SEE CHEM PREP

Lithiun Ion batteries

* Rechargeable batteries which stores energy by reversible reduction of Li ions.
* 2 types:
  + Primary: redox rex proceed only in one dirn.
  + Reactants in battery consumed after a certain amt of time.
  + Cannot be used once chemicals inside are consumed.
  + Eg: dry cells
  + Secondary: rechargale li ion bat.
  + Electroactive materials converts to electro inactive during discharge and visa versa during charging
  + Eg: LiCoO2

LiCoO2:

* Cathode: LiCoO2, lithiated form of a transition metal oxide.
* Anode: C6 (graphite), lithiated carbon
* Electrolyte: solid Li salt and organic solvents
* A diagram of a graph

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* SEI (solid electrolyte interphase)
  + Passivation layer
  + Formed on electrode surface from decomposition products of electrolyes
  + Allows Li+ ions transport and blocks e- in order to prevent further electrolyte decomposition ensuring continued electorchemical reactions.
  + A close up of a paper

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* Working mech
  + Lithium salts are used as electrolytes along with 1,2 dimeoxy ethane and propylene carbonate.
  + Reason for selection of this solvent is its density and high boiling inert nature
  + During discharge reaction, Li metal in anode component converts to Li+ ion and moves through SEI and separator towards cobalt cathode.
  + In cathode, it reacts with cobalt oxide and e- to form LiCoO2.
  + This process is reversible during charging.
  + Charging and discharging reactions:
    - At anode: LixC6 🡪 Li+ + xe- + 6C
    - At cathode: Li(1-x)CoO2 +xLi+ +xe- 🡪 LiCoO2
  + Overall reaction: LixC6 + Li(1-x)CoO2 🡪 LiCoO2 +6C
  + Chemical reaction that takes place inside the battery during charge and discharge operations: LiCoO2 +C6 🡨🡪 Li(1-x)CoO2 + LixC6

Lithium air batteries:

* Cathode: air
* Anode: metal incorporated in carbon matrix
* Adv: high density and light weight
* A diagram of a diagram with writing on it

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* Working:
  + Li ions moves between the anode and cathode across the electrolyte.
  + During discharge, e- flow through the external circuit where electrical work is done and li ions migrate towards the cathode.
  + During charging, the li metal is in anode, freeing oxygen at cathode.
  + In non aqueous, byproducts are li2o2 or lio2
  + In aqueous, by product is lioh
  + In aq battery, a protective layer is required to protect the li metal in anode.
  + Reactions:
    - Non aq: anode: li metal and cathode: o2 (air)
    - Anode: li 🡪 li+ + e-
    - Cathode: li+ + e- + o2 🡪 lio2
    - Li+ +e- + lio2 🡪 li2o2
    - Aq:
    - acidic: 2li + 0.5o2 + 2h+ 🡪 2li+ + h20
    - alkaline: 2li + 0.5o2 + h20 🡪 2lioh

Hydrogen Oxygen Fuel cells

* Categorised under Alkaline Fuel Cells AFCs
* AFCs are high performance FC because of how quickly chemicals processes occur inside the cell.
* Drawback is that CO2 can easily poison it and it is vital to purify both hydrogen and oxygen before use.

Construction:

* Uses hydrogen as fuel and oxygen as oxidant.
* Electrodes: Two inert porous carbon plates
* Anode: Porous carbon with platinum as a catalyst.
* Cathode: Porous carbon with silver as a catalyst.
* Electrolyte: Aqueous potassium hydroxide (KOH) or NaOH solution, placed between electrodes.

A diagram of an electrolyte cell

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Working:

* Hydrogen gas is pumped at anode where hydrogen reacts with hydroxide ions.
* H2 + 4OH- 🡪 4H2O +4e (oxidation reaction)
* Liberated electrons from anode pass through the external circuit and work is done.
* At cathode, oxygen reacts with water and incoming electrons.
* O2 + 2H2O + 4e 🡪 4OH- (reduction reactions)
* Net reaction: 2H2 + O2 🡪 2H2O

Advantages

* Zero Emissions: Only water as a by-product, no pollution.
* No Recharging Needed: Operates continuously as long as fuel is supplied.

Limitations

* CO₂ Sensitivity: CO₂ can poison the catalyst and affect performance.
* Hydrogen Storage: Difficult to store and distribute hydrogen safely.

Amorphous Silicon Solar Cells

* Made of n-type (Phosphorus doped) and p-type (Boron doped) silicon.
* P and n type materials are joined to form a p-n junction.
* Front electrodes are placed on the n-type side.
* Metal back contact is attached to the p-type layer.
* An antireflective coating is filled between front electrodes to avoid reflection of sunlight.
* Layers are connected externally to a circuit and sealed from the environment.
* A diagram of a structure

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Working

* Sunlight is incident on the solar cells and photon strikes the p-n junction.
* Electron-hole pairs are created at the junction by absorption of photons.
* Electrons move to the n-type layer, holes to the p-type layer, driven by affinity and diffusion.
* Movement of charges generates electric current.
* A drawing of a diagram

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| Quantum Dots   * They are tiny particles or nanocrystals of semiconducting materials with diameter in range of 2-10 nm. * When illuminated by UV light, electrons get excited from valence band (VB) to conduction band (CB). * These excited electrons can then be harvested for electricity. * The energy difference between CB and VB determines the color of emitted light.   Construction:   * Two electrodes: cathode (graphite/platinum) and anode includes ITO (Indium Tin Oxide): a transparent conducting layer. * Anode is coated with a layer of nanoporous materials (TiO2 /ZnO). Further these nanoporous materials are coated with CdSe QDs act as light absorbing semiconductors. * A triiodide electrolyte between electrodes facilitates electron transfer. * Diagram of a diagram of a nuclear reactor    AI-generated content may be incorrect.   Working:   * When photon strikes the solar cell, it passes through ITO layer and hits quantum dots. * Once the photon hits the ODs, it undergoes excitation with liberation of electron which jumps to CB. * Electrons travel through the network TiO2 nanoparticles and reach the cathode. * At the cathode, electrons reduce triiodide (I3-) to three iodide (I-). * I3- + 3e 🡪 3I- * Iodide is oxidized back to triiodide at the anode, releasing electrons again. * These electrons are again absorbed by QDs and the cycle continues as long as sunlight is present.   Extras:   | 🔢 | Battery | Fuel Cell | | --- | --- | --- | | 1 | Energy storage devices | Energy conversion devices | | 2 | Secondary batteries are rechargeable | Fuel cells are not rechargeable | | 3 | Reactants/products are within the cell | Fuel and oxidant are supplied continuously | | 4 | Products stay inside the cell | Products are removed from the cell |   EDLC (Electrostatic double layer capacitors)   * Made of two similar carbon-based electrodes, an electrolyte, and a separator. * They store energy electrostatically (non-Faradaic process), without any chemical reaction. * Voltage causes charge to accumulate on the surface of the electrodes. * This is followed by a natural attraction of unlike charges, ions in electrolyte solution diffuse across the separator into the pores of the electrode of opposite charge. * Electrodes are designed to avoid recombination of ions. * This creates an double-layer at each electrode. * There is no direct charge transfer between electrode and electrolyte. * The separator prevents recombination of ions and enables ion diffusion. * These double layers are coupled with high surface area and small distance between layers to achieve high energy density. * No chemical reactions result in high reversibility and very high cycling stability. * Performance can be tuned by changing the nature of the electrolyte. * EDLCs can use: Aqueous electrolytes (e.g., H₂SO₄, KOH): Lower pore size requirement. [OR] Organic electrolytes (e.g., acetonitrile): Often used with larger voltage windows.   Electrochemical Pseudo Capacitor   * Uses metal oxide or conducting polymer electrodes with high amount of electrochemical pseudo capacitance additional to the double layer capacitance. * Achieved by Faradic electron charge transfer with redox reactions, intercalation or electro sorption. * Diagram of a diagram of a cell    AI-generated content may be incorrect. * Applying voltage causes electrolyte ions to move to the oppositely polarized electrode, forming a double layer. * A single layer of solvent molecules acts as a separator. * Pseudo capacitance originates when specifically adsorbed ions from the electrolyte cross the double layer. * Pseudo capacitance stores electrical energy by means of reversible redox reaction on the surface of suitable electrodes in the capacitor w the double layer. * The ion is de-solvated and adsorbed, with no chemical reaction with electrode atoms and only charge transfer between electrolyte and electrode. * Electrons are transferred to/from valence orbitals of redox-active reagents. * The flow continues from negative to positive electrode, forming another double-layer at the positive side. * The electrons reaching the positive electrode are not transferred to the anion forming a double layer instead remain in strongly ionised (electron hungry) state. * The storage capacity is limited by the finite number of redox-active sites available on the electrode surface.   Hybrid capacitor   * Lithium ion capacitor which uses electrodes with differing characteristics. One that stores energy electrostatically (like in supercapacitors) and the other that stores energy chemically (like in batteries). * Principles of both battery and SC are involved to increase energy density and power density. * They use Faradaic reactions (involving electron transfer through redox reactions) and non-faradaic processes (electrostatic charge accumulation in a double layer). * This dual mechanism allows them to deliver high power quickly (like capacitors) and store more energy for a longer time (like batteries).   Primary batteries:   * Non recahrgable * Self discharge * Eg: Leclanche   Secondary   * Rechargable (cell reactions are reversible) * Eg: lithium ion, nickel cadmium   Reserve   * Electrolyte is kept isolated from the rest of the battery until battery needs to be used. * Eg: MgAgCl   Battery characteristics   * Voltage (V): High voltage is preferred. Depends on the electromotive force (emf) of the cells making up the battery. Emf is related to the free energy of the cell reaction and is given by the Nernst equation: * Current (A): Current indicates the discharge rate of a battery. It increases with the spontaneity of the reaction and the surface area of electrodes. Given by: I=V / R * Capacity (Ah): Capacity is the total charge the battery can deliver and is measured in ampere-hours. It is directly proportional to the quantity of charge transported from anode to cathode.   Where: w: Weight of active material (kg)   n: Number of electrons   F: Faraday’s constant (96500 C/mol)   M: Molar mass of active material   * Energy Density (Wh/kg): It is the energy stored per unit weight of the battery, including all components. Depends on good design and appropriate electrode reaction. * Power Density (W/kg): It is the power output per unit weight or volume of the battery. Power density drops during discharge and increases during recharge. * Energy Efficiency (%): * Cycle Life: Refers to the number of complete charge-discharge cycles a secondary battery can undergo before failing. Depends on correct composition, particle shape, and distribution of active material. * Shelf Life: The time a battery can be stored under specific conditions and still perform effectively. Good shelf life implies minimal self-discharge and no corrosion of current collectors.   UNIT2  Low Temperature Solution Combustion (SCS) Method   * Definition: A low-temperature, energy-efficient, spontaneous exothermic redox process between metal nitrates (oxidizers) and organic fuels (reducing agents) to synthesize nano-metal oxides. * Principle: Based on the utilization of the heat energy produced during the exothermic reaction between a metal nitrate (oxidizer) and an organic fuel (RA). * Fuels include: urea, glycine, sugar, EDTA, glucose, etc. * Reaction occurs at ~500°C, producing nano metal oxides and gases. * General Reaction: Metal nitrate + Fuel —[500°C]→ Nano Metal Oxide + Gases * The amount of fuel can be determined by matching the oxidizing valency (from fuel) with reducing valency (from metal nitrate). * For calculation of valency of fuel and metal nitrate, the valency of elements to be considered: N(0), O(-2), H(+1), C(+4) Mn+ (+n) etc   Procedure   * Step 1: Mixing * Weigh metal nitrate and fuel in 1:1 stoichiometry. * Dissolve in minimum distilled water. * Stir the mixture using a magnetic stirrer till a uniform redox solution forms. * Step 2: Combustion * Transfer to a furnace at 500°C. * Solution undergoes evaporation and turns into a more concentrated, uniformly mixed viscous gel type substance. * After sometime, it catches fire and spontaneous combustion takes place for about 1–2 mins. * During flame propagation, large quantity of gasses and high temp produced helps in formation of a porous nano-metal oxide powder.   Advantages   * Simple and fast with minimal equipment. * High-purity nano-materials.   Worked Example: Synthesis of MgO Using Urea   * Chemicals: Magnesium nitrate (Mg(NO3)2·6H2O, Mol. Wt. = 256.41) and organic fuel say urea (NH2CONH2, Mol. Wt. = 60) and distilled water. * Valency: * Urea (N2H4CO) = 2(0) + 4(+1) + 1(+4) + 1(-2) = 6 * Mg(NO3)2·6H2O = 1(+2) + 2(0) + 6(-2) + 6(0) = 10 * Formula: * Weight of fuel = (Wt of metal nitrate) x (Valency of metal nitrate) x (Mol. Wt of fuel)   (Mol. Wt of metal nitrate) x (Valency of fuel)    * Fuel Weight Calculation: Wt of urea = (5 × 10 × 60) / (256.41 × 6) = 1.95 g   Procedure   * Weigh 5.0 g Mg(NO3)2·6H2O and 1.95 g urea. (1:1 stoichiometry) * Dissolve in 250 mL beaker with minimal distilled water. * Stir 10 min using magnetic stirrer. * Transfer to pre-heated furnace at 500°C. * Observe gel formation followed by ignition and finally results in highly porous nano MgO formation.   Other Examples:   * Calculate the wt of fuel and write the combustion procedure for: * 1. ZnO from Zn(NO₃)₂·6H₂O (Mol. Wt. = 297.49) using glycine (NH₂CH₂COOH, Mol. Wt = 75) * Solution: * 2. CaO from Ca(NO₃)₂·4H₂O (Mol. Wt. = 236.15) using glucose (C₆H₁₂O₆, Mol. Wt = 180) * Solution: do it yourself   Sol-Gel Method   * Definition: A wet chemical technique used to fabricate nano-structured ceramic materials and thin films. * Principle: Converts a precursor solution (usually metal alkoxides or salts) into a solid network of metal oxides through inorganic polymerization reactions catalysed by water /(hydrolysis and condensation, forming a gel). * Precursor: Metal alkoxides (M-OR). * Chemical Reactions: * Hydrolysis: M-OR + H2O 🡪 M-OH + ROH * Metal alkoxide reacts with water 🡪 Metal hydroxide + alcohol. * Condensation: * M-OH + M-OR 🡪 M-O-M + ROH * Forms a polymeric network through M–O–M bonds (inorganic).   Sol-Gel Process Steps   * Step 1: Solution Preparation * Dissolve metal salt or alkoxide in a solvent (often alcohol). * Ensures a homogeneous solution. * Step 2: Sol Formation by Hydrolysis * Formation of colloidal sol through hydrolysis (nucleophilic attack by oxygen atom of water on -OR group). * Sol is a stable dispersion of colloidal particles of precursors in a solvent * Step 3: Gel Formation by Condensation * Aging leads to condensation (M-O-M bonds). * Forms rigid 3D gel network. * Gel is an interconnected, rigid and porous inorganic network covered completely with liquid phase. * The transformation is called sol-gel transition. * Step 4: Drying of Gel * Removes liq phase from gel network. * Three methods: * Supercritical drying (drying under high critical conditions) results in formation of Aerogel. * Dehydration (removes ROH) results in Xerogel. * Sintering at high temp (800°C) results in Powder (dense, decomposed network). * Diagram of a diagram of gel drying    AI-generated content may be incorrect.   Example: TiO₂ Preparation   * Chemical Used: Titanium isopropoxide. [Ti(O(CH(CH3)2)4)], alc, distilled water, HNO3 * Process: * Dissolve Ti complex in ethanol + water (1:4). * Add HNO3 to adjust pH and control hydrolysis. * Stir for about 30 mins to form sol * Keep to age for about a day to form gel. * Dry at 120°C and sinter at 450°C to get TiO₂ nanoparticles. * Mechanism: Nucleophilic attack by water on alkoxy group.   Advantage:   * Simple and economic. * Highly flexible with stoichiometry & dopants. * High-quality coatings.   Carbon Nanomaterials (CNTs)   * Definition: CNTs are cylindrical structures composed of a hexagonal network of carbon atoms (rolled-up graphene sheets). * Types of CNTs: * Single-Walled Nanotubes (SWNTs): * Consist of a single graphene layer. * Can be Armchair, Zig-Zag, or Chiral in structure. * Multi-Walled Nanotubes (MWNTs): * Made of multiple concentric graphene cylinders. * Multiple rolled layers of graphene sheets.   Synthesis of CNTs – Modified CVD Method   * Chemical Vapor Deposition (CVD) requirements: * Furnace: High-temperature tubular furnace (500–1500°C). * Carbon Source: Benzene, xylene, natural gas, acetylene. * Substrate: Carbon, quartz, silicon. * Inert Gases: Argon, Hydrogen, Nitrogen. * Catalysts: Ferrocene, Nickelocene, Cobaltocene.   Exp setup   * Diagram of a heater with a diagram    AI-generated content may be incorrect. * A typical catalytic chemical vapour deposition system. * Equipped with a horizontal tubular furnace as the reactor. The tube is made of quartz with diameter 30mm and length 1000mm.   Working   * Ferrocene acts as catalyst and benzene/toluene vapours acts as the carbon atom precursor which are transported to reaction chamber by inert gases like hydrogen, argon or both. * This is decomposed into respective ions of Fe and carbon atoms resulting in carbon nanostructures. * These nano structures grow into CNTs either in, before, or after the heating zone (typically 500–1150°C for ~30 minutes).   Mechanism of CNT growth   * Diffusion of hydrocarbon gas. * Adsorption on catalyst active sites. * Dissociation (homolytic fission) into C and H free radicals. * Saturation via repetition of above steps. * Precipitation of carbon atoms forms CNT structure and H radicals form H₂ gas. |  |  |  |
| Graphene   * Definition: Allotrope of carbon which is a single thick layer of carbon atoms arranged in a hexagonal lattice (sp² hybridized). * Properties: Extremely strong, conductive, and flexible. * Graphene Oxide (GO): Oxidized form of graphene with oxygen-containing groups (like –OH, –COOH, –O–) disrupting the conjugated π-network. * Reduced Graphene Oxide (rGO): Partially restores the π-network by removing some oxygen groups from GO.   Synthesis: Modified Hummer’s Method   * Start: Graphite + NaNO3 + H2SO4 (in ice bath, stirred 30 min) * Oxidation: Add KMnO4 to form graphite oxide * Sonication at 50°C for 2 hrs and add H2O2 + Deionised water. * Washing: Wash with HCl (10% and then 37%) * Drying: gives GO powder * Reduction: GO + NaBH4 (sodium borohydride) → rGO   Plasma Enhanced Chemical Vapor Deposition (PECVD)   * Definition: PECVD is a type of chemical vapor deposition that uses plasma to enhance chemical reactions at lower temperatures. * It is used to deposit thin films from gas state (vapor) to solid state. * It converts reactant gases into a plasma, allowing thin films to be deposited on substrates from vapor.   Key Features   * The plasma is created by applying Radio Frequency or DC energy between electrodes. * Plasma activates gases, leading to surface reactions. * Films form on substrates as gases decompose and react.   Advantages Over Conventional CVD   * High deposition rates * Lower deposition temperatures * Better step coverage on uneven surfaces   How PECVD Works   * The substrate is placed between two electrodes in a deposition chamber * Substrate is heated to 250–350°C * Gases like silane (SiH₄) and ammonia (NH₃), with argon or nitrogen, are introduced * Electrical discharge ignites plasma (100–300 eV), forming a glowing sheath * Energized electrons collide with gas molecules in plasma * Reactive species are transported via gas flow to substrate * Chemical reactions form a film on the substrate * By-products are pumped away * Gas flow rates and temperatures affect film thickness, hardness, refractive index * Diagram of a vacuum supply system    AI-generated content may be incorrect.   Metal-Organic Chemical Vapor Deposition (MOCVD)   * Definition: It is a technique for depositing thin solid films (usually semiconductors) onto solid substrates (wafers) using organometallic compounds as precursors.   Applications   * Primarily used in Electronic and optoelectronic devices such as cell phones, LEDs and traffic lights, billboards, etc   Working Principle   * Transport of group-III metalorganics and group-V hydrides/alkyls act as the precursors. * Carrier gases (H₂ or N₂) transport these precursor molecules onto heated substrate. * Chemical reactions occur on a heated substrate (RF induction heating), forming a thin film. * Process is also known as organometal vapor phase epitaxy. * Reaction: Pyrolysis of metalorganics to form InN and GaN thin films * Example Reactions: * (CH₃)₃In + NH₃ → 3CH₄ (gas) + InN (solid) * (C₂H₅)₃Ga + NH₃ → 3C₂H₆ (gas) + GaN (solid) * Exhaust System: gases are released to air through rotary and diffusion pumps * Applications: transistors, led, solar cell   UNIT 4  E waste:   * It is a term that describes out-dated, end-of-life, or abandoned electronic appliances. It contains all of their parts, consumables, and spares. * Toxic compounds naturally leak from the metals inside e-waste when it is buried, making it very harmful. * Informal or uncontrolled e-waste processing, particularly in developing countries, can be harmful to human health and pollute the environment. * E-waste types: * Type 1- Major appliances (refrigerators, washing machines, dryers etc.) * Type 2 – Small appliances (vacuum cleaners, irons, blenders, fryers etc.) * Type 3 – Computer and telecommunication appliances (laptops, PCs, telephones, mobile phones etc.)   Impacts:  On environment:   * The manufacturing, reprocessing, and disposal of electrical and electronic equipment creates an interface between the e-wastes and the environment. * Environmental degradation is caused by the release of fumes, gases, and particulate matter into the air, the discharge of liquid waste into water and drainage systems, and the dumping of hazardous wastes. * Burning wires and cables to recover metal produces brominated and chlorinated dioxins, which pollute the air.   On human health:   * Human health is harmed by the inappropriate treatment of e waste. * Processes such as dismantling components, wet chemical processing, and cremation results in direct chemical exposure and inhalation. * Inhalation of these chemicals by workers and locals increases the risk of cancer. * Long-term exposure to lead from printed circuit boards, computer and television screens can impair the central and peripheral neurological systems as well as the kidneys, with children being particularly vulnerable.   E-waste Recycling:   * There are four methods of managing waste – recycling, landfilling, composting and burning. * Impact of E-waste recycling: Conserve natural resources, Protects the environment, Create Jobs, Reduces global warming   Recycle Management:   * Collection: Gathering E-waste from various sources * Storage: While safe storage may not appear critical, it can prove very important. * Manual Sorting: Disintegration of all the components and materials of the E-waste to analyse which can be reused and which can go as scrap. * Mechanical Separation: The mechanical separation of the different materials actually consists of several processes one after the other. The two key steps are magnetic separation and water separation. * a) Magnetic separation: The shredded E-waste is passed under a giant magnet, which is able to pull ferrous metals such as iron and steel from the mix of waste. * b) Water separation: With a solid waste stream that now consists mainly of plastic and glass, water is used to separate the materials, further purifying for the separation of different plastics as well as hand-sorting obvious contaminants. |  |  |  |

E nose:

* It is a device that can detect and recognise odors and flavours using sensor array.
* The materials used in sensor array in enose are called chemo resistive molecules.
* They can change their electrical resistance when they interact with diff molecules.
* Examples of chemoresistive materials include Metal oxides such as tin oxide, organics such as polymers etc

Mechanism and working:

* Detects smell more efficiently.
* It consists of array of gas sensors that are overlapping selectively along with a pattern reorganisation component.
* Principle: it is based on the detection of volatile organic compounds (VOCs) present in the air.
* Vocs are adsorbed onto the surface of the sensor and cause a change in its electrical properties.
* The change is then measured and analysed by a pattern recognition algorithm
* A black background with white text

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* Applications:
  + Maintaining quality and control grading
  + Food quality and related properties determination

E skin

* It is a thin flexible material that can mimic the function and mechanical properties of human skin.
* Sensors help measure pressure, temp, humidity and airflow.
* They are considered rehealable because of reversible bond exchange meaning that bonds holding back the network together are able to break and reform under certain conditions such as solvation and heating.
* Tiny electronic wires generate impulses like bodys nervous system
* It is made up of a network of covalently bound polymers that are thermoset, ie cured at a specific temperature
* The material is reusable and recyclable
* Typical materials used for eskin are cnts, organic polymers, etc
* Materials used to simulate skin are epoxy resins, metals etc
* Nano and micro fillers can be used to tune physical properties.
* Principle of flexible tactile sensor is the piezoresistive effect of graphene film
* When a micro pressure is applied, the surface collects stress evenly to the graphene film.
* The stress will fracture or crack the c-c bond
* The pressure can be measured according to the varied resistance of the film.
* Sensitivity and flexibility of graphene film improves the sensitivity of the sensor
* A diagram of a pressure

  AI-generated content may be incorrect.
* Common requirements:
  + Heterogeneous integration between sensors, active devices, data storage, processing components and other components.
  + Biocompatibility, conformability of skin topography, flexibility and stretchability.

Materials and mechanism:

* It is made of 4x4 tactile sensing units which contains 3 layers:
  + Substrate layer (PI substrate)
  + Piezoresistive layer (graphene)
  + Polydimethylsiloxane (PDMS) bump
* A blackboard with colorful writing

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RFID (radio frequency identification)

* It is a form of wireless communication that incorporates the use of electromagnetic or electrostatic coupling in the radio freq portion of the electromagnetic spectrum to uniquely identify an object, animal or person.
* Materials include:
  + rfid transponder: microchip of Si
  + antenna: etched Cu /Al
  + chip+antenna are put on a substrate ie PET (polyethylene terephthalate)

Working

* The RFID system consists of 3 components: scanning antenna, transceiver, transponder (RFID tag)
* The scanning antenna and transceiver together are called RFID reader.
* It is portable or permanently attached.
* It uses radio waves to transmit signals that activate the tag which once activated sends a wave back to the antenna where it is translated into data.
* Rfid reader are of 2 types: fixed readers or mobile readers.
* The read range of rfid tags varies based on factors including type of tag, type of reader, frequency etc.
* Stronger the power source, longer the range.
* Rfid tags are made up of IC, antenna and substrate.
* A part of the tag encodes identifying info called rfid inlay
* They are of two types:
  + Active: own source of power (battery)
  + Passive: receives power from reading antenna whose emw induces current in rfid tags antenna
* Consists of low freq, high freq, ultra high freq and microwave freq RFID systems.

Photochromic Materials:

* Definition: Substances that reversibly change color when exposed to light, especially UV light.
* They absorb light, undergo a reversible chemical change in structure and color, and return to the original state when the light source is removed.
* Available in glass, plastic, or powder form.

Working Principle

* It is a reversible photochemical reaction that occurs when material is exposed to light.
* The photochromic material absorbs light energy and undergoes a reversible chemical reaction that changes its molecular structure and color.
* When the light source is removed, the material returns to its original state.
* UV light changes molecular structure.
* UV exposure triggers molecular shift, increasing light absorption and gives the lenses a darkened appearance.
* In absence of UV, molecules revert and become transparent again.
* Photochemical molecules are sensitive to both the presence and amount of UV light.

Photochromic Lenses: Structure & Mechanism

* Transparent indoors and darken when exposed to UV light from sun
* Provide benefits of both glasses and sunglasses in a single frame.
* Plastic Lenses: Have carbon based compounds within them that change structure in presence of UV light.
* Glass Lenses: Contain silver halide crystals (like silver chloride).
* UV light causes silver gains an electron (Ag⁺ → Ag⁰), darkening the lens.
* In absence of UV, a second compound (like copper chloride) reverses the reaction.
* A diagram of a light source

  AI-generated content may be incorrect.
* UV light causes a bond to cleave (oxygen-carbon), altering the molecules shape and properties.

Advantages of Photochromic Lenses

* Dual purpose: Act as both prescription glasses and sunglasses.
* Provide full protection from UVA and UVB rays.

Disadvantages

* Unsafe for driving: Lenses may darken behind windshields.
* Some are not polarized, causing glare issues.

Thermochromic Materials:

* Definition: Thermochromic materials change color due to temperature changes.
* Common Applications: Kettles, Coffee cups, Temperature indicators

Types of Thermochromic Materials:

* 1. Liquid Crystals (LCs):
  + Organic compounds that reflect different colors at different temperatures.
  + Examples: Cholesteryl esters, ethers, benzoates, oleyl carbonates.
  + Applications: Thermometers, mood rings, thermal cards.
* 2. Leuco Dyes:
  + Organic molecules that switch between colored and colorless states when they interact with other chemicals at certain temps
  + Examples: Crystal violet lactone, malachite green lactone, phenolphthalein, fluoran.
  + Used in papers, polymers, inks, etc.
* 3. Inorganic Materials:
  + Change optical properties due to change in crystal structure or electronic configuration at certain temps.
  + Include metal oxides like: Titanium dioxide (TiO₂), Zinc oxide (ZnO)

Working Principle of Liquid Crystal Thermochromic Materials:

* These materials reflect light differently depending on temperature and molecular alignment.
* Operate based on selective reflection of certain wavelengths depending on temp and orientation of molecules.
* Exhibit a phase change from crystalline (chiral/twisted nematic phase) at low temp to isotropic (liquid) phase at high temp.
* Only nematic mesophase shows thermochromic properties which restricts the effective temperature range of material.
* A diagram of refreshment and refreshment

  AI-generated content may be incorrect.
* Hot: Crystals are closer together, reflects blue light.
* Cold: Crystals spread out, reflects red light.

Applications of Thermochromic Materials:

* Temperature Indicators in Industry
* Thermometers for rooms, refrigerators etc

Electrochromic Materials

* Definition: Electrochromic materials change color or opacity when an electric field is applied.
* Unlike photochromic (light sensitive) or thermochromic (temperature sensitive) materials, electrochromic materials respond to voltage/electric field.
* Applications: Used in smart windows, mirrors, sunglasses, and other devices that manage light and heat transmission.

Types of Electrochromic Materials

* Metal Oxides:
  + Inorganic compounds that undergo color changes by ion/electron exchange.
  + Example: Tungsten oxide (WO₃) changes from transparent to blue when voltage is applied.
* Conducting Polymers:
  + Organic compounds that change color by oxidation state changes.
  + Example: Polyaniline shifts from green to blue.
* Organic Dyes:
  + Undergo redox reactions to change molecular structure and hence color.
  + Example: Viologen changes from colorless to blue or red.

Working Principle

* It is based on reversible change in optical properties caused by redox reactions.
* When the material is placed on the surface of an electrode, an electric field can induce redox reactions and change the color or opacity of the material.
* The color change can be between a transparent state and a color state or between two colored states.
* The color change can be controlled by the mag of the applied voltage.

Device Structure: Electrochromic Device (ECD)

* Mechanism:
  + Electrons and charge balancing ions migrate into EC layer and thus optical absorption occurs.
  + Voltage induces redox reactions, changing color or transparency.
* Diagram of a diagram of a diagram of a diagram of a diagram of a diagram of a diagram of a diagram of a diagram of a diagram of a diagram of a diagram of a diagram of a

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* Shows electron & ion movement between ion storage and EC layers, enclosed by electrodes.

Device Operation Modes:

* 1. Transmittance Mode:
  + Transparent conducting electrodes (TCE) on both sides.
  + Controls light intensity (used in smart windows).
* 2. Reflectance Mode:
  + One TCE replaced by reflective material (e.g., aluminum, silver).
  + Controls light reflection (used in rear-view mirrors).

Applications:

* Auto dimming rearview mirrors
* Smart sunglasses or adaptive goggles
* Sensors, optical shutters/modulators

Electrostrictive Materials

* Definition: Materials that exhibit a quadratic relationship between mechanical stress and the square of the electric polarization.
* Examples include PMN-PT (Lead Manganese Niobate Lead Titanate)
* Principle: Shape change occurs due to ion displacement in response to an electric field.
* Strain is quadratic and independent of polarity.

Working:

* Electric field causes positive and negative ions in material to move in opp directions creating a compressive force.
* This leads to deformation
* Deformation depends on the square of electric polarization (alignment of electric dipoles in the material)
* No reversal of shape with reversed field
* Applications include: Actuators, Micro-pumps and MEMS devices

Magnetostrictive Materials

* Definition: Smart materials that convert energy between magnetic and elastic states using magnetostriction (shape change due to magnetization).
* Examples include Nickel, Iron, Cobalt

Working:

* When magnetic field applied to the material, molecular dipoles & bloch walls rotate to align with the applied field.
* The rotation of dipoles leads to deformation of material.
* Strain depends on field intensity and magnetic anisotropy (tendency of material to magnetise more easily in certain directions than others)
* Inverse effect also occurs. Mechanical stress leads to change in magnetization
* If field is angled, the material realigns to reduce energy which inturn induces strain
* Applications include loudspeakers, headphones, ultrasonic machining, etc.

UNIT 3

Production of Electronic Grade Silicon (EGS)

* Purpose: To produce high purity, single crystal silicon from bulk polycrystalline material for semiconductor devices.
* Method: solidifying silicon from its molten state. (Melt growth)

Crystal Growth Techniques

* Czochralski Method
* Float Zone Method

Czochralski Method

* Overview: A technique to grow single crystal silicon ingots (boules).
* These boules are sliced into thin circular wafers and then diced into little Si chips from which large scale integrated circuits are made.

Requirements:

* Furnace:
  + Includes fused silica crucible (SiO2), graphite susceptor, heating mechanism (resistance or RF), power supply and rotation system.
* Crystal Pulling Mechanism:
  + Includes seed holder, counterclockwise rotation
* Ambient Control:
  + Oxygen exclusion using Argon gas. Graphite parts can react with O2, forming CO2 which must be avoided.
* Control System:
  + Microprocessor based. Controls temperature, crystal diameter, pull rate, rotation speed

Working Principle:

* Melting: Polycrystalline silicon (the feed material) is melted at 1410°C in a crucible by resistance or radio frequency heater.
* Seeding: A seed crystal is dipped into the saturated molten silicon.
* Crystallization: Seed rotates counterclockwise, and the crucible rotates clockwise.
* Crystal grows as the seed is slowly pulled upward.
* Shape Control: Achieved by adjusting heating power, pull rate and rotation speed
* Diagram of a diagram of a process

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Final Product:

* Crystals up to 300 mm diameter, 300 kg weight
* Most imp technical application is growth of dislocation free silicon which is crucial in high performance electronics.

Float Zone (FZ) Method

Why FZ Over Cz?

* Cz wafers contain oxygen impurities due to contact with the SiO2 crucible, reducing minority carrier lifetime and inturn reducing efficiency of solar cells.
* Oxygen and its complexes may become active in higher temp making wafers sensitive to high temperature processing.
* FZ wafers are preferred in high efficiency or lab grade solar cells where purity is critical.

Working:

* It is a crucible free process i.e. no container touches the silicon.
* Surface tension maintains the molten silicon zone to be kept between the two vertical solid rods.
* A seed crystal is dipped into one end of the melt.
* The molten zone is moved along the feed rod.
* At the other end, crystal growth occurs as the molten silicon solidifies.

Advantages

* Avoids contamination from crucible materials.
* High purity crystals.
* Minimal crystal defects due to lack of container interaction.
* A diagram of a structure

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Disadvantage of FZ

* Size limitation: Max wafer diameter ≈ 200 mm (compared to up to 300 mm in Cz).
* Surface tension limits the zone width.
* This restricts its use to specialized applications, not mass production.

Polyaniline (originally called aniline black).

* It is a mixed oxidation state polymer containing benzoid and quinoid units.
* It has characteristics of switching between conductive and insulating states depending on experimental conditions.
* A black and white diagram of a hexagon

  AI-generated content may be incorrect.
* PANI exists in three oxidation states, defined by the parameter 1−y:

| Form | Oxidation State (1 − y) | Description |
| --- | --- | --- |
| Leucoemeraldine (LE) | 0 | Fully reduced, all benzoid units |
| Emeraldine Base (EB) | 0.5 | Half oxidized, alternating benzoid and quinoid units; most stable and useful form, acts as a semiconductor |
| Pernigraniline (PE) | 1 | Fully oxidized, all quinoid units |

Preparation of (PANI)

* Synthesis Steps:
* Reactants: Aniline and APS (Ammonium Persulfate) in 1.0 M HCl.
* Process:
* Stirred vigorously at ~0 °C.
* Oxidative polymerization occurs forming a dark green PANI powder.
* Post-treatment:
* Filter and wash with 1.0 M HCl and distilled water until clear.
* Final wash with acetone, dry at 60 °C.

A diagram of a chemical reaction

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Applications of PANI

* Solar Cells
* Electrochromic Glasses: Smart glass changes color under electric current.
* Sensors

Magnetic Materials for data storing

Principle of Magnetic Recording:

* Data is written on a medium (disk/tape) that contains magnetic layers.
* Uses magnets with north and south poles to encode data.
* Magnetic field sensors detect the magnetic field which allows data reading.
* External magnetic fields change polarity which allows data writing.

Working Mechanism:

* Identical poles (N–N or S–S) create a magnetic field whose voltage detected by GMR sensor which represents “1”.
* Opposite poles (N–S) do not produce a field. Thus no voltage and represents “0”.

Dielectric Materials for Storage Devices

* Dielectrics are poor conductors but get polarized when voltage is applied.
* Used in volatile (DRAM) and non-volatile (RRAM) as memory storage media.

Working Principle:

* It is a simple Electrode/Dielectric/Electrode sandwich structure.
* The dielectric is the carrier for resistance transformation and hence called storage medium.
* It is based on resistance change (switching between high and low resistance).
* The storage medium uses High Resistance State (HRS) and Low Resistance State (LRS) to represent 0 and 1 of binary code.
* Flexible versions use cross array structures to maximize density to improve storage density.

Applications of Dielectric Materials:

* Resistive switching memory
* Thin-film transistors

Examples of dielectric materials

* Inorganic materials eg: binary metal oxides like TiO2 and flexible multimetal oxide such HfTiO4 are used DRAM and RRAM
* Organic materials eg: lignin
* Organic-inorganic composite materials eg: graphene oxide

Extras:

GaAs

General Overview

* GaAs (Gallium Arsenide) is a III-V compound semiconductor.
* Widely used in optoelectronics (LEDs, laser diodes) and microelectronics (high frequency ICs).
* Has FCC cubic structure

Electrical Properties

* Poor intrinsic conductivity makes it semi insulating in pure form.
* Doping with p-type or n-type impurities allows conductivity for device applications.
* High mobility and saturated drift velocity making it better than silicon for high freq applications.
* A graph of a graph of a number of mobility carriers

  AI-generated content may be incorrect.
* GaAs velocity peaks then drops (due to intervalley scattering), while Si saturates more gradually.

Optical Properties

* It is a direct bandgap semiconductor (1.42 eV)
* Direct bandgap means that the min of the CB is directly over the max of the VB.
* Transitions across the VB n CB require only a change in energy and no change in momentum
* This leads to efficient photon emission making it ideal for LEDs and laser diodes.
* A diagram of a graph

  AI-generated content may be incorrect.
* Only GaAs and InP are suitable for efficient light emission.

Semi-Insulating (SI) GaAs

* Used as substrates for Integrated circuits due to high resistivity and electrical isolation.
* Formed by either intentional doping with transition metal impurities during growth from melt or by relying on the formation of native defects during crystal growth.
* SI GaAs is mostly used as substrate for devices made by ion implantation method since it reduces parasitic capacitances.
* Key features include high resistivity, high mobility, thermal stability and low crystalline defects.

Applications of GaAs

* Transistors and Computer: Used in transistors and logic circuits.
* Defence and Aerospace: Used in radars, sensors, and secure comms.

Silicon Germanium (Si₁₋ₓGeₓ) Summary

* Silicon and germanium are completely miscible over the full range of x (0 to 1).
* The structure is diamond like cubic (same as silicon).

Thermoelectric Properties

* Thermoelectric effect: In presence of temperature gradient generates electric voltage and visa versa.
* Depends on the thermoelectric material figure of merit (zT)
* A mathematical equation with black text

  AI-generated content may be incorrect.
* S: Seebeck coefficient, σ: Electrical conductivity, κ: Thermal conductivity, T: Temperature
* For high efficiency, high S and σ, low κ are preferred.

Performance Highlights:

* Operates up to 1050°C without degradation.
* Doping (e.g., phosphorus (n-type), boron (p-type)) adjusts carrier concentration.
* Strategies like using 0D (clusters), 1D (nanotubes), 2D (layers) improve thermoelectric performance by reducing dimensionality.

Band Gap

* SiGe is an indirect band gap semiconductor.
* Has a narrower band gap than pure silicon.
* The band gap is tunable by changing germanium content (x).

Doping & Fabrication

* SiGe can be doped p- or n-type when amorphous.
* Doping is difficult in crystalline SiGe due to high crystallization temperatures.
* Challenges in growing high quality doped films for mass production.

Applications

* Electronics & Telecommunication: Used in Heterojunction Bipolar Transistors (HBTs).
* Solar Industry: 4× faster carrier mobility in comparison to silicon.

Pentacene

* Structure: A linear acene molecule made of five fused benzene rings.
* Application: Ideal for highly ordered organic thin-film transistors (OTFTs).
* Crystal Structure: Forms molecular crystals with a herringbone packing.
* Electron Transport: Delocalized π orbitals facilitate efficient charge movement via π–π stacking.
* Lattice: Adopts a triclinic lattice structure in bulk.
* A diagram of a chemical structure

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Synthesis of Pentacene

Step 1:

* Reactant: Pentacene-6,13-dione.
* Solid NaBH4 was added to the round bottom flask containing suspension of THF at 0 °C.
* Then the reaction mixture was purged with N2 and water was added.
* The mixture was heated to 50–60 °C until it becomes homogeneous.
* After 2 hrs of heating, THF was evaporated at reduced pressure, water was added and the reaction mixture was filtered.
* The solid were washed with water. After drying, a white solid was recovered.
* Product: 6,13-dihydroxy-6,13-dihydropentacene (85% yield).

Step 2:

* Reactant: Dihydropentacene.
* The obtained product was stirred with SnCl2 (1:2 mole ratio) in acetone.
* The resulting crude pentacene was isolated by centrifuge and washed with both methanol and THF.
* Purification of sublimation resulted in pure pentacene (yield ~60%).

A structure of a chemical formula

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Fabrication of Pentacene Thin Films

* It is sensitive to air (moisture, oxygen) and low solubility makes it unstable with standard fabrication methods.
* Thus, pentacene should be deposited using evaporation techniques to fabricate thin films for electronic devices.
* It is an energy intensive process.
* To overcome this, substituents are introduced to the aromatic core, which increases the stability, solubility, and packing for better electrical properties. of the pentacene.

Thermal Evaporation Technique

* Organic molecular beam deposition (OMBD) one of the thermal deposition technique is used to produce high quality thin films of pentacene.
* Uses ultra high vacuum to evaporate material.
* Molecules are sublimated and deposited on a substrate which is placed parallel to the sublimed molecules.
* Advantages include high control over film thickness and order.
* Diagram of a vacuum chamber

  AI-generated content may be incorrect.

Spin Coating:

* Simple and widely used due to its capacity for mass production and cheaper costs.
* A solution is dropped on a spinning substrate which starts spinning with a certain acceleration rate and remains at const. speed for a period of time.
* Thin film is formed as solvent evaporates.
* A diagram of a structure

  AI-generated content may be incorrect.
* App of pentacene: Solar cells, Photodetector

UNIT 5

Sensors:

* It is device that measures change in a physical (heat, light, sound, pressure etc) and/or chemical (pH, smell, taste, concentration, humidity etc) parameters of interest in an environment and transforms it into an electronic signal.

Optoelectronic sensors

* Converts light, change in light to electric signal
* Detects polarization, wavelength or freq of light rays like visible, infrared, uv and converts that change into electric signal via photoelectric effect.
* Works like a photovoltaic cell

Pulse oximeter

* Principle: oxygenated blood absorbs mor IR, allows red light to pass through while deoxygenated blood absorbs more red light allowing IR to pass through.

Working:

* Consists of 2 leds, one emitting red light and the other emitting IR light and photodetector which measures the intensity of the transmitted light at each wavelength.
* Using the differences in the reading, the blood oxygen content is calculated.
* A probe is placed on a suitable body part usually the finger/ear lobe.

Methods of monitoring oxygen saturation in blood

* Transmission method:
  + Transimitter (led) and the receiver (photoditector) are placed on opposite sides of the finger while the finger is placed between the leds and photodetector.
  + When the finger is placed, a part of light will be absorbed and some part will reach the photodetector.
  + With each heartbeat, volume of blood increases, light absorbed increases sand light reaching the photodetector decreases.
  + Waveform of received light signal peaks in between heartbeats and trough at each heartbeat.
  + Difference between the peak and trough value is the reflection value deu to blood flow at heartbeat.
* Reflectance method
  + Led and photodetector are placed on the same side.
  + There will be some fixed light reflection back to the sensor due to the finger.
  + With each heartbeat, blood volume in finger increases and light reflection back to the sensor increases.
  + Troughs and peaks in reflected light occur at each heartbeat
  + Duration between two spikes can be used to measure the persons heartbeat.
* A graph on a blackboard

  AI-generated content may be incorrect.
* Oxygenated haemoglobin (RED line) absorbs more infrared light than red light and De-Oxygenated haemoglobin (blue line) absorbs more red light as compared to infrared light
* The oxygen content in the blood can be easily calculated by comparing how much red light is absorbed as compared to IR light.

Piezoelectric Sensors

* It is a device which converts physical parameters like acceleration, pressure, etc into an electrical charge which can then be measured.
* Characteristics of PE sensors include: High strength, High stability, Highly flexible, etc
* A diagram of a metal plate

  AI-generated content may be incorrect.
* Strain sensor: When external force is applied on an object, the strain (permanent/temporary) is induced in the object due to its structural (internal) deformation which results in change in internal resistance of the object and can be measured using strain sensor.
* Strain sensors are widely used in medical industry applications:
  + Pulse measurement: PE sensors are very sensitive to record pulse measurements and effective in monitoring the patients’ health.
  + Stethoscopes: Due to high sensitivity and robustness PE sensors, they are often used within stethoscopes.
  + Anaesthesia Effectiveness: PE sensors are capable of accurately measuring the muscles stimulations and hence can clarify the effectiveness of anaesthesia.
  + Sleep Studies: PE sensors can be attached to various parts of the patient body and can be used to measure the smallest movements of patients during the sleep also.
* Other applications include wearable and stretchable electronics used in healthcare and biomedical engineering, sport performance monitoring, soft robotics, and gaming and virtual reality.

Electrochemical Sensors

* It is a device that converts electrochemical information into a measurable electrical signal.
* Principle: It measures the current produced by chemical reactions in the electrochemical system.
* Main components include electrodes system, transducer, amplifier and recorder.
* The electrode system consists of three electrodes namely working electrode, counter/auxiliary electrode and reference electrode.
* It has a potentiostat which is an electronic instrument that controls the voltage between two electrodes.
* WE is sensitive to any change in analyte solution and provides the surface for the analyte to undergo reaction, when the potential is applied between WE and RE.
* CE helps in completing the circuit by allowing the reaction (opposite to WE reaction) to happen.
* RE is independent of the analyte and other ions concentration. Its potential is constant while measuring the potential of WE.
* By measuring the current of redox reaction, the analyte can be identified.
* A diagram of electrical wiring

  AI-generated content may be incorrect.
* WE – graphite/carbon based ink
* CE – carbon ink
* RE – silver/silver chloride ink
* They undergo redox reactions upon applying voltage and resultant current is measured by transducer.
* A diagram of a transducer

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Applications

* A blackboard with text on it

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* A blackboard with writing on it

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Electrochemical gas sensor

* It is designed to identify and measure the quantity of the concentration of gasses like oxygen, carbon dioxide, etc.
* These gases are produced from industrial emissions, vehicle exhaust and open burning of garbage waste.
* These sensors can be effective tool for analyzing them, as it consumes less power than other conventional gas sensors.
* It consists of combination of two or three electrodes which are called reference, working, auxiliary/counter electrodes and ionic conductor between them.
* A blackboard with red writing

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