ability to ride on the shock waves it generates.
  - **Dongfeng Missiles:** Hypersonic missile systems.

➔ AIRCRAFT CARRIERS OF INDIAN NAVY

17. INS VIKRANT

- 1st aircraft carrier of India
- Decommissioned in 1997 after serving for 37 years.

18. INS VIRAAT

- 2nd and the longest serving aircraft carrier of India.
- Decommissioned in 2017 after serving for 56 years. (26 years as HMS Hermes and 30 as INS Vikrant)

19. INS VIKRAMADITYA

- India and Russia signed $1.5 billion for the acquisition of the warship INS Vikramaditya inducted to the Indian Navy in 2013.

20. INS VIKRANT

- India's 1stIndigenous Aircraft Carrier, inducted into the Indian Navy in 2022.

21. INS VISHAL

A 65000 tonne Naval supercarrier on the lines of HMS Elizabeth is planned to be built by India.

➔ SUBMARINE ARM OF INDIA

CONVENTIONAL SUBMARINES OF INDIA

22. PROJECT 75-I

- 6 Scorpene class submarines are being constructed with Transfer of Technology from France.
- The 6 Scorpene class submarines will be the core of India's conventional attack submarine arm.

Project 75-I Submarines (Scorpène-class)

- **INS Kalvari:** Inducted in 2017
- **INS Kandheri:** Inducted in 2019
- **INS Karanj:** Inducted in 2021
- **INS Vela:** Inducted 2021
- **INS Vagir:** Inducted 2023
- **INS Vagsheer:** Launched for trails in April 2023

- The submarines built under the project will be capable of
  - Anti submarine warfare
  - Intelligence, Surveillance and Reconnaissance missions
  - Underwater mining operations
  - Equipped with the Air Independent Propulsion (AIP) system in order to stay underwater for longer duration and thus increase their operational range and stealth capabilities.

NUCLEAR-POWERED SUBMARINES

Nuclear submarines can be classified into two categories namely SSN and SSBN:

23. SSN: (SUBMERSIBLE SHIP NUCLEAR)

- SSNs are attack submarines
- They are propelled by nuclear power.
- They are capable of launching **conventional weapons** like torpedoes and cruise missiles

24. SSBN: (SUBMERSIBLE SHIP BALLISTIC NUCLEAR)

- SSBNs are also propelled by nuclear power.
- They are usually equipped with nuclear weapons like ballistic missiles.
- Therefore they are usually used as deterrents and not as attack submarines.

25. NUCLEAR-POWERED SUBMARINE FLEET OF INDIA

SSN FLEET

CHAKRA-I

- 1st nuclear-powered submarine to be inducted into the Indian Navy.

CHAKRA-II

- 2nd nuclear submarine to be inducted into Indian Navy. It was inducted in 2012

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- It is an advanced version of Chakra I with following features:
  - It can displace twice the amount of water compared to Chakra I, thereby higher operating depths.
  - Higher speed of 30 knots.
  - The onboard nuclear reactor produces double the power.
  - It has a more advanced weapon system including tube-launched missiles.
  - Chakra II is deployed with the Eastern Naval Command.

CHAKRA-III

- In 2019, India and Russia signed an agreement for leasing of the Akula class nuclear powered submarine Chakra III for $3 billion for at least 10 years.
- Powered by 190 MW nuclear power. Expected to be delivered in 2026 or later.

SSBN FLEET

Arihant

- Under the Advanced Technology Vehicle programme, India has indigenously-built Arihant, SSBN.
- India's 1st nuclear-powered ballistic missile submarine.
- Displacement capacity of 6,000 tonnes.
- Powered by an 83 MW pressurised light-water reactor with enriched uranium.
- Formally inducted in November 2019 marking the Nuclear Triad capability of India.
- Capable of launching K-15 Missile with a range of 750 km and K-4 ICBM with a range of 3,500 km.

Arighat

- 2nd Arihant-class submarine built under Advanced Technology Vessel Program.
- Powered by a pressurised water reactor.
- Maximum speed of 12–15 knots (22–28 km/h) when on surface and 24 knots (44 km/h) when submerged.
- 4 launch tubes can carry up to 12 K-15 Sagarika missiles or 4 four of the under-development K-4 missiles.

POSEIDON

- Anti Submarine Warfare aircraft, which India has acquired from the USA.
- It is a boost to maritime ISR capabilities (intelligence, surveillance and reconnaissance)
- Long-range maritime patrol aircraft capable of undersea surveillance from a height of up to 40000 ft.
- It has an operational speed of 450 mph, range of 4,500 nautical miles and operational time of up to 10 hours.
- It is equipped with Active Electronically Scanned Array (AESA) radars capable of engaging multiple targets simultaneously. Magnetic Anomaly Detection radar will help locate submarines in deep seas.

26. IMPORTANT FIGHTER JETS OF INDIA

TEJAS LCA	• 4th generation supersonic, single-seat, single-engine multirole light fighter aircraft. • Conceived in the early 1980s to replace the Russian-made MIG 21 of the Indian Air Force. • Designed and developed by Aeronautical Development Agency. • The combat-ready version of the fighter comprises battle-time requirements such as mid-air refuelling, AESA radar, electronic warfare suites, bombs and weapons etc. • India does not have even a single squadron of the indigenously produced fighters. • In contrast, both China has fifth generation fighters already in the test flying stage. • Pakistan also has an operational indigenously built fighter jet, JF 17 developed with Chinese assistance.
MIG 29	• India's premier Air Defense Fighter aircraft.

	• Light-weight air-superiority fighter aircraft developed by Russia. • Twin-engine jet fighter inducted into Indian Air Force in 1985. • With about 110 Mig-29s operated by the Indian Air Force and Indian Navy combined, India is the second biggest operator of Mig-29s in the world after Russia. • The MiG-29 aircraft played an important role during the Kargil War of 1999. • Three squadrons of 16-18 MiG-29s aircrafts each are deployed in the strategically important Adampur Air Force Station, which is around 100 km from Pakistan and 250 km away from China borders. • The MiG 29s are far more superior to F-16s of the Pakistan Air Force with the capacity to launch Beyond Visual Range BVR missiles.
SUKHOI-30 MKI	• Multirole combat fighter aircraft • Jointly developed by Russia and India. • India's answer to Pakistan's F-16. • Top speed of 2120 kph (Mach 1.7). • Capable of launching up to 6 air-air, 6 air-to-surface missiles, 6 laser guided bombs and 8500kg of cluster bombs. • This has provided a significant strategic deterrence against China and Pakistan in multi-mission roles, including precision strikes on terror camps across the LoC, against high-value naval targets, including aircraft carriers and nuclear bunkers.
RAFALE	• Twin-engine medium multi-role combat aircraft, manufactured by French company Dassault Aviation. • Can carry weapons more than 9 tonnes including air-air, air-ground and air-ship missiles. • Main roles include missions including Air-defence/air-superiority, Reconnaissance, close air support dynamic targeting, Air-to-ground precision strike/interdiction, anti-ship attacks, and nuclear deterrence, buddy-buddy refuelling. • Can carry out both air-to-ground, as well as air-to-air attacks and interceptions during the same sortie. • Maximum speed of 1.9 mach. • Range of more than 3700 km vs 400-550 of Su 30. • Weapon system include SCALP and METEOR missiles • **SCALP:** Precision long range ground attack missile that can take out targets with extreme accuracy. Has a range of 300 km, capped by the missile technology control regime. • **METEOR:** Beyond visual range air to air missile that is possibly the best in its class. Can take out enemy aircraft at a range of over 100 km.

27. IMPORTANT HELICOPTERS

LIGHT UTILITY HELICOPTER	• Developed as a replacement for Cheetah and Chetak helicopters. • New generation 3-Ton class helicopter. • Being indigenously developed by Hindustan Aeronautics Limited (HAL).
DHRUV	• Utility helicopter developed and manufactured by HAL. **Important Roles** • Commuter Role, Evacuation, Rapid Deployment of Forces, Logistic Air Support, Search and Rescue
CHINOOK	**Characteristics** • Acquired from USA under Foreign Military Assistance

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	• Heavy-lift Capability • Modern heavy-lift helicopter with payload lifting capacity of 10-12.5 tonne • Vertical-lift platform • Will replace the Mi-26 heavy-lift helicopters of IAF. **Importance** • Airlift artillery, light armoured vehicles, troops and supplies to difficult Himalayan mountainous terrains. • Assist Border Road Organisation to carry road construction and engineering equipment to difficult high-altitude terrains of North East. • Deployed in disaster relief operations.
APACHE	• Acquired from USA under Foreign Military Assistance • Multi-role combat helicopter. • All-weather helicopter that can engage both air and ground targets. • It is equipped with **Hellfire missiles** (air to surface anti-tank missiles). **SIGNIFICANCE** • Can approach enemy troops covertly with relative stealth and launch as close range attack. Capability to operate in hostile airspace. • Capability to destroy enemy tanks, armoured personnel carriers and fortified positions in mountainous terrain.
MH-60R (ROMEO) SEAHAWK HELICOPTERS	• Acquired from USA under Foreign Military Assistance • Naval multi-role helicopter. • Capable of being operated from various types of warships including frigates, destroyers, cruisers and aircraft carriers • Equipped with state-of-art SONAR suite which provides navigation, situational awareness, target data and weapon guidance capabilities.

28. AIRBORNE EARLY WARNING & CONTROL SYSTEM (AWACS)

- Indian Air Force has undergone a doctrinal shift from conventional warfare to sub-conventional warfare due to threats from proxy wars by Pakistan post 1990s.
- AWACS are one the short-term operational requirements identified by IAF in line with the counter-proxy war strategy.

WHAT ARE AWACS?

- Known as 'eyes in the sky'. Air-borne radar systems mounted on aircrafts for scanning and surveillance.
- With a 360-degree span, they are deployed to carry out surveillance on enemy Air Defence systems and to prepare an Air Situation Picture useful in aerial combats.
- **PHALCON:** AWACS procured by India from Israel.

29. NETRA

- The Netra Airborne Early Warning & Control System (AEW&CS) aircraft is a multi-sensor platform indigenously developed by DRDO.
- Netra has an indigenously developed Active Electronically Scanned Array (AESA) radar system mounted on the Embraer ERJ 145 twin-engine aircraft.

- The AESA radar is an airborne surveillance system with detection and tracking capabilities. It can track and find aircraft, missiles, ships and vehicles.

➔ MISCELLANEOUS

30. ANTI SATELLITE TECHNOLOGY

BACKGROUND

- Satellites form an integral part of a country's critical infrastructure.
- Intercepting satellites can halt various critical applications including navigation systems, communication networks, broadcasting, banking systems, surveillance etc.

WHAT IS A-SAT?

Anti-satellite technology is a counter-space capability of a country to neutralise space-based assets of an enemy country.

TYPES OF A-SAT

- **Missile-based A-SAT**: A missile is used to hit and destroy satellite using:
  - **Direct-ascent** kinetic kill vehicle (Chinese A-SAT in 2007, India now, USA and Russia)
  - **Co-orbiting** missile (Russia has this type)
- **Co-orbital drones**: Approach the target satellite and deviate it from its orbit. (China, UK, Russia are working on this technology)
- **High-energy lasers**: Blind the sensors of the satellites.
- **Interception and jamming** of signals from the satellites by sending more powerful radio signals.

HISTORY OF A-SAT MISSILE TESTS

- ASAT missile tests have been conducted by the USA and Russia in the cold-war era.
- The USA has had the anti-satellite weapon since 1959 followed by Russia in 1960.
- The cold-war witnessed the anti-satellite weaponry tests till early 1980s.
- China conducted the A-SAT weaponry test in 2007. (800 km orbit)

OUTER SPACE TREATY 1967

- According to this treaty, outer space shall be used only for peaceful purposes.
- It prohibits countries from placing into orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction.
- It requires that celestial bodies shall be used by all parties exclusively for peaceful purposes and no weapon can be stationed on them.
- However, the Outer Space Treaty by itself does not prevent an arms race in space.
- India is a party to the Outer Space Treaty.

31. MISSION SHAKTI

- Under Mission Shakti, India demonstrated the capability to destroy a satellite in low earth orbit using an anti-satellite missile in 2019.
- India became only the 4th country to conduct an Anti-Satellite missile test after the USA, Russia and China.

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TARGET

- Microsat R was a military imaging satellite placed in an orbit 274 km above the Earth surface with an orbital velocity of 7.8km/s.

TECHNOLOGY: 'HIT TO KILL'

- The anti- satellite test involved the 'hit to kill' missile technology.
- Under the 'hit to kill' technology, a missile is shot at the satellite in order to hit and kill the satellite.

KILL VEHICLE TECHNOLOGY

- The A-SAT missile was based on the exo-atmospheric kill vehicle technology.
- It includes
  - an 18-tonne, 3-stage interceptor missile
  - with 2-stage solid propellants
  - with a long range tracking radar and
  - Infra-red and radar frequency seekers to reach the target satellite and hit it.
- Accordingly, the anti-satellite missile used was an advanced version of 'Prithvi Defence Vehicle' of India's Ballistic Missile Defence system. This is because the target satellite was in a 300 km orbit.

32. NAGASTRA-1 SUICIDE DRONE

- Nagastra-1 is the first indigenous Loiter Munition or suicide drone which can strike targets within a 15-30 km range using GPS-enabled precision.
- It can loiter over a target for a maximum of 60 minutes and has an accuracy of less than 2 metres.
- It can undertake shallow strikes with precision, without endangering the lives of soldiers and is capable of destroying various soft-skinned targets using its pre-fragmented high explosive warhead. The munition carries a day-and-night camera for surveillance as well.
- Nagastra-1 in its 'Kamikaze' mode can search and destroy any target by crashing into it. In case, a target is not detected or if the mission is aborted, it can be called back and made a soft landing with a parachute recovery mechanism, thus, enabling it to be reused multiple times.

33. INDRAJAAL

- Hyderabad-based Grene Robotics has launched Indrajaal, India's first AI-powered anti-drone system.
- It provides a 360-degree coverage/defence against all types and intensities of unmanned autonomous threats across regions up to 4000 square kilometres.
- It can quickly and accurately identify, categorise, track, and eliminate threats in real time.
- It offers protection from all kinds of autonomous drones, including low Radar Cross Section (RCS) threats, medium-altitude long-endurance (MALE) and high-altitude long-endurance (HALE) UAVs.
- It can also be used for loitering munitions, smart bombs, rocket showers, nano and micro drones, and even swarm drones.

34. HIGH ALTITUDE PSEUDO SATELLITES (HAPS)

- HAPS are unmanned air vehicles that can fly at an altitude of 18-20 km from the ground (stratosphere), almost double the heights attained by commercial aeroplanes.
- They have the ability to generate solar power, so they can remain in the air for months and even years, giving the advantage of a satellite.
- They move at just about 80-100 km per hour at a height of 20 km above the Earth's surface. These features help it to gauge an area for a long time. They can easily keep an eye over 200 km and can observe everything even over a 400 sq km area with 5 cm resolution.

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- HAPS can work like a geostationary satellite and can be easily redeployed over another location, or can be reequipped with a different payload.
- **Primary utility** of HAPS vehicles is in the field of surveillance and monitoring, but it can be also useful in disaster management, emergency/public safety communications, maritime surveillance, land border control applications, etc.

35. BHAR OS SOFTWARE

- IIT Madras has recently developed 'BharOS' - an indigenous mobile operating system.
- It is a government funded AOSP (Android Open-Source Project) based operating system with no Google Apps or services.
- It comes with No Default Apps (NDA) which means that users are not forced to use apps that they may not be familiar with, giving more permission controls to users.
- It offers 'Native Over The Air' (NOTA) updates which means that security updates and bug fixes will be automatically installed on the device.
- Private App Store Services (PASS) provides access to a curated list of apps that have been thoroughly vetted and have met certain security and privacy standards of organisations.
- It will be used in government and public systems and will reduce the reliance on foreign OS in smartphones**.**

36. MAYA OS

- Maya OS is an operating system developed by experts from the Indian Defence Research and Development Organisation, the Centre for Development of Advanced Computing (C-DAC), and the National Informatics Centre (NIC).
- The Indian Defence Ministry has decided to replace Microsoft's Windows with Maya OS on all its computers.
- It is an open-source Ubuntu-based operating system launched to prevent malware attacks by cybercriminals increasingly targeting critical infrastructure and government agencies.
- It is powered by an endpoint detection and protection system called **"Chakravyuh"**. Chakravyuh is an end-point anti-malware and antivirus software that creates a virtual layer between the user and the internet, preventing hackers from accessing sensitive data.

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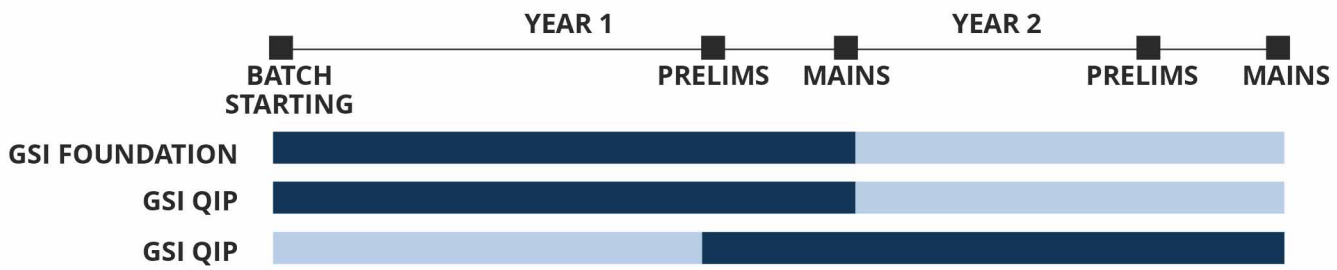

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