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MAINS HARVEST™

SCIENCE & TECHNOLOGY

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GS-III SCIENCE & TECHNOLOGY

Mains Harvest

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OFFICERS IAS ACADEMY
(IAS Academy by IAS Officers)

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MESSAGE FROM THE DIRECTOR

Dear Aspirant,

This book is dedicated to YOU, the untiring civil service aspirant who has the drive and commitment to persevere towards clearing this exam which is considered as one of the toughest exams in the world.

We congratulate you on choosing this book for "**Science & Technology**". Our attempt here is to simplify important concepts without losing the key points. Hence, we hope you will find this book useful in your civil services journey.

About this book

This book is a distillation of the expertise of the faculty at Officers IAS academy, explained in simple and easy to understand language. What you get to study in this book has been painstakingly collated by our faculty through their years of teaching and mentoring thousands of aspirants.

A strong zeal from you to clear this exam combined with our coaching and textbook will, I am sure help you scale great heights.

I wish you the very best in the most important endeavour of your life.

R. A. Israel Jebasingh

(IAS, 2004 Batch All India Rank 59)

Director of Officers IAS Academy

HOW TO USE THIS BOOK?

Hello Aspirant!

There is a subtle difference between putting in effort and putting in the right and focussed effort. That difference could determine whether you get into the civil services or not! This statement becomes highly relevant during the UPSC Main Examination stage.

Aspirants know that every mark scored or missed in the Main examination determines their presence as well as their place in the All-India Rank list. Unlike the Preliminary examination, Main exams are fairly predictable. But with Mains, completing the examination on time becomes the biggest challenge.

Even with persistent efforts, aspirants generally tend to struggle in completing the Mains Syllabus. And even when the syllabus is covered, there is a struggle in recollecting appropriate points during the examination.

Such challenges are faced by all UPSC Mains Candidates. This is because of the sheer mindboggling number of topics, dimensions, and links with current affairs that aspirants have to sift through in their mind before writing an answer – something that is indeed a herculean task.

We in the R&D team of the Officers IAS Academy, have been pondering over this challenge, and have found a solution.

Our R&D team spent a year meticulously combing through the ***past 47 years'*** Mains General Studies question papers, to identify all possible topics and dimensions ever covered for each subject in an UPSC Main examination. Our researchers, then set out to prepare a series of books for each of the 'Main exam subjects' (pertaining to GS1, GS2, & GS3) where all relevant content is covered in a scientific and precise manner. Aspirants can confidently use these books to 'complete' the UPSC Main Exam syllabus effectively and efficiently.

Please note, we do not advocate the use of these 'Mains Harvest' books as 'Standard' sources. However, instead of reading endless number of books for the UPSC preparation, aspirants can focus on the standard books (NCERTs) for foundational knowledge and then devout the rest of their time in studying the Officers IAS Academy's Mains Harvest books.

For you, dear aspirants, we have practically 'harvested' the 'essence' of the UPSC main examination to produce the 'Mains Harvest' book series. Use them well!

Thanking and wishing you all the very best in your preparations,

R&D Team,

Officers IAS Academy, Chennai.

Contents

Nano-technology

1) Nano-Technology

What is Nano-technology?

- Nanotechnology is a technology that involves rearranging and processing of atoms and molecules to fabricate materials to nano specifications such as a nanometre.
- This includes particles of a scale of **1 and 100 nanometers**.

Nanomaterials

- Nanomaterials may be in the form of particles, **tubes, rods or fibers**.
- **Properties of Nano materials**
    - They have a **relatively larger surface area** when compared to the same mass of material produced in a larger form. This can make materials more **chemically reactive** and affect their **strength or electrical properties.**
    - **Quantum effects** can begin to dominate the behavior of matter at the nanoscale – particularly at the lower end – affecting the optical, electrical and magnetic behavior of materials.
- Nano materials can be both found naturally (particles that make up volcanic ash, smoke, hemoglobin) and produced artificially (exhaust from fossil fuel-burning engines and some forms of pollution).
- Fullerenes, Quantum dots, Nano-tubes, Graphene are all some of the Nano materials.

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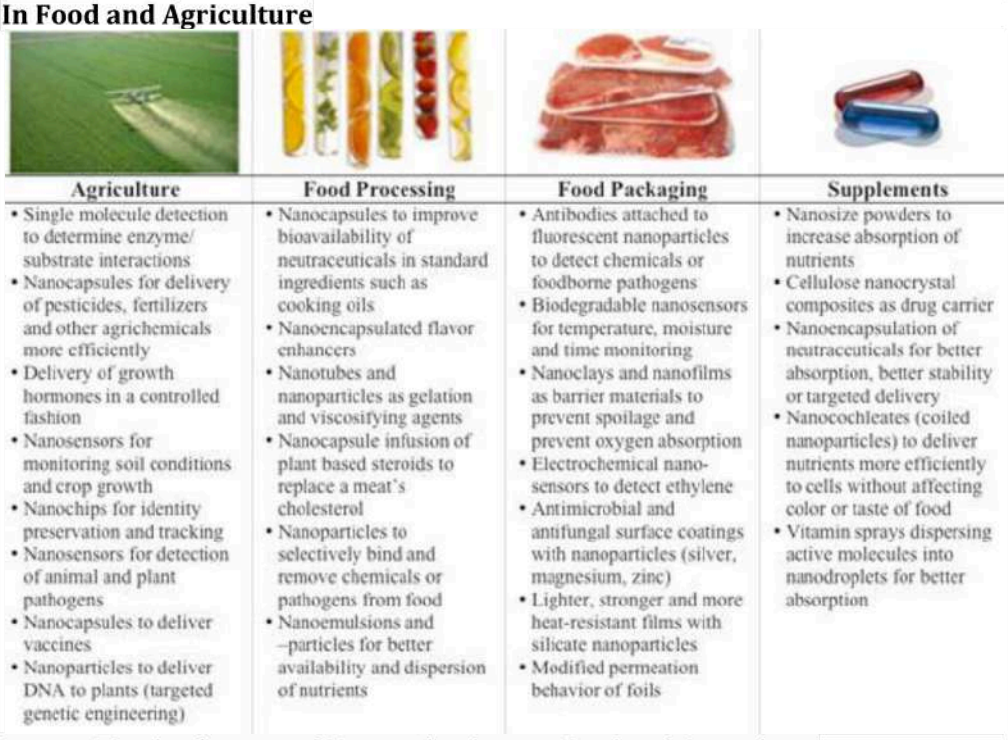
- Current applications include **healthcare** (in targeted drug delivery, regenerative medicine, and diagnostics), **electronics, cosmetics, textiles, information technology and environmental protection.** For example,
    - Nanosilver appears in a range of products, including washing machines, socks, food packaging, wound dressings and food supplements.
    - Nanoclays are often used to coat packing materials as they strengthen the material's heat resistance and flame-retardant properties.
    - **Nano clays -** containing naturally occurring nanoparticles have long been important as construction materials and are undergoing continuous improvement. Clay particle-based composites containing plastics and nano-sized flakes of clay are also finding applications such as in car bumpers.
    - **Nano paints -** Incorporating nanoparticles in paints could improve their performance, for example by making them lighter and giving them different properties. For example, nano paints on aircraft would reduce their weight, which could be beneficial to the environment.
    - **Nanobiotechnology -** is a new field of science that introduces special physio-chemical and biological properties of nanostructures and their applications in various areas such as
        - **In Medicine**
            - Gene therapy
            - Tissue engineering: graphene nanoribbons help repair spinal cord injuries.
            - Drug delivery: Nanomicelles are used for targeted drug delivery.
            - Cancer immunotherapy: Gold nanoparticles are used for the detection of targeted sequences of nucleic acids, and they are also being clinically investigated as potential treatments for cancer and other diseases.
            - Wound healing

        - Diagnostics: NanoFlares are used for detection of cancer cells in the bloodstream.
    - **In agriculture**
        - Pesticide delivery system - through bioactive nanoencapsulation: Liquid nano urea replaces conventional urea in recent times.
        - Used as Biosensors to detect and quantify pathogens.
        - Can be used in alteration of food composition.
- **Smart Dust**
    - **Wireless devices** that can monitor just about any environment, as well as store and transmit data are now the size of a grain of salt.
    - It is a system of many tiny MicroElectroMechanical systems **(MEMS)** such as sensors, robots or other devices, that detect everything from light to vibrations to temperature.
    - They can:
        - **Collect data** including acceleration, stress, pressure, humidity, sound and more from sensors
        - **Store the data** in memory
        - **Wirelessly communicate the data** to the cloud, a base or other MEMs
- **In cosmetics**
    - As **UV filters** (Titanium dioxide and zinc oxide) are used in sunscreens.
    - As **drug delivery agents** (solid lipid nanoparticles and nanostructured lipid carriers)
    - **Penetration enhancer** - Encapsulating or suspending key ingredients in so-called **nanospheres** or **nanoemulsions**, increases their penetration into the skin.
- **In Food and Agriculture**



Agriculture	Food Processing	Food Packaging	Supplements
• Single molecule detection to determine enzyme/ substrate interactions • Nanocapsules for delivery of pesticides, fertilizers and other agrichemicals more efficiently • Delivery of growth hormones in a controlled fashion • Nanosensors for monitoring soil conditions and crop growth • Nanochips for identity preservation and tracking • Nanosensors for detection of animal and plant pathogens • Nanocapsules to deliver vaccines • Nanoparticles to deliver DNA to plants (targeted genetic engineering)	• Nanocapsules to improve bioavailability of neutraceuticals in standard ingredients such as cooking oils • Nanoencapsulated flavor enhancers • Nanotubes and nanoparticles as gelation and viscosifying agents • Nanocapsule infusion of plant based steroids to replace a meat's cholesterol • Nanoparticles to selectively bind and remove chemicals or pathogens from food • Nanoemulsions and –particles for better availability and dispersion of nutrients	• Antibodies attached to fluorescent nanoparticles to detect chemicals or foodborne pathogens • Biodegradable nanosensors for temperature, moisture and time monitoring • Nanoclays and nanofilms as barrier materials to prevent spoilage and prevent oxygen absorption • Electrochemical nano-sensors to detect ethylene • Antimicrobial and antifungal surface coatings with nanoparticles (silver, magnesium, zinc) • Lighter, stronger and more heat-resistant films with silicate nanoparticles • Modified permeation behavior of foils	• Nanosize powders to increase absorption of nutrients • Cellulose nanocrystal composites as drug carrier • Nanoencapsulation of neutraceuticals for better absorption, better stability or targeted delivery • Nanocochleates (coiled nanoparticles) to deliver nutrients more efficiently to cells without affecting color or taste of food • Vitamin sprays dispersing active molecules into nanodroplets for better absorption

Fig: Application of Nanotechnology in Food and Agriculture

Applications of specific nanomaterials

Fullerenes

- Fullerenes are **allotropes of carbon** whose molecule consists of carbon atoms connected by single and double bonds organized in hexagons and pentagons forming a cage-like structure.
- Fullerenes are atom-thick sheets of another carbon allotrope, graphene, rolled into spheres or tubes.

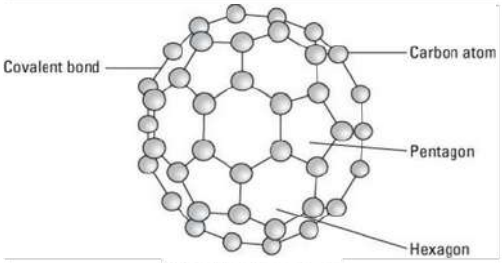


Fig: Fullerenes

- **Applications:**
  - Fullerene is used as a **material for semiconductor technology** such as diodes, transistors, photocells, etc.
  - Fullerenes and its different chemical derivatives are used in combination with semiconducting polymers for the **production of solar cells.**
  - Paints composed of fullerenes can be applied on any surface and become **photovoltaic**, generating electricity but integrated into the environment.
  - As an **additive in fire retardant paint**.
  - Fullerene C60 - is a **great antioxidant** because of its ability to easily penetrate inside the cells, in its nucleus and its mitochondria, making it a more effective **intracellular free radical scavenger** that exists.
  - In **Nanomedicine -** for **controlled release of drugs** enclosing beneficial molecules for the organism inside fullerene balls and directing them to bacteria, or cancer cells. Upon reaching the destination, the spheres are dissolved, releasing all their content at the appropriate points, thus displaying all their effectiveness without being lost along the way.

Carbon nanotubes

- Carbon nanotubes are composed of carbon atoms linked in hexagonal shapes, with each carbon atom covalently bonded to three other carbon atoms. Carbon nanotubes have diameters as small as 1 nm and lengths up to several centimetres.
- Carbon nanotubes are remarkably strong and flexible. Carbon nanotubes are harder than diamonds and more flexible than rubber.
- **Applications:**
  - CNTs are mainly used as **additives to synthetics.**
  - CNTs are spun into fibres and used for **speciality textiles**.
  - a highly attractive alternative to conventional **composite materials** used in
    - sporting goods (bicycle frames, tennis rackets, hockey sticks, kayaks, sports arrows)
    - Yachting (masts, hulls and other parts of sailboats)
    - Textiles (smart textiles, bullet-proof vests, water-retardant and fire-retardant textiles)
    - Automotive, aeronautics and space (light-weight, high-strength composites)
    - Industrial engineering (Coating of wind-turbine rotor blades, industrial robot arms)
  - In the electronics industry as transistors, sensors, and catalysts.

Quantum dots (QD)

- Quantum dots are man-made semiconductor crystals that can transport electrons.
- Quantum dots can possess many varied properties, depending on their material and shape.
- QD emits light of a specific wavelength when a current is applied or exposed to light.
- **Applications**
  - **QD in medicine:** These artificial semiconductor nanoparticles have found applications in **composites, solar cells (Grätzel cells)** and **fluorescent biological labels** (for example to trace a biological molecule) which use both the small particle size and tuneable energy levels.
  - **QD in Solar cells:**
    - can be manufactured in an energy-saving room-temperature process.
    - do not require extensive purification, as silicon does.
    - and they can be applied to a variety of inexpensive and even flexible substrate materials, such as lightweight plastics.
  - The most commonly known use of quantum dots nowadays may be **TV screens.** Samsung and LG launched their QLED TVs in 2015, and a few other companies followed not long after.
  - Quantum dots, because they are both **photo-active (photoluminescent)** and **electro-active (electroluminescent)** and have unique physical properties, will be at the core of **next-generation displays.**

Graphene

- A single layer (monolayer) sheet of carbon atoms that are bonded together in a repeating pattern of hexagons.
- This sheet is only one atom thick.
- Monolayers of graphene stacked on top of each other form graphite.
- Since a typical carbon atom has a diameter of about 0.33 nanometers, there are about 3 million layers of graphene in a 1 mm thick sheet of graphite.
- Harder than diamond yet more elastic than rubber; tougher than steel yet lighter than aluminium – graphene is the strongest known material.
- Represents two-dimensional (2D) materials.
- Graphene is the basic building block for other graphitic materials like carbon nanotubes.

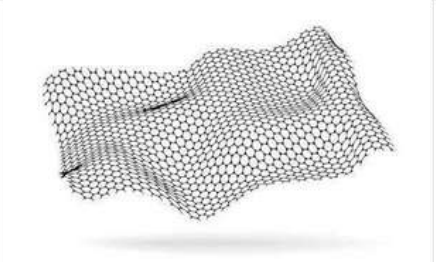


Fig: Graphene

- **Forms of Graphene**
  - graphene oxide
  - Graphdiyne
  - Holey graphene
- **Applications**
  - **Energy storage and solar cells**
    - Graphene improves both **energy capacity and charge rate** in rechargeable batteries.
    - Activated graphene makes superior **supercapacitors** for energy storage.

        - Graphene electrodes may lead to a promising approach for making solar cells that are inexpensive, lightweight and flexible
        - multifunctional graphene mats are promising substrates for catalytic systems.
    - **Sensors**
        - The distinctive 2D structure of graphene oxide (GO), combined with its super permeability to water molecules, leads to sensing devices with unprecedented speed.
        - Wireless graphene nanosensors onto biomaterials via silk biosorption.
        - Graphene foam detects explosives, and emissions better than today's gas sensors.
    - **Bio-medical**
        - Graphene as **bio-sensors.** For instance, Graphene-DNA biosensor
        - Used as a **biocompatible scaffold** in stem cell therapies.
        - **Graphene oxides(GO) nanosheets** tend to be **hydrophilic** and the surface contains reactive groups for increased functionality or for loading drugs through covalent and non-covalent interactions.
        - A **drug delivery** technique that utilizes graphene strips as "**flying carpets**" to deliver two anticancer drugs sequentially to cancer cells, with each drug targeting the distinct part of the cell where it will be most effective.
        - Replacing antibiotics with graphene-based **photothermal agent**s to trap and kill bacteria.
        - Graphene nanoribbons can provide actuation.
    - Graphene also is the world's **thinnest known coating** for protecting metals against corrosion. It was found that graphene, whether made directly on copper or nickel or transferred onto another metal, protects against corrosion.

NanoEngineering

- **Nanoengineering** is a branch of engineering that deals with all aspects of the design, building, and use of engines, machines, and structures on the nanoscale. At its core, nanoengineering deals with nanomaterials and how they interact to make useful materials, structures, devices and systems.
- **Nanomanufacturing** is an economic activity with industrial production facilities with more or less fully automated assembly lines.
- **Nanofabrication** is more of a research activity based on developing new materials and processes – it's more a domain of skilled craftsmen and not of mass production.
- Nanoscale objects are difficult to manipulate, as they are too tiny to see directly by eye, far too small to hold, and often have incompatible surfaces for assembling into ordered structures. Therefore the fabrication of complex nano-architectures requires sophisticated techniques of nanoscale engineering.
- **NanoPatterning:** There are different ways of fabricating functional nanostructures
    - **Top-down** methods - predominantly done by **photolithography**, where a block of material is reshaped into desired shape and size by removing bits and pieces.
    - **Bottom-up** methods - driven by a combination of **thermodynamics and kinetics,** which then determines the yield of the desired structure. This doesn't need expensive tooling to create nanoscale structures, and scaling to large volumes is potentially straightforward.
- **DNA nanotechnology** employs DNA as a programmable building material for self-assembled, nanoscale structures with precisely controlled structures, that can lead to improved surface properties relevant to biosensing, materials science, and cell biology.
- **3D printing -** also called **additive manufacturing,** where desired products and structures can be made independent of the complexity of their shapes. 3D printing can now be used to print lithium-ion microbatteries the size of a grain of sand.

Nanobots

- are quintessential **NEMS (nanoelectromechanical systems)** and raise all the important issues that must be addressed in NEMS design: sensing, actuation, control, communications, power, and interfacing across spatial scales and between organic and inorganic materials.
- Nanobots are molecules with a unique property that enables them to be **programmed to carry out a specific task** and are ~50-100 nm wide.
- Most actively researched areas of nanorobotics today involve DNA assembly, particularly a technique called **DNA origami -** which is used by nanotechnology researchers to fold DNA strands into something resembling a programmable pegboard on which different nanocomponents can be attached.
- **Application**
    - **In medicine**
        - **deliver drugs to diseased cells**. For instance, nanorobots can be programmed to transport molecular payloads and cause on-site tumor blood supply blockages, which can lead to tissue death and shrink the tumor.
        - cell-like nanorobots **clear bacteria and toxins** from the blood - these nanobots are built by coating **gold nanowires** with a hybrid of platelet and red blood cell membranes.
        - **Special sensor nanobots** can be inserted into the blood under the skin where microchips, coated with human molecules and designed to emit an electrical impulse signal, **monitor the sugar level in the blood**.

Government initiatives

- **Mission on Nanoscience and Technology (Nano Mission):**
    - Launched in **May 2007.**
    - It is an **"umbrella capacity-building programme"** to carry out very focused **research** in Nanoscience and develop nanotechnology-based applications aimed at delivering breakthroughs in Nano S&T and applications in a concerted manner.
    - Nodal agency- **Department of Science and Technology**(DST) and steered by a Nano Mission Council chaired by an eminent scientist.
    - Target Audience: all scientists, institutions and industries in the country.
    - Since **2016**, the Indian Nano Initiative has achieved a significant milestone by securing the **third** position in the global ranking through its contribution to Nanoscience and technology publications.
    - Some useful products like nano hydrogel-based eye drops, pesticide removal technology for drinking water, water filters for arsenic and fluoride removal, nanosilver-based antimicrobial textile coating, etc. are developed.
- **Indian Nanoelectronics Users Programme-Idea to Innovation (INUP-i2i):**
    - It is a flagship programme initiated by MeitY (Nanotechnology Initiatives Division)
    - It is being implemented at the Centre of Excellence in Nanoelectronics (CEN) at IISc, IIT Bombay, IIT Delhi, IIT Madras, IIT Kharagpur and IIT Guwahati.
    - It has provided a great opportunity for the R&D community all over the country to access state of the art nanofabrication facilities for undertaking research and skill development in Nanoelectronics.
    - Research outcomes: A few of the technologies developed successfully such as the Portable Polymerase chain reaction (PCR) platform, Gas sensors, Soil moisture sensors, and Nanomaterial based Air quality monitoring system.

Concerns

- A missing element in India's march towards becoming a nanotechnology powerhouse is the **lack of focus on risk analysis and regulation.**
- Research showed that 95% of the practitioners recognised **ethical issues in nanotech research.**
- Adverse effects of nanotechnology on the environment and humans, their use as an **undetectable weapon in warfare**, and the incorporation of nano-devices as **performance enhancers** in human beings.
- Over-regulation may end up stifling further development while under-regulation could expose the public to adverse health effects.
- Lack of investment in risk studies.
- Most of them are **toxic.** Ironically, the existence of heavy metals in QDs such as **cadmium**, a well-established human toxicant and carcinogen, poses potential dangers, especially for future medical applications, where q-dots are deliberately injected into the body.
- **Nanopollution** is the generic term that is used to describe the waste generated by the nanodevices or nanomaterials during the manufacturing process.

Recommendations

- The Department of Science and Technology released the '**Guidelines and best practices for safe handling of nano-materials in research laboratories and industries**'. The guidelines are precautionary in nature, layout methods for the safe handling and disposal of nanoparticles by researchers and the industry. Though much delayed, it is a welcome step towards safer nanotechnology research in India.
- To fully harness the advances made in nanotechnology and consolidate our leadership in the field, we must work towards building a regulatory framework encompassing public safety.

BioTechnology

What is Biotechnology?

- **Biotechnology** is defined as the industrial application of living organisms, and their biological processes(brewing, baking, wine making, cheese making etc.), cells or cell components such as biochemistry, microbiology, and genetic engineering, to make the best use of the microorganisms for the benefit of mankind.
- The significant applications of biotechnology include therapeutics, diagnostics, food processing, bioremediation, waste treatment, production of energy and genetically modified crops to improve agriculture.

Branches of Biotechnology based on color

Color designation	Description
Gold biotechnology or Bioinformatics or computational biology	Use of computational techniques for analysis of biological data.
Red Biotechnology (Biopharma)	Medicine and human health include the development of vaccines and drugs, Genetic engineering etc.
White Biotechnology	industrial processes involving micro-organisms include designing energy-efficient, less polluting, low resource consumption, etc.
Yellow Biotechnology	Food and nutrition such as brewing, baking etc.
Grey Biotechnology	Environment applications such as removal of pollutants and contaminants
Green Biotechnology	Agriculture - for creating new plant varieties, biopesticides, and biofertilizers.
Blue Biotechnology	Marine and aquatic
Violet Biotechnology	Ethics, Law and Philosophy
Dark Biotechnology	Bioterrorism, biological weapons and biowarfare using microorganisms, and toxins to cause diseases and death in humans, domestic animals, and crops.

Techniques of Biotechnology

- **Genetic Engineering Technology** - The method involves the manipulation of the DNA of an organism by inserting foreign DNA.
- **Cell and Tissue Culture Technology** - cells/tissues are grown under laboratory conditions to produce an organism or new products.
- **Antisense or RNAi(RNA interference) Technology** - involves using small RNAs(less than 30 bases long) to regulate the expression of genes in eukaryotic organisms.

Bioinformatics Technology - Computational analysis of biological data, e.g., sequence analysis of macromolecular structures, high-throughput profiling data analysis.

- **Genomics -** used to determine the biological function of genes and their products.

Advances

- **Health care**
  - India is now a leader in vaccine manufacture and development with several advancements.
    - Dengue vaccine, malaria vaccine
  - DBT launched "Sohum" an innovative newborn hearing screening device
  - Neonatal resuscitation device (Neo Breathe)
  - Feto-maternal parameter monitoring system (BRUN)
  - Bio-designs
    - Emergency medical alert device
    - Posture support device
    - Fluid extraction device
- **Agriculture**
  - **Biotech-KISAN**
    - Farmer centric programme whose objective is to demonstrate, scale-up and address issues of local farmers related to water, soil, seed and marketing, with validated technologies.
    - It also serves as an interaction platform between scientists and farmers.
  - **New programme for Brucella-free villages**
    - Brucella diagnostic kits were launched.
- **Food and Nutrition**
  - **Department of BioTechnology (DBT)**supports food formulations for severe acute malnutrition in children
    - The Rady to use food (RUTF) supplement with the brand name BIB POSHAN, was developed with financial support from DBT.
  - **Iron fortification** in rice and wheat to address anemia in school children.
- **Bio-Energy**
  - India's first second-generation(2G) Ethanol plant was launched.
  - Bio-CNG from industrial/ Municipal waste.
- **Environment and sanitation**
  - **Green remediation technology** for wastewater - DBT is participating in the Swachh Bharat Abhiyan through a range of initiatives including bioremediation of filthy water.
  - **Anaerobic membrane Bioreactor** removes organic waste from municipal wastewater with 95% efficiency.
  - **The Rhino Digester** - A cost-effective appliance for decentralized waste processing developed.
  - Conversion of **waste to green chemicals** via biogas with the help of engineered strains.
  - Novel **Bio-Toilet** technologies promise a cleaner India.
- **Human Resources and development**
  - DBT's **Skill Development initiative** launched in partnership with Indian institutions will provide high-quality hands-on training for 10+2 students, fresh graduates, and faculty in areas of biotechnology will speed up India's development.
- **Societal development**
  - **DBT** recognizes the Himalayan Environmental Studies and Conservation Organisation (HESCO) for the **"Biotechnology Social Development Award".**
    - HESCO - NGO has been applying knowledge of the environmental and bio-sciences and propagating simple technologies to bring consistent development to the rural villages of the Himalayas.

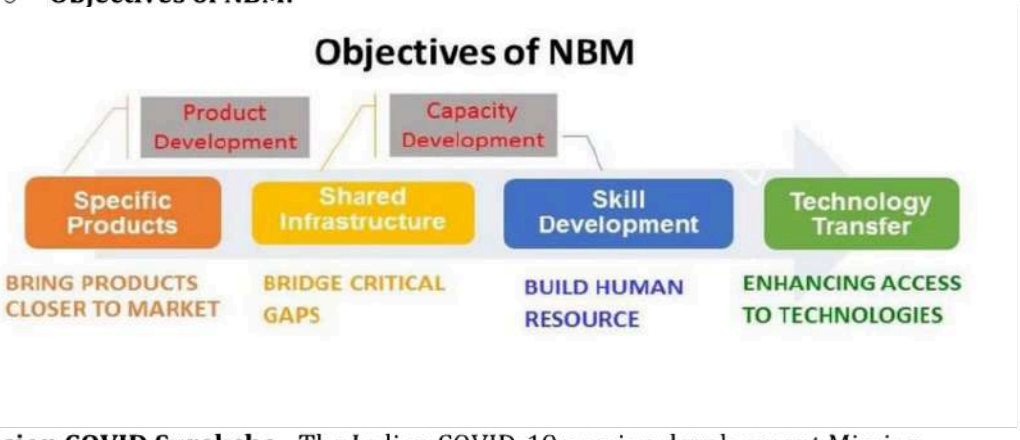
- **Phyto-pharma plant Mission:** Conservation and cultivation of endangered and threatened endemic medicinal plants of North East India and discovery of new botanical drugs for unmet medical needs using the rich traditional ethnobotanical knowledge and biodiversity of these states.
- **Brahmaputra Biodiversity and Biology Boat (B4):** well-equipped laboratory would contain facilities for analysis of all components of the entire ecosystem of the river and surroundings.

Achievements

- India is among the **top 12 biotech destinations** in the world
- India ranks 2nd in Asia, after China
- India is the world's largest producer of recombinant Hepatitis B vaccine.
- Bharat Biotech commercially launched the 1st novel ROTOVAC vaccine, to eradicate rotavirus diarrhea, in India.

Government initiatives

- The **National Biotechnology Development Strategy 2015-2020** programme is aimed at ensuring strategic and focused investment in building human capital by setting up a **Life Science and Biotechnology Education Council** which will spearhead the initiative.
- **National Biotechnology Park scheme:**
  - The government will provide financial assistance for setting up new biotechnology parks that lead to facilitating biotech product development, entrepreneurship, research and innovation.
  - **Ministry/Department:** Ministry of Science and Technology/ Department of Biotechnology.
- **National Biopharma mission -** To enable and nurture an ecosystem for preparing India's Technological and product development capabilities on biopharmaceuticals to a level that will be globally competitive over the next decade and transform the health standards of India's population.
  - **Ministry/Department:** Ministry of Science and Technology/ Department of Biotechnology.
  - **Objectives of NBM:**



- **Mission COVID Suraksha** - The Indian COVID-19 vaccine development Mission.
- **Biotech KISAN** scheme:
  - The Department of Biotechnology (DBT) launched a **farmers-centric Mission** Programme known as Biotech Krishi Innovation Science Application Network, which will link India's farmers with Indian and global best in science for India's future.
  - Launched in **2007**.

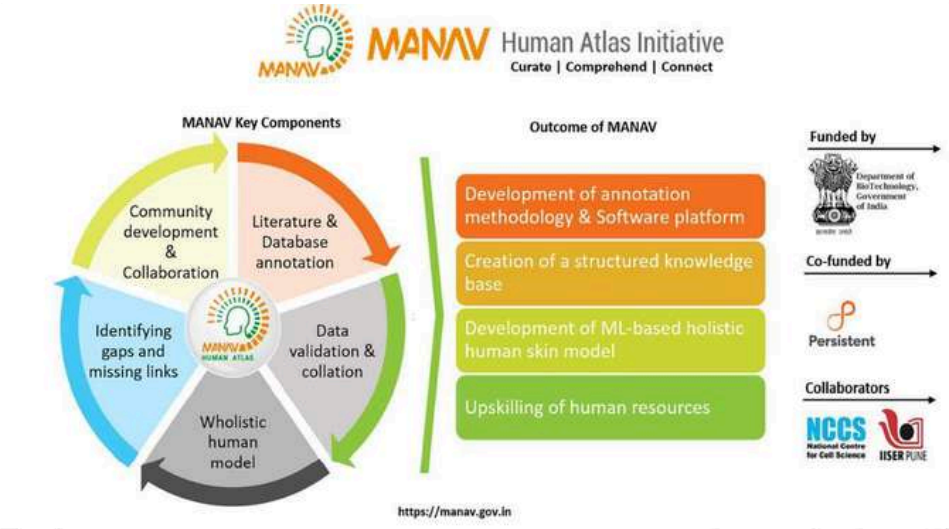
- a **scientist-farmer partnership scheme** for agriculture innovation through participatory research to connect science laboratories with the farmers to find out innovative solutions and technologies to be developed and applied at the farm level.

- **Atal Jai Anusandhan Biotech Mission: Undertaking Nationally Relevant Technology Innovation (UNaTI) includes**
  - **GARBH-INi:** A mission to promote maternal and child health and develop prediction tools for preterm birth.
  - **IndCEPI:** A mission to develop affordable vaccines for endemic diseases.
  - **Clean Energy Mission:** Innovative technology interventions for Swachh Bharat.
  - **POSHAN Abhiyan:** Development of Biofortified and protein-rich wheat.
  - **Mission on Antimicrobial Resistance:** for affordable diagnostics and therapeutics.

Bioinformatics

About

- Bioinformatics, as related to **genetics and genomics**, is a scientific subdiscipline that involves using computer technology to **collect, store, analyze and disseminate biological data and information**, such as DNA and amino acid sequences or annotations about those sequences.
- Bioinformatics has also been referred to as **'computational biology'.**
- It is a **multi-disciplinary subject** which combines the tools of Biology, Chemistry, Mathematics, statics and computer science to understand life and its process.
- The **main components** of bioinformatics are
  - **development of software tools and algorithms**
  - **analysis and interpretation of biological data** by using a variety of software tools and particular algorithms.
- Scientists and clinicians use databases that organize and index such biological information to increase our understanding of health and disease and, in certain cases, as part of medical care.
- In India
  - **1983** -Formation of the task group on **bioinformatics** by **Dr S. Ramachandra.**
  - **1986** - the **Department of Biotechnology (DBT)** was established.
  - **1987 - Biotechnology Information System Network (BTISNet)** was established.
    - **India is the first country** to establish BTISNet.
    - It covers around **165 institutions** from all over the country.
    - BTISNet covers several **interdisciplinary areas of biotechnology.**
    - It has also provided a **strong linkage among scientists** engaged in R & D activities in India.
    - To **coordinate efforts to access biotechnology information worldwide** including establishing linkages with some of the international resources of biotechnology information eg. Databanks on genetic materials, published literature, patents and other information of scientific and commercial value.
  - **Indian Biological Data centre (IBDC)**
  - **MANAV: Human Atlas Initiative Programme:** for construction of the world's most comprehensive human atlas to date by assimilating all the known macro-level and micro-level information from scientific literature and public databases.



- **Indo-Japan DAICENTER Programme:** Department of Biotechnology (DBT) and the National Institute of Advanced Industrial Science and Technology (AIST) Japan, have initiated a programme called 'DBT-AIST International Centre for Translational and Environment Research (DAICENTER)'.
- DBT Apex BTIC
- North Western Himalayan Bioinformatics Grid

Indian Biological Data center (IBDC)

- **India's Biological Data life science data** is an effort by the Government of India for the deposition, storage, annotation and sharing of biological data.
- **First National repository for life science data in India**
- The data center is supported by the Government of India (GOI) through the **Department of Biotechnology (DBT).**
- **IBDC** is mandated to archive all life science data generated from publicly-funded research in India.
- It is being established at the regional centre of Biotechnology (RCB), Faridabad in the national capital region in collaboration with the National Informatics Centre (NIC), India.
- It has a data storage capacity of about 4 petabytes and houses the **'Brahm'** High-Performance Computing (HPC) facility.
- It also hosts an **online 'Dashboard'** for the genomic surveillance data generated by the INSACOG labs
- It has accumulated over 200 billion bases from 2,08,055 submissions from more than 50 research labs across India.

Objectives

- Provide an IT platform for perpetually archiving biological data in the country.
- Development of standard operating Procedures (SOPs) for storing and sharing the data as per the FAIR (Findable, Accessible, Interoperable and Reusable) Principle.
- Perform quality control, curation/annotation of data, data backup and management of data life cycle.
- Development of web-based tools/APIs for data sharing/retrieval.
- Organization of training programs on 'Big' data analysis and benefits of data sharing.

Sections of IBDC

- IBDC has started nucleotide data submission services via two data portals.
  - Indian Nucleotide Data Archive (INDA)
  - Indian Nucleotide Data Archive - Controlled Access (INDA-CA)

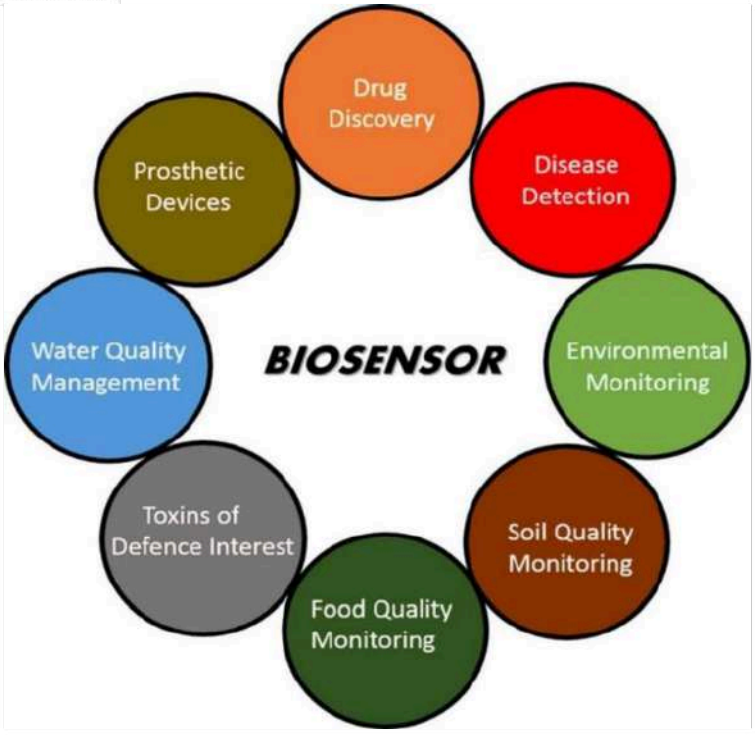
Biosensors

About

- Biosensors (Biological sensors) can be defined as **analytical devices** which include a **combination of biological detecting elements like a sensor system and a transducer.**
- The main features of biosensors are stability, cost, sensitivity, and reproducibility.
- In this sensor, a biological element may be an enzyme, a nucleic acid otherwise an antibody. The bio-element communicates through the analyte being checked & the biological reply can be changed into an electrical signal using the transducer.
- The signal generated when the sensor interacts with the analyte may be electrical, optical or thermal. It is then converted by means of a suitable transducer into a measurable electrical parameter – usually a current or voltage
- Depending on their particular application, biosensors are also known as immuno sensors, optrodes, resonant mirrors, chemical canaries, biochips, glucometers and biocomputers.

Application

- These devices are applicable in the medical, food industry, and the marine sector as they offer good sensitivity & stability as compared with the usual techniques.
- In recent years, these sensors have become very popular, and they are applicable in different fields which are mentioned below
- Biosensors are used for the **detection of pathogens** in food. The presence of *Escherichia coli* in vegetables is a bioindicator of faecal contamination in food.
- **Environment:** Used to **check the quality of air and water;** to pick up traces of organophosphates from pesticides or to check the toxicity levels of wastewater.
- **Food industry:** to measure carbohydrates, alcohols and acids, for example, during quality control processes. The devices may also be used to check fermentation during the production of beer, yoghurt and soft drinks.



Biosignatures

About

- A biosignature is any **characteristic, element, molecule, substance or feature that can be used as evidence for past or present life**. It also needs to be something that can't be made without the presence of life. - NASA
- Also called **Chemical fossils** or **molecular fossils**
- A biosignature can provide evidence for living organisms **outside the Earth** and can be directly or indirectly detected by searching for their unique byproducts.
- It can be something like a leaf or a feather, but could also be fossils stored away in the rocks, organic molecules made by life, and even differences in the chemistry of an atmosphere or a body of water.

Types of biosignatures

- A **morphological biosignature** is one that we can tell was made from a life **based on its shape and size.** For instance, microorganisms living together in goopy microbial mats in shallow waters can create layered structures of minerals called stromatolites. If we were to go exploring another world like Mars and found layered minerals from stromatolites in a rock, then that might be a biosignature.
- **Chemical biosignatures** include a huge range of possible ways that life can leave its mark within the **chemistry of rocks, bodies of water, and even atmospheres.** For instance, biological macromolecules such as lipids, carbohydrates, nucleic acids, and proteins might all be used as biosignatures.

Technosignatures: or **technomarker** is any measurable property or effect that provides scientific evidence of past or present technology. This would indicate the existence of intelligent life beyond Earth. It is part of SETI (Search for Extraterrestrial Intelligence).

Genetics

1) Genome

- It refers to the total genetic information present in a cell.
- The organization of the human genome is very complex. It comprises two genomes (Nuclear and Mitochondrial).
- **Nuclear genome**
  - The nuclear genome constitutes more than 99% of the total genome.
  - The haploid genome is distributed in 23 different types of chromosomes (22 autosomes and 1 allosome).
  - Each chromosome contains many genes. The genes are not uniformly distributed on the chromosomes. A certain area of the chromosome may be rich in genes while areas like centromere and telomeres are largely devoid of genes. Some chromosomes are rich in genes (22nd chromosome) some are gene-poor (4th chromosome).
- **Mitochondrial genome**
  - The total amount of mitochondrial genome is <1%.
  - In contrast to the nuclear genome, about 93% of the mtDNA is coding.
  - mtDNA shows maternal inheritance because all the mitochondria received by the zygote are from the ovum.
  - Mutations in mtDNA are responsible for certain diseases in humans.
- There are pseudogenes in the genome which are nonfunctional copies of a functional gene eg. pseudo beta in the beta-globin gene family.

Genetic code

- The **genetic code** is the **set of rules** used by living cells to translate information encoded within **genetic material** (DNA or RNA sequences of nucleotide triplets, or **codons**) into **proteins.**
- Each gene's code uses the four nucleotide bases of DNA: **adenine (A)**, **cytosine (C)**, **guanine (G)** and **thymine (T)** — in various ways to spell out three-letter **"codons"** that specify which amino acid is needed at each position within a protein.
- **Translation** is accomplished by the **ribosome,** which links proteinogenic amino acids in an order specified by messenger RNA (**mRNA**), using transfer RNA (**tRNA**) molecules to carry amino acids and to read the mRNA three nucleotides at a time.
- The genetic code is a **triplet**: The code is read in 3 letter words. A group of three nucleotides codes for one amino acid. Eg: UGU, CGA, AUG etc.
- The genetic code is degenerate, non-overlapping and occurs without any gap between two codons. Eg: 5'AGCGCAAGCCGA...3'.

Genetic expression

- Gene expression is a process in which a **protein is synthesised from a gene.**
- It occurs in two major steps.
  - The first step is **transcription**, in which the linear DNA is transcribed into linear mRNA. It occurs in the nucleus in a **5' → 3' direction**. It needs **RNA polymerase**, **ribonucleotides** and several proteins for initiation.
  - The second step is **translation** during which mRNA associates with the ribosomes present in the cytoplasm and directs the synthesis of proteins. It requires **mRNA, tRNA, ribosomes, ATP** and various **protein** factors. It occurs on ribosomes in the cytoplasm. It also occurs in **5'→3'** direction.

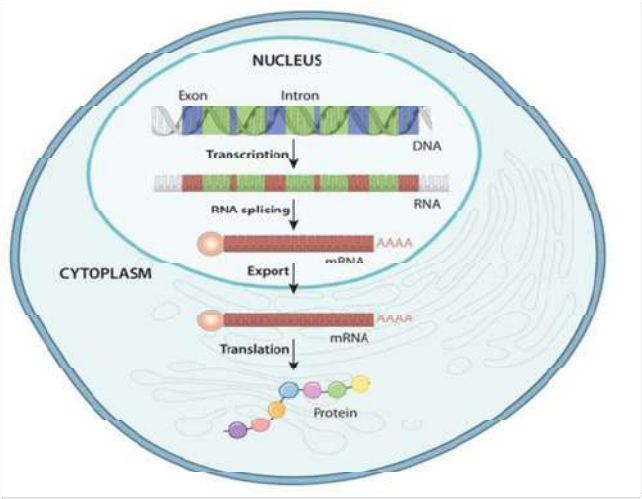


Fig: Gene Expression

2) Molecular Genetics

Chromosomes

- Chromosomes are **threadlike structures** made of protein (**histones** and **non-histones**), a single molecule of DNA and also RNA that serve to **carry the genomic information** from cell to cell.
- Chromosomes are found in the nucleus of each cell.
- Each chromosome has a constriction point called the **centromere**, which divides the chromosome into two sections, or **"arms."** The short arm of the chromosome is labelled the **"p arm."** The long arm of the chromosome is labelled the **"q arm."**
- Humans have **22 pairs** of numbered chromosomes (**autosomes**) and **one pair** of sex chromosomes (**XX or XY**)(**allosomes**), totalling **46**.
- Each pair contains two chromosomes, one coming from each parent, which means that children inherit half of their chromosomes from their mother and a half from their father.
- Typically, biologically **female** individuals have two X chromosomes **(XX)** while biologically male individuals have one X and one Y chromosome (**XY**).
- Chromosomes are also of different sizes. The human X chromosome is about three times larger than the human Y chromosome, containing about 900 genes, while the Y chromosome has about 55 genes.

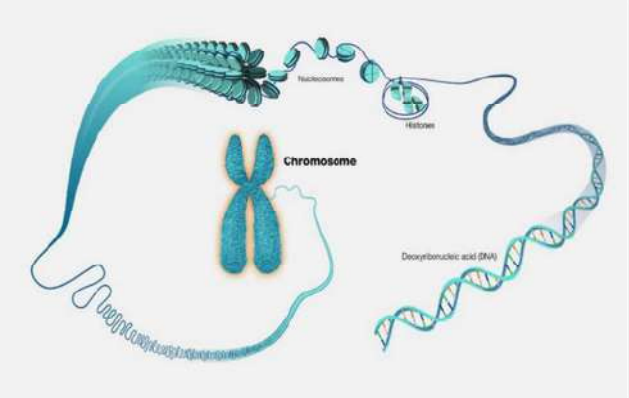


Fig: Chromosome

- **Types:** Based on the position of the centromere, the chromosomes can be classified into four types
    - **metacentric** chromosome: the middle centromere forming two equal arms of the chromosome.
    - **sub-metacentric** chromosome: centromere slightly away from the middle of the chromosome resulting in one shorter arm and one long arm.
    - **acrocentric** chromosome: centromere is situated close to its end forming one extremely short and one very long arm.
    - **telocentric** chromosome: terminal centromere.
- Sometimes a few chromosomes have non-staining secondary constrictions at a constant location. This gives the appearance of a small fragment called the **satellite.**
- The chromosomes are considered the **organs of heredity** because of the following reasons:
    - They form the only **link between two generations.**
    - A **diploid chromosome(2n)** set consists of two morphologically similar (except the X and Y sex chromosomes) sets, one is derived from the mother and another from the father at fertilization.
    - The genetic material, DNA or RNA is localized in the chromosome and its contents are relatively constant from one generation to the next.
    - The chromosomes **maintain and replicate the genetic information** contained in their DNA molecule and this information is transcribed at the right time in proper sequence into the specific types of RNA molecules which directs the synthesis of different types of proteins to form a body form like the parents.
- **Karyotype:** A karyotype is an **individual's complete set of chromosomes.**
    - The term also refers to a laboratory-produced image of a person's chromosomes isolated from an individual cell and arranged in **numerical order**.
    - Karyotypes can be used for many purposes; such as, to study chromosomal aberrations, cellular function, and taxonomic relationships, and to gather information about past evolutionary events.
- **Chromosomal aberrations or Chromosomal abnormalities:** a disorder characterized by a **morphological** or **numerical alteration** in single or multiple chromosomes, affecting autosomes, sex chromosomes, or both.
    - **Autosomal Trisomies**
        - Trisomy 13 (Patau syndrome): Karyotype - 47, XX or XY, +13
        - Trisomy 18 (Edwards syndrome):
            - Karyotype - 47, XX or XY, +18
        - Trisomy 21 (Down syndrome): Karyotype - 47, XX or XY, +21
    - **Sex chromosome Aneuploidies**
        - Klinefelter syndrome: Karyotype - 47, XXY and 48, XXXY
        - Triple X syndrome: Karyotype - 47, XXX
        - XYY syndrome: Karyotype - 47, XYY
        - Turner syndrome: Karyotype - 45, X
- **Telomeres**
    - Telomeres are regions of **repeated nucleotides at the end** of chromosomes.
    - They **protect the ends of the chromosome** from being damaged or fusing with other chromosomes.

- Each time a cell divides and DNA is replicated, the telomere becomes shorter.

Gene

- A gene is the basic **physical and functional unit of heredity.**
- Genes are **made up of DNA.** Each chromosome contains many genes.
- Some genes act as instructions to make molecules called **proteins**.
- Every person has two copies of each gene, one inherited from each parent.
- Most genes are the same in all people, but a small number of genes (less than 1% of the total) are slightly different between people.

DeoxyriboNucleic acid (DNA)

- Deoxyribonucleic acid (abbreviated DNA) is the molecule that carries the **genetic information** for the development and functioning of an organism.
- DNA is made up of molecules called **nucleotides**. Each nucleotide contains three components: a **phosphate group**, which is one phosphorus atom bonded to four oxygen atoms; a **sugar molecule**; and a **nitrogen base**.
- Each strand has a backbone made of alternating sugar (deoxyribose) and phosphate groups.
- Attached to each sugar is one of **four bases**: **adenine (A)**, **cytosine (C)**, **guanine (G)** or **thymine (T)**. The two strands are connected by chemical bonds between the bases: adenine bonds with thymine**(A – T)**, and cytosine bonds with guanine**(C – G)**.
- Nucleotides are arranged in two long strands that form a spiral called a **double helix.**
- Human DNA consists of about **3 billion bases**, and more than 99% of those bases are the same in all people.
- The sequence of the bases along DNA's backbone **encodes biological information**, such as the instructions for making a protein or RNA molecule.
- Transmission of all or part of an organism's DNA helps ensure a certain level of continuity from one generation to the next, while still allowing for slight changes that contribute to the diversity of life.
- An important property of DNA is that it can **replicate**, or make copies of itself. Each strand of DNA in the double helix can serve as a pattern for duplicating the sequence of bases. This is critical when cells divide because each new cell needs to have an exact copy of the DNA present in the old cell.
- Most DNA lives in the **nuclei of cells** and some exist in **mitochondria**, which are the powerhouses of the cells.

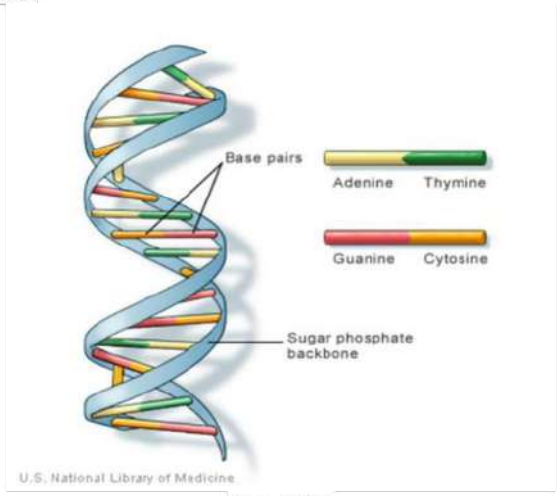


Fig: DNA

- **Functions of DNA**
  - DNA carries the instructions for the development, growth, reproduction, and functioning of all life.
  - **Protein creation ("The central dogma"** of molecular biology**)**
    - **Transcription:** The DNA code duplicates into messenger RNA (mRNA). RNA is a copy of DNA, but it is normally single-stranded. Another difference is that RNA does not contain the base thymine (T). In RNA, uracil (U) replaces thymine (T).
    - **Translation:** The mRNA translates into amino acids by transfer RNA (tRNA).
    - mRNA provides information on a particular amino acid via three-letter sections called **codons**. Each codon codes for a specific amino acid or a building block of a protein. For instance, the codon GUG codes for the amino acid valine.
- **DNA mutation**
  - A mutation is a **change in the DNA sequence** of an organism. Mutations can result from **errors in DNA replication** during cell division, **exposure to mutagens** or a **viral infection**.
  - **Germline mutations** (that occur in eggs and sperm) can be passed to offspring, while **somatic mutations** (that occur in body cells) are not passed on.
  - Certain mutations in a person's genetic code can lead to the development of a variety of diseases or conditions.
  - A person can inherit a gene that may cause problems with their health.
  - Environmental factors can influence how these mutated genes manifest.

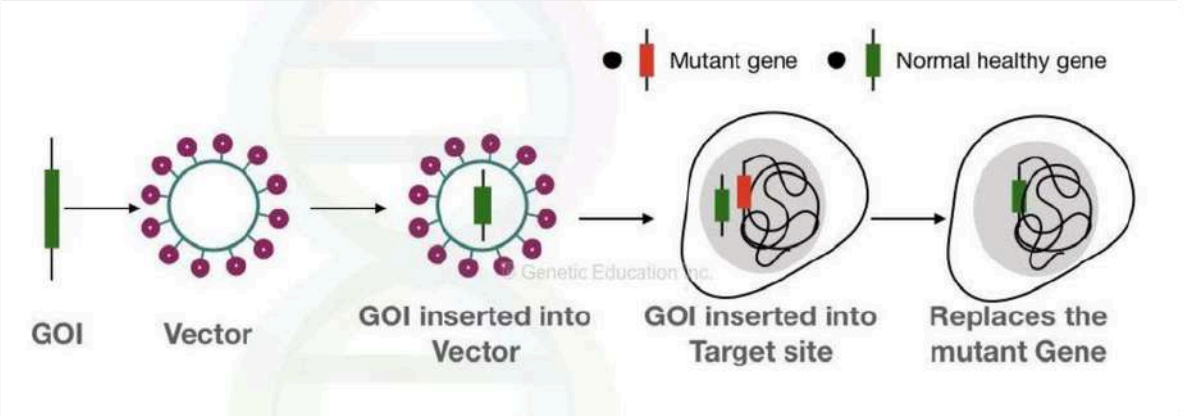
Ribonucleic acid (RNA)

- RNA is a nucleic acid present in all living cells that has structural similarities to DNA. Unlike DNA, however, RNA is most often **single-stranded**. An RNA molecule has a backbone made of alternating phosphate groups and sugar ribose, rather than the deoxyribose found in DNA.
- Attached to each sugar is one of four bases: adenine (A), uracil (U), cytosine (C) or guanine (G).
- Different types of RNA exist in cells: messenger RNA (**mRNA**), ribosomal RNA (**rRNA**) and transfer RNA (**tRNA**).
- In addition, some RNAs are involved in regulating **gene expression**. Certain viruses use RNA as their **genomic material.**
- RNA contains **ribose sugars** rather than deoxyribose sugars, which makes RNA more unstable and more prone to degradation.
- RNA is synthesized from DNA by an enzyme known as **RNA polymerase** during a process called **transcription.**
- The new RNA sequences are complementary to their DNA template, rather than being identical copies of the template. RNA is then translated into proteins by structures called **ribosomes.**
- Although some RNA molecules are **passive copies of DNA,** many play crucial, active roles in the cell. For example, some RNA molecules are involved in **switching genes on and off**, and other RNA molecules make up the critical protein synthesis machinery in ribosomes.

3) Application of Genetics

Gene therapy

- Gene therapy is a technique that uses a gene(s) to treat, prevent or cure a disease or medical order. Often, gene therapy works by adding new copies of a gene that is broken, or by replacing a defective or missing gene in a patient's cells with a healthy version of that gene.
- Both inherited **genetic diseases** (e.g., haemophilia and sickle cell disease) and **acquired disorders** (e.g., leukaemia) have been treated with gene therapy.
- **Process of Gene therapy**



GOI (Gene of Interest): A DNA sequence which we want to insert in our target cells.
Vector: using the plasmid DNA like vectors the gene of interest is inserted into the host genome. Vectors are kind of vehicles which transfer the genetic material.
Target cells: target cells are the population of cells whose genome we wish to manipulate or change.

- **Classification of Gene therapy**
  - **Germ-line gene therapy** is applied to **germline or gametes** which can be **transmitted vertically** across generations. The concept of germ-line gene therapy is to introduce gene-modified cells into the germline. However, germline or *in-utero* gene therapy is **prohibited in India**, due to ethical and social considerations.
  - **Somatic cell gene therapy** is viewed as the only and more socially acceptable approach because it affects the targeted cells/tissue/organs in the patient, and is not passed on to subsequent generations. This also includes genome modification as exemplified by CRISPR-related and other technologies or epigenetic modulation by gene therapy approaches with similar effects. Somatic gene therapy has two categories: *ex vivo* and *in vivo.*
    - ***ex vivo* approach:** cells obtained from an individual are genetically modified/corrected outside the body followed by transplantation into the same or a different individual. E.g. bone marrow, immune cells, stem cells etc.
    - ***in vivo* approach:** the gene of interest is delivered directly to target cells/tissues/organs in the patients. Gene delivery can be carried out by viral or non-viral vector systems. These include the liver, pancreas, muscle, heart, skin, spleen, lung, brain, bone marrow, eye and others.
- **Methods of gene therapy**
  - Introduce a new gene into cells to help fight a disease.
  - Introduce a non-faulty copy of a gene to stand in for the altered copy causing disease.
  - **Molecular cloning (Recombinant DNA)**
  - **Genome editing (Gene editing) (CRISPR):** Instead of introducing new genetic material into cells, genome editing introduces molecular tools to change the existing DNA in the cell. Genome editing technologies allow genetic material to be added, removed, or altered at precise locations in the genome. **CRISPR-Cas9** is a well-known type of genome editing.
- **Ethical consideration**
  - involves the use of genetic science for human good and the avoidance of preventable harms
  - the control and confidentiality of results of genetic testing

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