

COURSE MATERIALS

ON

1910E4A - BATTERY TECHNOLOGY

B.E VII SEMESTER



DEPARTMENT OF ELECTRICAL AND ELECTRONICSENGINEERING

P.S.R. ENGINEERING COLLEGE

(Autonomous)

SIVAKASI-626140

Institute Vision and Mission

Vision

To contribute to the society through excellence in technical education with societal values and thus a valuable resource for industry and the humanity.

Mission

- To create an ambience for quality learning experience by providing sustained care and facilities.
- To offer higher level training encompassing both theory and practices with human and social values.
- To provide knowledge based services and professional skills to adapt tomorrow's technology and embedded global changes.

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Vision

- To be a technical hub of creating Electrical and Electronics engineers with superior quality, human values and ethical views.

Mission

- To provide an excellent, innovative and comprehensive education in electrical and electronics engineering.
- To create a conducive learning environment and train the students in the latest technological development domain.
- To enhance the student's potential by creating awareness on educational and career opportunities.
- To produce competent and disciplined engineers suitable for making a successful career in industry/research.

1910E4A

BATTERY TECHNOLOGY

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Programme: B.E –Electrical and Electronics Engineering
Pre-requisites: Engineering Physics, Engineering Chemistry

Sem: **Category:** **OE**

AIM:

To impart fundamental knowledge on electrochemical energy storage systems considering the operation and design of various battery technologies. To enable the students to understand the requirement of batteries for automotive application combined with environment policy considerations.

Pre-requisite:

Course Outcomes:

The Students will be able to

- CO1. Recognize the basic physical concepts of thermodynamics and kinetics involved in electrochemical reactions.
- CO2. Select the appropriate battery system with respect to application.
- CO3. Analyse the characterization methods of batteries and interpret concepts describing battery performance.
- CO4. Describe the recent developments battery systems.
- CO5. Understand the requirements of battery systems for automotive applications and understand the modelling of battery systems.
- CO6. Discuss the Life Cycle Analysis according to cost and environmental aspects; material and energy consumption, reuse, recycling.

INTRODUCTION TO ELECTROCHEMICAL ENERGY STORAGE

9

Introduction to battery technologies- Electromotive force- Reversible cells- Relation between electrical energy and energy content of a cell-Free energy changes and electromotive force in cell- Current challenges in Energy storage Technologies.

MAJOR BATTERY CHEMISTRIES DEVELOPMENT AND TESTING

9

Battery performance evaluation- Primary battery - Service time- Voltage data- Service life – ohmic load curve- Effect of operating temperature on service life. Secondary batteries- Discharge curves- Terminal voltages- Plateau voltage –Lead acid Batteries – Construction and application.

RECENT TECHNOLOGIES:

9

Recent development of electrode materials in lithium ion batteries- Recent development of solid electrolytes and their application to solid state batteries-Polymer solid electrolytes for lithium ion conduction– Thin Film solid state Batteries: Fundamentals, Construction and application – Super Capacitors: Fundamental, Construction and application.

BATTERIES FOR AUTOMOTIVES – FUTURE PROSPECTS

9

Degrees of vehicle electrification - Battery size vs. application -USABC and DOE targets for vehicular energy storage systems - Analysis and Simulation of batteries - Equivalent circuit and life modeling – Environmental concerns in battery production – Recycling of batteries

BATTERY MANAGEMENT SYSTEM

9

Introduction to Battery Management System, Cells & Batteries, Nominal voltage and capacity, C rate, Energy and power, Cells connected in series, Cells connected in parallel, Electrochemical and lithium-ion cells, Rechargeable cell, Charging and Discharging Process, Overcharge and Undercharge, Modes of Charging

Total Periods 45

Text Books

1. T.Minami, M.Tatsumisago,M.Wakihara,C. Iwakura,S. Kohijiya, Solid state ionics for batteries, Springer Publication, 2009
2. Sandeep Dhameja, Electric Vehicle Battery Systems, Newnes publication, 2001.

Reference

Book

1. Bard, Allen J., and Larry R. Faulkner. Electrochemical Methods: Fundamentals and Applications. 2nd ed., Wiley– VCH, Verlag, GmbH, 2000.
2. Masataka Wakihara and Osamu Yamamoto, Lithium ion Batteries Fundamental and Performance,Wiley–VCH, Verlag GmbH, 1999.
3. Robert A.Huggins, Advanced Batteries – Materials science aspects,Springer, 2009.

Course Outcomes	Program Outcomes (POs)												Program Specific Outcomes (PSOs)			
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3	PSO4
CO1	1		1	2									1			1
CO2	1	2	2	1									1			2
CO3	1	2	2	1									1			2
CO4	1		1	1									2			1
CO5	1	2	2	1									2			2
CO6	2	2	2	1									2	1	1	2

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

1910E4A - BATTERY TECHNOLOGY

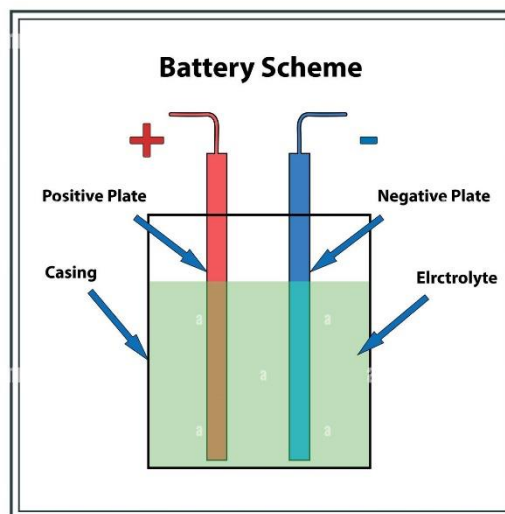
UNIT 1

INTRODUCTION TO ELECTRO CHEMICAL ENERGY STORAGE

INTRODUCTION TO BATTERY TECHNOLOGIES

Battery technology is an essential component of our modern world, powering a wide range of devices and enabling energy storage for various applications. Batteries store electrical energy in chemical form and convert it into usable electricity when needed. They have become increasingly important as the demand for portable electronics, electric vehicles, and renewable energy sources has grown.

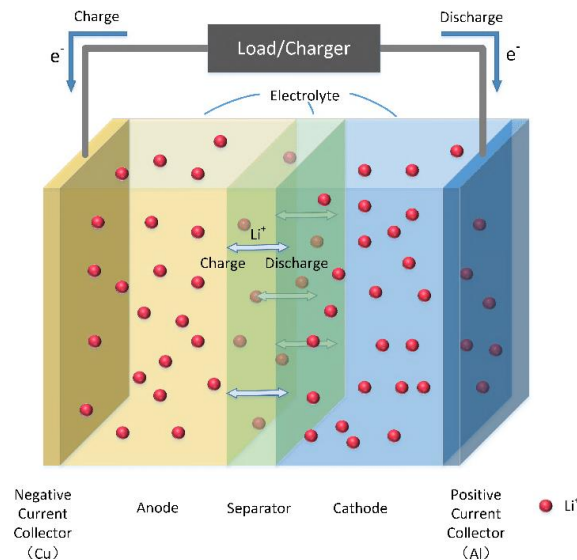
A battery consists of one or more electrochemical cells, which are enclosed compartments containing two electrodes (a positive and a negative) and an electrolyte that allows the movement of ions. When a circuit is connected to the battery, a chemical reaction occurs within the cell, leading to the flow of electrons from the negative electrode (anode) to the positive electrode (cathode) through the external circuit, creating an electric current.



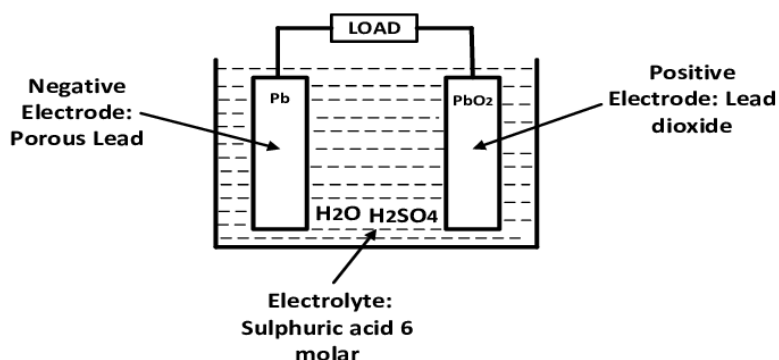
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There are several types of batteries available, each with its unique characteristics and applications. Some of the most common types include:

Lithium-ion (Li-ion) Batteries: Li-ion batteries are widely used in portable electronics, electric vehicles, and renewable energy storage systems. They offer high energy density, long cycle life, and low self-discharge rates. Li-ion batteries use lithium ions to move between the anode and cathode during charging and discharging.



Lead-Acid Batteries: Lead-acid batteries have been used for over a century and are commonly found in vehicles, uninterruptible power supplies (UPS), and off-grid solar systems. They are reliable and relatively low-cost but have lower energy density compared to other battery types.



Nickel-Cadmium (Ni-Cd) Batteries: Ni-Cd batteries were once popular but are being phased out due to their environmental impact. They have good cycle life and can withstand

high discharge rates, making them suitable for applications such as power tools and emergency lighting.

Nickel-Metal Hydride (Ni-MH) Batteries: Ni-MH batteries are commonly used in portable electronics and hybrid vehicles. They offer higher energy density than Ni-Cd batteries and are more environmentally friendly.

Solid-State Batteries: Solid-state batteries are an emerging technology that uses solid electrolytes instead of liquid or gel electrolytes. They have the potential to offer higher energy density, improved safety, and longer cycle life compared to traditional batteries.

Battery technology continues to evolve, driven by the demand for improved energy storage solutions. Researchers are actively working on developing batteries with higher energy densities, faster charging capabilities, and longer lifespans.

ELECTROMOTIVE FORCE

Electromotive Force (EMF) refers to the electric potential difference or voltage generated by a source such as a battery or a generator. It is the driving force that causes electric charges to move in an electrical circuit.

The term "electromotive force" can be misleading because it does not actually involve any motion or force. Instead, it represents the work done per unit charge by the source to move the charge through the circuit.

EMF is measured in volts (V) and represents the potential energy difference between two points in an electrical circuit. When a circuit is connected to a source of EMF, such as a battery, the potential difference between the positive and negative terminals causes the electric charges to move in a closed loop.

It's important to note that EMF is not the same as the voltage drop across components in the circuit. The voltage drop occurs as the electric charges pass through various components, such as resistors or capacitors, and is a measure of the energy consumed or lost by the charges in overcoming the resistance or stored in the component. The sum of the voltage drops in a closed loop circuit is equal to the EMF of the source.

EMF is influenced by factors such as the chemical reactions occurring within a battery, the strength of magnetic fields in a generator, or the intensity of light falling on a solar cell. Different types of batteries or generators can have different EMF values, which determine the voltage output they can provide to the circuit.

It's important to note that EMF alone does not determine the current flowing in a circuit. The current is influenced by the resistance in the circuit, which is governed by Ohm's Law ($V = I * R$), where V is the voltage, I is the current, and R is the resistance. The relationship between EMF, current, and resistance is further described by Kirchhoff's laws.

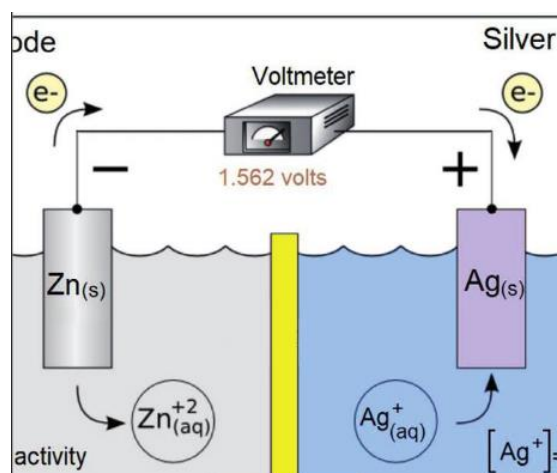
REVERSIBLE CELLS

Reversible cells, also known as reversible electrochemical cells, are a type of electrochemical cell that can undergo reversible reactions. In these cells, the chemical reactions that occur during the discharge (output) and charge (input) processes can be reversed, allowing the cell to be used repeatedly.

A reversible cell consists of two half-cells, each containing an electrode immersed in an electrolyte solution. The half-cell at which oxidation occurs is called the anode, while the half-cell at which reduction occurs is called the cathode. The anode and cathode are connected externally through a conductor, completing the electrical circuit.

During the discharge process, the anode undergoes oxidation, releasing electrons into the external circuit, while the cathode undergoes reduction, accepting those electrons. This electron flow generates an electric current that can be used to power external devices. At the same time, ions move through the electrolyte from one half-cell to the other to maintain charge balance.

In a reversible cell, the reactions that occur during discharge can be fully reversed during the charging process. When an external electrical current is applied to the cell, the direction of the reactions is reversed. The cathode becomes the anode, and the anode becomes the cathode. The products formed during discharge are converted back to the original reactants.



The reversibility of a cell is influenced by several factors, including the nature of the electrode materials, the concentration and composition of the electrolyte, and the cell design. Reversible cells are typically designed with electrode materials that can easily switch between different oxidation states or chemical compositions.

Reversible cells are important in various applications, including rechargeable batteries. Examples of reversible cells include lithium-ion batteries, lead-acid batteries, and nickel-

metal hydride batteries. These batteries can be charged and discharged multiple times, allowing for efficient energy storage and utilization.

It's worth noting that while reversible cells are designed to be as close to ideal reversibility as possible, there are always some losses due to various factors such as resistance, side reactions, and the formation of irreversible compounds. These losses can result in decreased efficiency and capacity over multiple charge-discharge cycles.

In summary, reversible cells are electrochemical cells in which the chemical reactions occurring during discharge and charge processes can be fully reversed. They are crucial for rechargeable battery technologies and enable efficient energy storage and utilization. By allowing repeated cycles of charge and discharge, reversible cells provide a practical and sustainable solution for various applications.

RELATION BETWEEN ELECTRICAL ENERGY AND ENERGY CONTENT OF A CELL

The relation between electrical energy and the energy content of a cell can be understood in terms of the efficiency and capacity of the cell.

Efficiency: The efficiency of a cell refers to the ratio of electrical energy output to the total energy input. It represents how effectively the cell converts the stored energy into electrical energy. Due to various factors such as internal resistance, chemical reactions, and heat dissipation, not all of the energy stored in a cell can be converted into usable electrical energy. Some energy is lost as waste heat. Therefore, the electrical energy output of a cell is always lower than its total energy content.

Capacity: The capacity of a cell refers to the total amount of electrical energy it can store or deliver. It is typically measured in units such as watt-hours (Wh) or ampere-hours (Ah). The capacity of a cell depends on its energy content, which is determined by factors such as the type of electrochemical reactions, the amount and concentration of active materials, and the cell design. Cells with higher energy content can store or deliver more electrical energy.

It's important to note that the energy content of a cell is not solely determined by its capacity but also by other factors such as the voltage output and the discharge characteristics. The voltage of a cell is related to the chemical reactions occurring within it and the potential difference between the electrodes. The higher the voltage, the more energy can be extracted per unit of charge.

When using a cell to power an electrical device, the energy content of the cell determines how long the device can operate before the cell is depleted. The energy content, along with the device's power consumption, determines the runtime or the amount of time the device can function on a single cell.

It's also worth mentioning that different types of cells have different energy content characteristics. For example, lithium-ion batteries generally have higher energy densities and capacities compared to lead-acid batteries. This means that, for the same physical size or weight, lithium-ion batteries can store more energy.

In summary, the relationship between electrical energy and the energy content of a cell is influenced by factors such as the efficiency and capacity of the cell. The electrical energy output of a cell is typically lower than its total energy content due to losses and inefficiencies. The capacity of a cell represents its ability to store or deliver electrical energy, while the efficiency determines how effectively the energy is converted. Understanding these factors is crucial in evaluating and utilizing cells for various applications.

FREE ENERGY CHANGES AND ELECTROMOTIVE FORCE IN CELL

Free energy changes and electromotive force (EMF) are closely related concepts in the context of electrochemical cells.

Free energy change (ΔG) is a thermodynamic quantity that represents the maximum work that can be obtained from a chemical reaction. In an electrochemical cell, the free energy change is associated with the redox (reduction-oxidation) reactions occurring at the electrodes.

The free energy change of an electrochemical cell can be related to its EMF, which is a measure of the cell's potential to drive an electric current. EMF is also known as the cell potential or voltage. It represents the difference in electric potential between the two electrodes of the cell.

The relationship between free energy change (ΔG) and EMF (E) can be described by the following equation:

$$\Delta G = -nFE$$

where:

ΔG is the change in free energy of the electrochemical reaction,

n is the number of moles of electrons transferred in the reaction,

F is the Faraday constant (approximately 96,485 C/mol), representing the charge of one mole of electrons,

E is the electromotive force (cell potential) of the electrochemical cell.

In this equation, the negative sign indicates that the free energy change is related to the EMF in a way that the reaction will proceed spontaneously ($\Delta G < 0$) if the cell potential is positive ($E > 0$). Conversely, if the cell potential is negative ($E < 0$), the reaction would not occur spontaneously.

The relationship between free energy change and EMF helps us understand the driving force and feasibility of electrochemical reactions. A positive EMF indicates that the cell can release energy and drive the flow of electrons through an external circuit. The greater the positive EMF, the greater the potential for the cell to deliver electrical energy.

It's important to note that the actual voltage or EMF observed in a cell may be influenced by factors such as concentration of reactants, temperature, and electrode materials. These factors can affect the kinetics of the redox reactions and may cause deviations from the ideal relationship between free energy change and EMF.

CURRENT CHALLENGES IN ENERGY STORAGE TECHNOLOGIES

Energy storage technologies play a crucial role in enabling the integration of renewable energy sources, supporting grid stability, and powering electric vehicles. However, several challenges still exist that limit their widespread adoption and effectiveness. Some of the current challenges in energy storage technologies include:

Cost: One of the significant challenges is the high cost associated with energy storage technologies. Many storage systems, such as lithium-ion batteries, are still relatively expensive to produce and deploy at a large scale. Lowering the cost of energy storage is essential to make it more economically viable and accessible for various applications.

Energy Density and Capacity: Energy density refers to the amount of energy that can be stored in a given volume or weight of an energy storage system. Increasing energy density is crucial for applications that require compact and lightweight storage, such as electric vehicles. Similarly, improving the capacity of energy storage systems allows for longer durations of energy supply, particularly for grid-scale applications.

Cycle Life and Degradation: Energy storage systems degrade over time and with repeated charge-discharge cycles, leading to a reduction in their capacity and performance. Extending the cycle life of energy storage technologies is essential to ensure their long-term viability and cost-effectiveness. Improving durability and minimizing degradation mechanisms are active areas of research.

Safety: Safety considerations are critical for energy storage systems, particularly for large-scale installations. Some technologies, such as lithium-ion batteries, can experience thermal runaway or fire incidents under certain conditions. Enhancing the safety features, including thermal management and fault-tolerant designs, is crucial to mitigate these risks and ensure the safe operation of energy storage systems.

Environmental Impact: The environmental impact of energy storage technologies, particularly during production, use, and disposal, is a concern. Some battery chemistries, such as those containing heavy metals like cadmium or lead-acid, can pose environmental risks if not managed properly. Developing and promoting more sustainable and environmentally friendly energy storage technologies is vital to minimize their ecological footprint.

Scale and Integration: Integrating energy storage systems into existing infrastructure and power grids at various scales can be complex. Coordinating the operation of storage systems with fluctuating renewable energy sources and managing multiple interconnected storage units pose challenges. Developing efficient control systems and grid management strategies to optimize the use of energy storage technologies are areas of ongoing research.

Materials Availability and Supply Chain: Some energy storage technologies rely on critical materials, such as lithium, cobalt, and rare earth elements, whose availability and responsible sourcing can be a concern. Ensuring a stable and sustainable supply chain for these materials is crucial for the long-term scalability and viability of energy storage technologies.

UNIT 2

MOJOR BATTERY CHEMISTRIES DEVELOPMENT AND TESTING

BATTERY PERFORMANCE EVALUTION

Battery performance evaluation involves a range of tests and measurements to assess various aspects of a battery's performance. Here are more details about some common evaluations conducted during battery performance testing:

Capacity Testing: Capacity testing determines the maximum amount of electrical energy a battery can store and deliver. It involves fully charging the battery and then discharging it at a controlled rate until it reaches a specified endpoint voltage. The total energy discharged during the test provides the battery's capacity.

Columbic Efficiency Measurement: Coulombic efficiency measures how efficiently a battery can convert electrical energy during charging and discharging cycles. It is the ratio of the total charge delivered during discharge compared to the total charge input during charging. Coulombic efficiency close to 100% indicates minimal energy losses.

Cycle Life Testing: Cycle life testing evaluates a battery's ability to endure repeated charge and discharge cycles without significant capacity degradation. In this test, the battery undergoes a specified number of charge and discharge cycles while monitoring its capacity and performance. The endpoint criteria, such as capacity retention or voltage drop, determine when the battery is considered to have reached its end of life.

Rate Capability Testing: Rate capability testing determines a battery's performance under different discharge rates. It involves subjecting the battery to discharge currents at varying rates and measuring its capacity, voltage stability, and efficiency. This evaluation is particularly important for applications where the battery needs to deliver high power output.

Self-Discharge Testing: Self-discharge testing assesses the battery's ability to retain its charge over time when not in use. The battery is fully charged and then left idle under controlled temperature conditions. The voltage is periodically monitored to determine the rate of self-discharge.

Temperature Performance Testing: Temperature performance testing evaluates how a battery performs at different temperature extremes. Batteries can experience reduced capacity and efficiency at both high and low temperatures. The battery is subjected to specific temperature conditions, and its performance is measured in terms of capacity, voltage stability, and overall functionality.

Internal Resistance Measurement: Internal resistance measurement assesses a battery's resistance to the flow of current. High internal resistance can lead to power loss and voltage drops during discharge. The battery is subjected to a known load, and the voltage drop across the load is measured to determine the internal resistance.

Safety Testing: Safety testing evaluates a battery's performance under various safety scenarios. This includes tests for thermal stability, overcharge protection, short circuit protection, and resistance to physical abuse. Safety evaluations ensure that batteries meet specific safety standards and regulations.

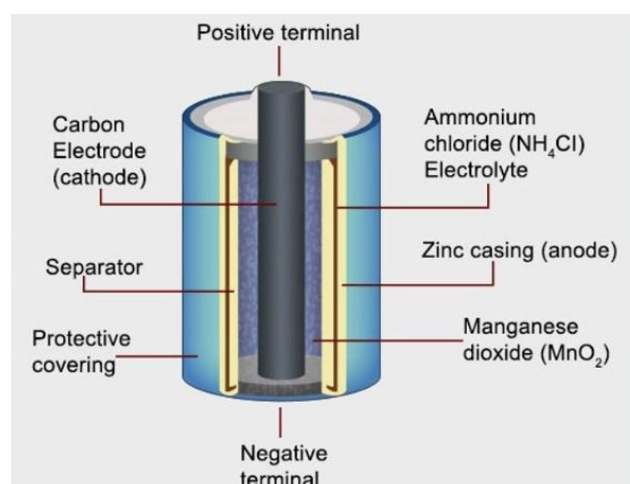
Aging and Degradation Studies: Long-term aging and degradation studies involve subjecting batteries to continuous charge and discharge cycles over an extended period. The battery's capacity, efficiency, and other performance parameters are monitored to observe changes over time. These studies help determine the expected lifespan and performance degradation of the battery.

Environmental Testing: Environmental testing evaluates a battery's performance under specific environmental conditions such as humidity, vibration, shock, and exposure to different chemicals. This testing ensures that the battery can withstand and function reliably in harsh environments.

PRIMARY BATTERY AND ITS SERVICE TIME, LIFE

A primary battery, also known as a disposable battery, is a type of battery that is designed for single-use and cannot be recharged. It is commonly used in various electronic devices, such as remote controls, toys, flashlights, and many other portable devices.

Primary batteries are available in different chemistries, each with its own characteristics and performance. The most common types of primary batteries include alkaline, zinc-carbon, lithium, and silver oxide batteries.



The service time of a primary battery refers to the duration for which it can provide power to a device before it becomes depleted. The service time of a primary battery depends on several factors:

Battery Chemistry: Different battery chemistries offer varying service times. Alkaline batteries, for example, generally have a longer service time compared to zinc-carbon batteries. Lithium and silver oxide batteries are also known for their longer service lives.

Capacity: The capacity of a primary battery determines the amount of electrical energy it can store. It is typically measured in mill ampere-hours (mAh) or watt-hours (Wh). A higher capacity battery can provide power for a longer duration compared to a battery with a lower capacity.

Load Current: The load current is the amount of current drawn from the battery by the device it is powering. Higher load currents result in a faster depletion of the battery's energy, leading to a shorter service time. Devices with high power requirements may drain the battery more quickly.

Environmental Conditions: The operating environment can affect the performance of a primary battery. Extreme temperatures, both hot and cold, can impact the battery's chemical reactions and reduce its efficiency. High humidity or exposure to moisture can also affect the battery's performance and potentially lead to leakage.

Storage Conditions: Proper storage conditions can influence a primary battery's shelf life and service time. Storing batteries in a cool and dry environment helps minimize self-discharge and prolong their usable life. Extreme temperatures, particularly high heat, can accelerate self-discharge and shorten the battery's shelf life.

The service life of a primary battery refers to the time it takes for the battery to reach its end of life or become unusable. This can vary depending on the factors mentioned above, as well as the specific battery model and quality. Primary batteries are designed for a limited service life, typically ranging from a few months to a few years.

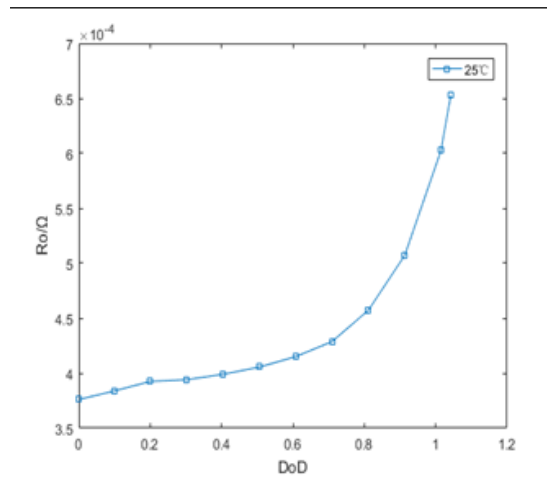
It is important to note that primary batteries cannot be recharged, and once they are depleted, they need to be replaced. When the battery no longer provides sufficient power to the device or fails to operate, it should be safely disposed of and replaced with a new battery.

To determine the specific service time and life of a primary battery, it is advisable to refer to the manufacturer's specifications and guidelines provided for the particular battery model. These specifications will provide accurate information on the expected performance and lifespan of the battery.

OHMIC LOAD CURVE

The term "Ohmic load curve" is not typically used specifically for batteries. The concept of an Ohmic load curve is more relevant to resistive components, such as resistors, rather than batteries.

Batteries, on the other hand, have their own characteristics that are typically represented by voltage versus capacity or discharge curves. These curves depict the relationship between the battery's voltage and its remaining capacity or the amount of energy it can provide over a given period.



The discharge curve of a battery shows how its voltage changes as the battery is discharged over time. Initially, the voltage is relatively high, and it gradually decreases as the battery discharges. The rate at which the voltage decreases depends on factors such as the battery chemistry, load current, and remaining capacity. The discharge curve can vary significantly depending on the specific battery chemistry and design. For example, lithium-ion batteries exhibit relatively flat discharge curves, maintaining a stable voltage for most of their discharge cycle, and then dropping rapidly towards the end. Other battery chemistries, such as alkaline or lead-acid, may have different discharge characteristics.

It's important to note that the discharge curve of a battery is influenced by various factors, including the discharge rate, temperature, and the battery's internal resistance. Manufacturers typically provide discharge curves or voltage versus capacity graphs specific to their battery models, allowing users to estimate the remaining capacity based on the battery's voltage level.

So, while there isn't an Ohmic load curve specifically for batteries, there are discharge curves or voltage versus capacity curves that represent the behaviour of a battery during discharge. These curves help users understand the battery's performance and estimate its remaining capacity or energy available.

EFFECT OF OPERATING TEMPERATURE ON SERVICE LIFE

Operating temperature has a significant impact on the service life of various devices, including batteries. Here are the effects of operating temperature on the service life of batteries:

Chemical Reactions: Battery chemistries have optimal temperature ranges in which their chemical reactions occur most efficiently. Deviating from these temperature ranges can affect

the chemical reactions within the battery. Extreme temperatures can accelerate the degradation of battery materials, reducing their overall service life.

Capacity Loss: High temperatures can lead to increased self-discharge and accelerated chemical reactions within the battery. This can result in a loss of capacity over time, meaning the battery will hold less charge and provide less energy than it would at lower temperatures. The rate of capacity loss tends to be higher at elevated temperatures.

Internal Resistance: High temperatures can increase the internal resistance of a battery, limiting its ability to deliver energy efficiently. The increased resistance can lead to voltage drops, reduced power output, and decreased overall performance. It may also cause the battery to heat up further, exacerbating the temperature-related issues.

Cycle Life Reduction: Cycle life refers to the number of charge-discharge cycles a battery can undergo before its capacity significantly degrades. Operating a battery at high temperatures can shorten its cycle life, as the accelerated chemical reactions and increased internal resistance contribute to the degradation of the battery's active materials. This means the battery will have a shorter overall lifespan.

Safety Concerns: Operating batteries at extreme temperatures can pose safety risks. High temperatures can increase the likelihood of thermal runaway, where the battery undergoes uncontrolled heating and potentially leads to leakage, venting, or even explosion. It is crucial to avoid exposing batteries to extreme heat to prevent safety hazards.

Cold Temperature Performance: Cold temperatures can also affect battery performance. At low temperatures, battery chemistries may experience reduced capacity and increased internal resistance, leading to diminished performance. Cold temperatures can make it more difficult for a battery to deliver energy efficiently, resulting in shorter service life and decreased power output.

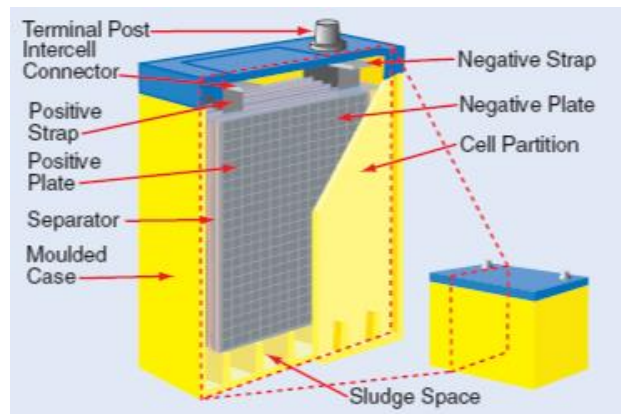
It is important to note that different battery chemistries have different temperature tolerances and optimal operating ranges. Manufacturers typically provide guidelines on the recommended temperature ranges for their batteries to ensure optimal performance and maximize service life.

To prolong the service life of batteries, it is advisable to operate them within their specified temperature ranges, avoiding exposure to extreme heat or cold conditions. Proper thermal management, such as using temperature control mechanisms or insulating battery compartments, can also help mitigate the impact of temperature on battery performance and prolong service life.

SECONDARY BATTERIES

Secondary batteries, also known as rechargeable batteries, are energy storage devices that can be recharged and reused multiple times. They provide a sustainable and cost-effective alternative to single-use primary batteries. Some common types of secondary batteries include lithium-ion (Li-ion), nickel-metal hydride (NiMH), lead-acid, nickel-cadmium (NiCd), and sodium-ion (Na-ion) batteries.

Secondary batteries work by utilizing reversible chemical reactions that occur within the battery during both discharge and charging cycles. When the battery is discharged, the chemical reactions generate electrical energy that can be used to power devices. When the battery is recharged, an external power source is applied, causing the chemical reactions to reverse, storing energy for future use.



Secondary batteries offer several advantages over primary batteries. They have a higher energy density, allowing them to store more energy in a smaller and lighter package. They can be recharged and reused multiple times, reducing waste and cost in the long run. Additionally, secondary batteries provide a more stable voltage output throughout their discharge cycle, ensuring consistent power delivery.

Each type of secondary battery has its own characteristics and applications. Li-ion batteries are popular for portable electronics and electric vehicles due to their high energy density and long cycle life. NiMH batteries are commonly used in cordless phones and hybrid vehicles. Lead-acid batteries are found in automotive applications and backup power systems. NiCd batteries, although less common today, have been used in power tools and consumer electronics. Sodium-ion batteries are still under development as a potential alternative to Li-ion batteries.

The performance and service life of secondary batteries can be affected by factors such as temperature, charging methods, and usage patterns. Proper charging practices, including avoiding overcharging and deep discharging, are crucial to maintaining the battery's performance and maximizing its lifespan.

DISCHARGE CURVES

Discharge curves represent the relationship between the voltage output of a battery and its remaining capacity or energy as it discharges. Here is a brief overview of discharge curves for batteries.

Flat Discharge Curve: Some batteries, such as lithium-ion (Li-ion) batteries, exhibit a flat discharge curve. They maintain a relatively constant voltage output throughout most of their discharge cycle. The voltage remains stable until the battery reaches a certain depth of discharge, typically around 80-90%, and then drops rapidly towards the end of the cycle.

Gradual Discharge Curve: Batteries like nickel-metal hydride (NiMH) and lead-acid batteries typically have gradual discharge curves. The voltage decreases gradually and linearly as the battery discharges. The rate of voltage decline is relatively consistent until the battery reaches a low state of charge, where the voltage drops more noticeably.

Steep Discharge Curve: Nickel-cadmium (NiCd) batteries often exhibit a steep discharge curve. They maintain a relatively constant voltage output during most of their discharge cycle, similar to Li-ion batteries. However, towards the end of the cycle, the voltage drops rapidly and more abruptly than in other battery types.

These descriptions provide a general overview of discharge curve characteristics for different battery chemistries. It's important to note that specific battery models and conditions may result in variations in discharge curves. Manufacturers typically provide discharge curve data specific to their batteries, enabling users to estimate the remaining capacity or energy based on the battery's voltage level during discharge.

Lead-Acid Batteries:

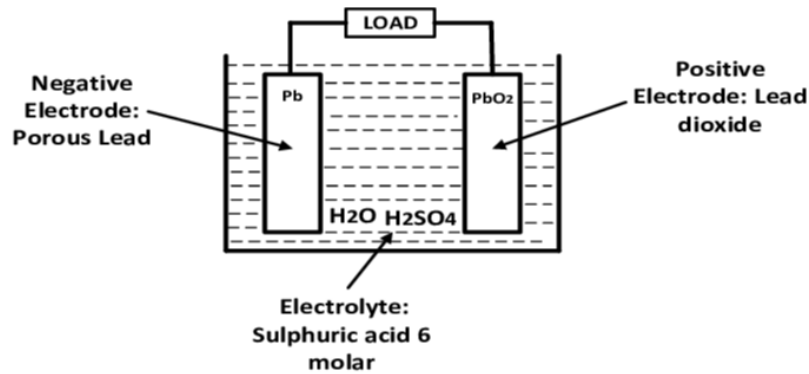
Lead-acid batteries have a characteristic discharge curve that exhibits a gradual decrease in voltage over time. The voltage decreases steadily as the battery discharges, indicating the reduction in available capacity. Towards the end of the discharge cycle, the voltage drops rapidly, signalling that the battery is nearing its fully discharged state.

CONSTRUCTION AND APPLICATION

Construction of batteries varies depending on the type and chemistry of the battery:

A battery consists of two electrodes—an anode (negative electrode) and a cathode (positive electrode). These electrodes are typically made of different materials, depending on the battery chemistry. For example, in a lithium-ion battery, the anode is usually made of graphite, while the cathode consists of various metal oxide compounds. The electrodes are separated by an electrolyte, which is a medium that allows the movement of ions between the electrodes. The electrolyte can be liquid, gel, or solid, depending on the battery type. It facilitates the flow of ions during the battery's charging and discharging processes. To prevent direct contact between the electrodes, a separator is placed between them. The separator is a permeable membrane that allows the movement of ions while preventing electrical short circuits. The electrodes, electrolyte, and separator are housed within a container, which is typically made of a non-conductive material to prevent external electrical contact. The container is designed to be durable, lightweight, and resistant to leakage. The

battery has two terminals—one connected to the anode and the other to the cathode. These terminals allow for the external connection of the battery to devices or circuits, enabling the flow of electrical current.



APPLICATION OF BATTERY

Portable Electronics: Batteries power a wide range of portable devices such as smartphones, laptops, tablets, cameras, and portable gaming devices. These batteries provide the necessary energy to operate these devices without the need for a continuous external power source.

Electric Vehicles (EVs): Batteries play a crucial role in electric vehicles, providing the energy required for propulsion. High-capacity batteries, such as lithium-ion batteries, are used in EVs to store and deliver energy efficiently.

Energy Storage Systems: Batteries are employed in energy storage systems, allowing for the storage of electricity generated from renewable sources such as solar and wind. These systems help balance supply and demand, store excess energy, and provide backup power during outages.

Industrial Applications: Batteries find applications in various industrial sectors, such as powering forklifts, providing backup power for critical equipment, and supporting uninterruptible power supplies (UPS) for data centres and critical infrastructure.

Marine and Aerospace: Batteries are utilized in marine applications, including electric boats and submarines. They also play a vital role in aerospace applications, powering satellites, spacecraft, and auxiliary systems in aircraft.

Off-grid Power: Batteries enable off-grid power solutions, allowing for electricity in remote areas or locations without access to a reliable power grid. They are used in standalone solar power systems, portable power stations, and camping equipment.

These are just a few examples of the wide range of applications for batteries. With ongoing advancements in battery technology, the applications continue to expand, supporting the transition to renewable energy, electrification of transportation, and enabling portable, reliable power sources.

UNIT 3

RECENT TECHNOLOGIES

RECENT DEVELOPMENT OF ELECTRODE MATERIAL IN LITHIUM ION BATTERIES

Lithium ion rechargeable batteries are used as the power supply of cellular phones and several other portable electrical devices at present, and demand appears to increase exponentially. The concern about energy sources in the near future, either for electric vehicles (EV) or for large-scale batteries for electricity power storage, has made lithium ion rechargeable battery development into a growth area which has gained high momentum for its research activities. Here, while presenting the state of the art of lithium ion battery technology, the current research into materials, which constitute anode, electrolyte and cathode is described and the underlying problems associated with their development, advantages and drawbacks is analyzed. Both polymer electrolytes, which is a recent topic, as well as conventional organic liquids electrolyte, are also described.

Silicon-graphene composites: Researchers have made progress in developing silicon-graphene composites for anodes. The addition of graphene helps improve the structural stability of silicon, mitigating volume expansion issues and enhancing cycling performance.

Sulphur-graphene cathodes: Sulphur has a high theoretical capacity, but suffers from poor conductivity and significant volume changes during cycling. By incorporating graphene into sulphur cathodes, researchers have achieved better stability, higher capacity, and improved cycling performance.

High-nickel cathodes: Nickel-rich cathode materials, such as nickel-cobalt-manganese (NCM) and nickel-cobalt-aluminium (NCA) compositions, have gained attention. Advancements have been made in optimizing the composition ratios and surface coatings of these cathodes to enhance energy density and cycle life.

Solid-state electrolytes: Solid-state electrolytes (SSEs) have shown promise for improving battery safety and energy density. Various materials, including sulphide-based and oxide-based SSEs, have been explored, with a focus on enhancing ionic conductivity and stability.

Lithium metal anodes: Efforts have been made to address the challenges associated with lithium metal anodes, such as dendrite formation and low Coulombic efficiency. Novel electrolyte formulations, protective coatings, and advanced characterization techniques have been employed to enable stable and efficient lithium metal deposition.

Advanced nanostructures: Nanomaterials continue to play a significant role in battery research. Advanced nanostructures, such as nanostructured metal oxides, carbon nanotubes,

and 2D materials like MXenes, have been investigated to improve electrode conductivity, surface area, and electrochemical performance.

These are just a few recent developments, and the field of electrode materials for lithium-ion batteries is evolving rapidly. Ongoing research focuses on improving energy density, cycle life, safety, and cost-effectiveness of lithium-ion batteries to meet the demands of various applications, including electric vehicles and renewable energy storage.

RECENT DEVELOPMENT OF SOLID ELECTROLYTES

Recent developments in solid electrolytes have shown promising advancements in the field of battery technology. Here are some notable developments:

Garnet-type electrolytes: Garnet-type solid electrolytes, such as lithium lanthanum zirconate (LLZO), have gained attention due to their high ionic conductivity and compatibility with lithium metal anodes. Recent research has focused on optimizing the synthesis methods and doping strategies to enhance the performance of garnet electrolytes.

Sulfide-based electrolytes: Sulfide-based solid electrolytes, such as lithium thiophosphates (LiPS) and lithium phosphorous sulfides (LiPS), have demonstrated high ionic conductivity at room temperature. Ongoing research aims to improve their stability and interface compatibility with electrode materials.

Polymer-based electrolytes: Polymer electrolytes offer advantages such as flexibility, processability, and improved safety. Recent developments have focused on enhancing the ionic conductivity of polymer electrolytes by incorporating various additives, optimizing polymer structure, and exploring new polymer materials.

Composite electrolytes: Composite electrolytes combine the advantages of different materials to achieve enhanced performance. For example, combining ceramic electrolytes with polymers or nanoscale fillers can improve both ionic conductivity and mechanical properties.

Hybrid electrolytes: Hybrid electrolytes, which combine liquid and solid components, have been developed to address the challenges of both liquid and solid electrolytes. These electrolytes aim to provide improved ion transport while maintaining good contact with electrode surfaces.

Interface engineering: Another area of focus is the development of solid electrolyte-electrode interfaces. Improving the stability and compatibility at the interface is crucial for efficient ion transfer and minimizing interfacial resistance.

APPLICATION TO SOLID STATE BATTERIES

Solid-state batteries have the potential to revolutionize various industries and applications due to their unique advantages. They are,

Electric Vehicles (EVs): Solid-state batteries offer higher energy density, improved safety, and faster charging compared to conventional lithium-ion batteries. They could enable longer driving ranges for EVs, shorter charging times, and enhanced overall performance. Solid-state batteries also have the potential to reduce the risk of thermal runaway and increase the lifespan of EVs.

Portable Electronics: Solid-state batteries can bring improvements to portable electronic devices such as smartphones, tablets, laptops, and wearables. Their higher energy density allows for longer battery life, and their enhanced safety reduces the risk of explosions or fires. Additionally, solid-state batteries can enable thinner and lighter devices due to their improved energy storage capabilities.

Aerospace and Aviation: Solid-state batteries have the potential to be used in aerospace applications, including aircraft and satellites. Their improved energy density and stability make them attractive for powering various on-board systems, such as avionics, communication equipment, and electric propulsion systems. The enhanced safety of solid-state batteries is particularly valuable in aviation, where safety is of paramount importance.

Energy Storage Systems: Solid-state batteries can be utilized in large-scale energy storage systems, such as grid-scale applications or renewable energy integration. Their higher energy density and improved safety can make them more suitable for stationary storage applications. Solid-state batteries also offer advantages in terms of faster response times and improved efficiency, allowing for better management of intermittent renewable energy sources.

Medical Devices: Solid-state batteries can find applications in medical devices, such as pacemakers, insulin pumps, and implantable devices. The improved safety, longer lifespan, and higher energy density of solid-state batteries make them suitable for powering critical medical devices that require long-term, reliable operation.

IoT Devices and Sensors: The Internet of Things (IoT) industry relies on small, low-power devices that require long battery life. Solid-state batteries can provide compact and long-lasting power solutions for IoT devices, such as sensors, smart home devices, and industrial monitoring systems.

POLYMER SOLID ELECTROLYTES FOR LITHIUM ION CONDUCTION

The current spreading of the implementation of the concepts of digitalization of the society and the Internet of Things requires the development of small portable electronic devices powered by efficient electrical energy storage systems. One of the most widely used energy storage systems that have been integrated into these devices is lithium-ion batteries (LIBs) because of their high specific capacity and long life cycles when compared with other battery

systems. Other properties of LIBs are their low cost, size, and self-discharge and their prolonged service life when compared with other battery types. Further, besides being used for portable electronic devices, they are also being used to power electric vehicles (EV) and hybrid electric vehicles (HEVs).

The basic constituents of LIBs are the anode (negative electrode), cathode (positive electrode), and a separator/electrolyte. The separator is composed of a porous membrane soaked in electrolyte solution (lithium salts dispersed in organic solvent), and its function is to allow the flow of Li ions between the electrodes and consequently to avoid short circuits. The relevance of the electrolyte solution is to confer the necessary high ionic conductivity between the electrodes, but it is highly reactive, flammable, toxic, and can leak out of the battery. Another disadvantage of the electrolyte solution is the formation of a passivating layer, denominated as solid-electrolyte interphase (SEI) during the first charge, resulting from the reactions with the anode electrode. Thus, in order to solve these issues, challenging efforts are being carried out to replace conventional separator/electrolytes with solid electrolytes, the main types being organic (polymer) and inorganic electrolytes, in order to obtain solid-state batteries.

THIN FILM SOLID STATE BATTERIES

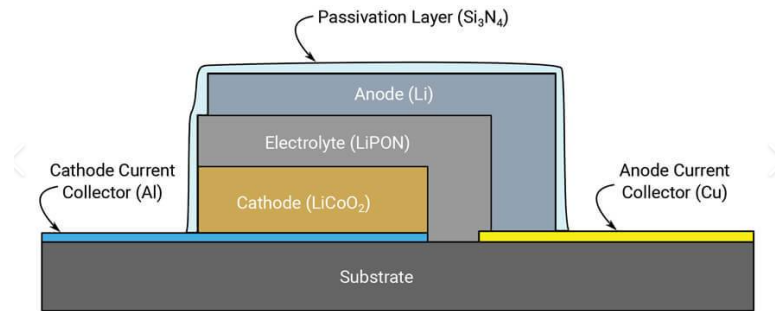
CONSTRUCTION

Thin film solid-state batteries are a type of solid-state battery that utilizes thin film deposition techniques to create the different battery components in a layered structure. Here is an overview of the construction process of thin film solid-state batteries:

Substrate Preparation: The construction of thin film solid-state batteries starts with preparing a suitable substrate. Common substrates include silicon, stainless steel, or flexible polymer films. The substrate provides structural support and serves as a foundation for subsequent thin film deposition.

Electrode Deposition: Thin film deposition techniques, such as physical vapor deposition (PVD) or chemical vapour deposition (CVD), are used to deposit the electrode materials onto the substrate. The choice of electrode materials depends on the battery design but typically includes materials like lithium cobalt oxide (LiCoO₂) for the positive electrode (cathode) and lithium metal or lithium alloy for the negative electrode (anode).

Solid Electrolyte Deposition: The solid electrolyte layer is then deposited on top of the electrode layers. Common solid electrolyte materials used in thin film batteries include lithium phosphorus oxynitride (LiPON), lithium lanthanum zirconium oxide (LLZO), or polymer electrolytes. The deposition techniques can include PVD, atomic layer deposition (ALD), or solution-based methods like spin-coating or inkjet printing.



Interfacial Layers: Interfacial layers may be added between the electrode and solid electrolyte layers to improve compatibility and reduce interfacial resistance. These layers help enhance the adhesion and conductivity between the different battery components. Interfacial layers can be deposited using techniques like sputtering or ALD.

Thin Film Encapsulation: To protect the thin film solid-state battery from environmental degradation, a thin film encapsulation layer is applied. This layer acts as a barrier to prevent moisture and oxygen ingress, thereby preserving the battery's performance and stability over time. Common encapsulation materials include thin films of silicon nitride or aluminum oxide.

Electrode Current Collectors: Finally, current collectors are added to the top and bottom of the battery structure to facilitate the flow of electrons during charging and discharging. These current collectors can be thin metal films, such as aluminum or copper, and are typically deposited using PVD techniques.

After the construction process, the thin film solid-state batteries undergo additional steps, such as cell assembly, sealing, and integration into battery modules or devices, depending on the specific application.

FUNDAMENTALS AND APPLICATIONS

Fundamentals of Thin Film Solid-State Batteries:

Solid Electrolyte: Thin film solid-state batteries utilize a solid electrolyte instead of a liquid electrolyte found in conventional batteries. The solid electrolyte enables the conduction of lithium ions while providing enhanced safety, stability, and resistance to dendrite formation.

Thin Film Deposition: Thin film deposition techniques, such as physical vapor deposition (PVD), chemical vapour deposition (CVD), or solution-based methods, are used to fabricate the different battery components, including electrodes, solid electrolytes, and interfacial layers. These deposition techniques allow for precise control of film thickness, composition, and morphology.

Interface Engineering: The interfaces between the different battery components, such as electrode/solid electrolyte interfaces, play a crucial role in achieving efficient ion conduction

and minimizing interfacial resistance. Interface engineering techniques are employed to enhance compatibility, adhesion, and interfacial stability.

Applications of Thin Film Solid-State Batteries:

Portable Electronics: Thin film solid-state batteries can be integrated into small electronic devices like smartphones, smartwatches, and wearable sensors. Their thin and flexible nature makes them ideal for compact and lightweight applications, providing longer battery life, improved safety, and the potential for flexible form factors.

Internet of Things (IoT) Devices: IoT devices, which include various connected sensors, require compact and long-lasting power sources. Thin film solid-state batteries offer a viable solution for powering IoT devices due to their small size, high energy density, and extended cycle life. They can be integrated into smart home devices, environmental monitoring sensors, and industrial IoT systems.

Medical Implants: Thin film solid-state batteries hold great potential for medical implantable devices such as pacemakers, defibrillators, and neurostimulators. These batteries offer improved safety, stability, and longer lifespan compared to traditional batteries. They can provide reliable power for medical implants, reducing the need for frequent battery replacements or invasive procedures.

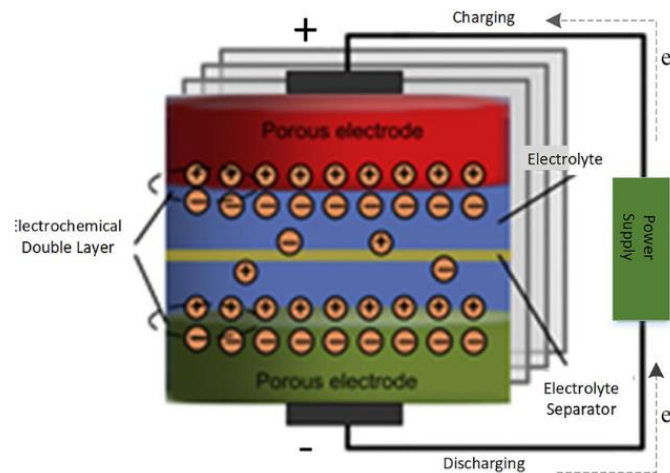
Microelectronics and MEMS: Thin film solid-state batteries can power microelectronic devices and microelectromechanical systems (MEMS). These batteries can be integrated directly onto silicon chips, enabling on-chip power sources for energy-efficient microsystems, wireless sensors, and bioelectronics.

Energy Storage Systems: Thin film solid-state batteries can be scaled up for large-scale energy storage applications. They can be integrated into grid-scale energy storage systems or used for renewable energy storage, such as solar or wind energy. The high energy density, long cycle life, and enhanced safety of thin film solid-state batteries make them attractive for stationary energy storage applications.

Electric Vehicles (EVs): While still in the research and development stage, thin film solid-state batteries have the potential to be utilized in electric vehicles. Their high energy density, fast charging capabilities, and improved safety could address some of the challenges associated with current lithium-ion batteries in EVs, such as range anxiety and longer charging times.

SUPER CAPACITORS

CONSTRUCTION



Super capacitors, also known as ultra capacitors or electrochemical capacitors, are energy storage devices that bridge the gap between conventional capacitors and batteries. They store energy electrostatically rather than through chemical reactions, allowing for rapid energy storage and discharge.

Super capacitors consist of two electrodes: a positive electrode (cathode) and a negative electrode (anode). These electrodes are typically made of high-surface-area materials with excellent electrical conductivity. Common electrode materials include activated carbon, carbon nanotubes, graphene, or conducting polymers. Current collectors are used to collect the electrical current from the electrodes. They are typically made of conductive materials such as aluminium or copper foils, which provide low resistance paths for the flow of electrons.

Separator: The electrodes are separated by a separator, which prevents electrical short circuits while allowing the movement of ions between the electrodes. The separator material is usually a porous and ion-permeable membrane made of materials like cellulose, polypropylene, or polyethylene. Super capacitors use an electrolyte solution to facilitate the ion movement between the electrodes. The choice of electrolyte depends on the type of super capacitor. There are two main types of super capacitors based on the electrolyte used: aqueous and organic. Aqueous super capacitors use water-based electrolytes such as sulphuric acid (H_2SO_4) or potassium hydroxide (KOH). Organic super capacitors use non-aqueous electrolytes, typically organic solvents combined with supporting electrolytes like tetraethyl ammonium tetra fluoroborate ($TEABF_4$) or lithium perchlorate ($LiClO_4$). The construction of a super capacitor involves stacking the positive and negative electrodes with the separator in between. The electrodes are typically coated or impregnated with the electrolyte to ensure good contact and ion permeation. The electrode-separator-electrode stack is then sandwiched between the current collectors and tightly sealed. Super capacitors

are often enclosed in a protective casing to provide mechanical support, insulation, and prevent contamination. The packaging is designed to be durable and resistant to environmental factors like moisture, temperature, and vibration.

FUNDAMENTALS AND APPLICATIONS

Fundamentals of Super capacitors:

Double Layer Capacitance: Super capacitors primarily rely on the electrostatic double layer capacitance at the electrode-electrolyte interface to store energy. When a voltage is applied, ions from the electrolyte accumulate at the electrode surface, forming a double layer of charges. This double layer stores energy by the separation of positive and negative charges.

Pseudo capacitance: Some super capacitors also exhibit pseudo capacitance, which involves reversible Faradaic redox reactions at the electrode surface. Pseudo capacitive materials, such as conducting polymers or transition metal oxides, can store additional charge through fast and reversible redox reactions, providing higher energy storage capacities compared to double layer capacitance alone.

High Power Density: Super capacitors offer high power density, enabling rapid charge and discharge rates. Due to their electrostatic storage mechanism, they can quickly deliver and absorb large amounts of energy in short durations, making them suitable for applications requiring high power bursts.

Long Cycle Life: Super capacitors have excellent cycling stability and can withstand a high number of charge-discharge cycles without significant degradation. Their energy storage mechanism does not involve chemical reactions that cause electrode degradation, allowing for long-term durability.

Applications of Super capacitors:

Energy Storage Systems: Super capacitors are employed in energy storage systems to provide short-term power backup, voltage stabilization, and energy smoothing. They can be used in combination with batteries or renewable energy sources like solar or wind to manage fluctuations in power supply and enhance system efficiency.

Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs): Super capacitors find application in HEVs and EVs as they can efficiently capture and release energy during regenerative braking and acceleration. They provide high power bursts for quick acceleration, reducing strain on the battery and improving overall vehicle efficiency.

Electronics and Portable Devices: Super capacitors are used in electronic devices as backup power sources during power interruptions or as power reservoirs to supplement batteries during peak power demands. They find applications in devices like laptops, smartphones, wearables, and IoT devices.

Power Electronics: Super capacitors are employed in power electronics to deliver high-power pulses for applications like pulsed lasers, electric motor drives, and electric grid

stabilization. They can provide instantaneous power demands during peak loads, reducing stress on the electrical grid and improving system reliability.

Renewable Energy Integration: Super capacitors can be utilized to store excess energy generated from renewable sources like solar or wind during periods of low demand. This stored energy can then be released during peak demand, enhancing grid stability and reducing reliance on fossil fuel-based power plants.

Aerospace and Defence: Super capacitors find applications in aerospace and defence systems, where high-power density, fast response times, and long cycle life are crucial. They can be used in applications such as aerospace power systems, electric propulsion systems, and backup power for critical defence systems.

UNIT 4

BATTERIES FOR AUTOMOTIVES-FUTURE PROSPECTS

DEGREES OF VEHICLE ELECTRIFICATION:

Degrees of vehicle electrification refer to the extent to which a vehicle relies on electric power for its propulsion and auxiliary systems. It represents a spectrum of technologies and configurations ranging from conventional internal combustion engines (ICE) to fully electric vehicles (EVs). The degrees of vehicle electrification can be categorized into the following levels:

Conventional Vehicles (Non-Electrified): These are vehicles that solely rely on internal combustion engines fuelled by gasoline or diesel. They have no electric components for propulsion or auxiliary systems.

Mild Hybrid Electric Vehicles (MHEVs): MHEVs have an internal combustion engine as their primary power source but are equipped with a small electric motor/generator and a battery. The electric motor assists the engine during acceleration and recovers energy during braking, but it cannot solely propel the vehicle.

Full Hybrid Electric Vehicles (HEVs): HEVs have both an internal combustion engine and an electric motor/generator. The electric motor can propel the vehicle independently at low speeds and assist the engine during high load conditions. HEVs also have a battery pack that is charged through regenerative braking and engine power.

Plug-in Hybrid Electric Vehicles (PHEVs): PHEVs have a larger battery pack compared to HEVs, which can be recharged by plugging into an external power source. They have an electric motor that can propel the vehicle independently for a significant distance, often referred to as the all-electric range (AER). Once the battery depletes, the vehicle operates as a conventional hybrid.

Battery Electric Vehicles (BEVs): BEVs are fully electric vehicles that rely solely on electric power for propulsion. They do not have an internal combustion engine and are powered by a large battery pack. BEVs need to be charged from external power sources, such as electric charging stations or home charging units.

Fuel Cell Electric Vehicles (FCEVs): FCEVs use hydrogen as a fuel source and convert it into electricity through a fuel cell stack. The electricity powers an electric motor to propel the vehicle. FCEVs also have a small battery pack to store excess energy from the fuel cell and assist during high power demand.

BATTERY SIZE AND APPLICATION

Passenger Cars:

Compact/City EVs: These vehicles are typically designed for urban commuting and shorter driving distances. Battery sizes range from around 30 to 60 kWh, providing a range of approximately 100-200 miles (160-320 km).

Mid-Size/Luxury EVs: These vehicles offer a balance between range and performance. Battery sizes typically range from 60 to 100 kWh, providing a range of approximately 200-300 miles (320-480 km).

Long-Range EVs/High-Performance Models: Vehicles in this category prioritize extended driving range and enhanced performance. Battery sizes often exceed 100 kWh, offering ranges of 300 miles (480 km) or more and improved acceleration.

Commercial Vehicles:

Light-Duty Commercial Vehicles: Delivery vans or small trucks used for local deliveries generally have battery sizes ranging from 30 to 100 kWh, providing a range of approximately 100-200 miles (160-320 km) depending on payload requirements.

Medium-Duty/Heavy-Duty Trucks: These trucks are used for longer hauls and heavier loads. Battery sizes can range from 100 to 300 kWh or more, providing ranges of 200 miles (320 km) or more to accommodate the higher energy demands.

Public Transit and Buses:

City Buses: Battery sizes for electric city buses typically range from 100 to 300 kWh, enabling a range of around 150-200 miles (240-320 km) to handle daily urban routes.

Intercity/Articulated Buses: These buses require larger battery packs to accommodate longer routes and higher passenger capacity. Battery sizes can exceed 500 kWh, providing ranges of 300 miles (480 km) or more.

Electric Two-Wheelers:

Electric Scooters: Battery sizes for small electric scooters used for short commutes generally range from 1 to 5 kWh, offering a range of around 30-60 miles (48-96 km).

Electric Motorcycles: Battery sizes for electric motorcycles vary depending on the desired range and performance. They typically range from 10 to 20 kWh, providing a range of approximately 100-200 miles (160-320 km).

Off-Road and Recreational Vehicles:

Electric ATVs/UTVs: Battery sizes for electric all-terrain vehicles (ATVs) and utility terrain vehicles (UTVs) can range from 5 to 20 kWh, offering a range of approximately 30-100 miles (48-160 km) depending on the vehicle's power demands and terrain.

Electric Boats: Battery sizes for electric boats vary significantly based on factors such as the boat's size and intended use. Smaller electric boats might have battery sizes ranging from 5 to 30 kWh, while larger electric yachts can feature battery packs exceeding 100 kWh to provide extended cruising ranges.

USABC AND DOE TARGETS FOR VEHICULAR ENERGY STORAGE SYSTEM

USABC (United States Advanced Battery Consortium) and DOE (U.S. Department of Energy) set targets and guidelines for vehicular energy storage systems, focusing on battery technologies. Here's a brief overview of their initiatives:

USABC: The USABC is a collaborative organization consisting of automakers (General Motors, Ford, and Stellantis), the Electric Power Research Institute (EPRI), and the DOE. Its goal is to advance battery technology for automotive applications. USABC sets targets and conducts research programs to accelerate the development of advanced energy storage systems. Key initiatives include:

Goals and Targets: USABC sets specific performance and cost targets for battery systems. These targets cover areas such as energy density, power density, cycle life, cost, and safety. Meeting these targets helps drive the development of advanced battery technologies.

Research Programs: USABC conducts research programs to address key technical challenges and improve battery performance. These programs include cell development, system integration, manufacturing processes, and validation testing.

DOE Targets:

The DOE plays a significant role in advancing energy storage technologies through various programs and initiatives. It sets targets and provides funding to support research and development efforts. Key DOE targets for vehicular energy storage systems include:

The DOE aims to achieve high energy density in battery systems, aiming for 350-500 Wh/kg (watt-hours per kilogram) by 2025. Higher energy density enables longer driving ranges for electric vehicles. The DOE has set a target of reducing the cost of battery systems to \$80/kWh by 2025. Cost reduction is crucial to make electric vehicles more affordable and competitive with conventional vehicles. The DOE focuses on developing fast-charging capabilities to reduce charging times and improve the convenience of electric vehicle charging. The goal is to achieve 15 minutes or less for recharging a significant portion of the battery. The DOE aims to improve the durability and lifespan of battery systems to ensure long-term reliability and performance. Extending battery life reduces the need for premature replacements and improves the overall sustainability of electric vehicles.

ANALYSIS AND SIMULATION OF BATTERY

Battery analysis involves assessing the performance, characteristics, and behaviour of a battery through various methods and techniques.

Performance Analysis:

Capacity Measurement: Battery analysis includes measuring the battery's capacity, which indicates the amount of charge it can store. Capacity testing helps determine the available energy and assess the battery's health.

Voltage and Current Behaviour: Monitoring the voltage and current during charging, discharging, and idle conditions provides insights into the battery's behaviour, efficiency, and power output.

Power and Energy Density: Analysing the power and energy density helps evaluate the battery's performance capabilities, such as its ability to deliver high power or store energy efficiently.

Electrical Characterization:

Internal Resistance: Measuring the internal resistance of a battery allows assessing its efficiency and ability to deliver power. Higher internal resistance can lead to voltage drops and reduced performance.

Open Circuit Voltage: The open circuit voltage (OCV) of a battery provides information about its state of charge (SOC) and can be used for estimating the battery's energy level.

Electrochemical Impedance Spectroscopy (EIS): EIS is a technique that analyses the frequency response of a battery to determine its impedance characteristics. It helps assess battery health, aging, and performance limitations.

Safety Analysis:

Thermal Runaway: Analysing the battery's thermal behaviour is crucial to understand the risk of thermal runaway, where the battery's temperature rapidly increases due to an internal event or fault.

Overcharge and Over Discharge Protection: Ensuring that a battery is protected against overcharging or over discharging is vital for preventing damage and improving safety. Analysis helps identify appropriate protection mechanisms.

Aging and Degradation Analysis:

Cycle Life: Assessing the number of charge-discharge cycles a battery can undergo before experiencing significant capacity loss helps determine its cycle life. This information is crucial for estimating battery lifespan and optimizing usage patterns.

Capacity Fade: Monitoring capacity fade, which refers to the gradual loss of a battery's capacity over time, helps identify the aging mechanisms and develop strategies to mitigate degradation.

Calendar Aging: Battery analysis involves considering calendar aging, which is the aging process that occurs even when a battery is not in use. It helps understand the battery's behaviour and lifespan during storage or idle periods.

Simulation of batteries involves using computational models and algorithms to replicate and predict the behaviour, performance, and characteristics of batteries under various conditions. Here's a brief overview of battery simulation.

Electrochemical Simulation:

Electrochemical Reaction Modelling: Simulation models replicate the electrochemical processes occurring within battery cells, including ion transport, charge transfer, and chemical reactions. These models help understand the battery's voltage response, capacity, and energy efficiency.

Voltage and Current Profiles: Simulations predict the voltage and current profiles of a battery during charging, discharging, and idle states. This information aids in estimating the battery's performance and behaviour under different operating conditions.

Thermal Simulation:

Temperature Distribution: Simulations analyse the temperature distribution within a battery cell or pack, considering factors such as heat generation, thermal conductivity, and cooling mechanisms. This helps assess thermal management strategies, prevent overheating, and optimize battery performance and safety.

Heat Dissipation: Simulation tools evaluate the effectiveness of cooling systems, such as heat sinks, fans, or liquid cooling, in dissipating heat generated during battery operation. It aids in optimizing thermal management and preventing thermal runaway.

Battery Management System (BMS) Simulation:

State of Charge (SOC) and State of Health (SOH) Estimation: Simulation models are used to develop algorithms that estimate SOC and SOH based on voltage, current, and temperature measurements. Accurate estimation is crucial for effective battery management, control, and optimization.

Fault Diagnosis and Prognosis: Simulations aid in developing techniques to detect and predict faults or malfunctions in battery systems. By simulating fault scenarios, potential failures can be identified, and appropriate corrective measures can be taken.

System-Level Simulation:

Vehicle Integration: Battery simulations consider the interaction between batteries, power electronics, motors, and other vehicle components in electric vehicles (EVs) or hybrid electric vehicles (HEVs). This helps optimize the overall system performance, efficiency, and range.

Energy Management: Simulations analyse energy flows within the system, optimizing the utilization of battery energy, regenerative braking, and power distribution to improve overall

system efficiency. Range Estimation: Simulation tools aid in estimating the driving range of EVs by considering factors such as battery capacity, vehicle dynamics, driving conditions, and energy consumption models. This helps users plan their journeys and assess the feasibility of specific routes.

EQUIVALENT CIRCUIT AND LIFE MODELLING

Equivalent circuit modelling and life modelling are two approaches used in the analysis and prediction of battery behaviour and performance. Here's a brief explanation of each:

Equivalent Circuit Modelling: Equivalent circuit modelling represents a battery as an electrical circuit consisting of idealized components that mimic the electrochemical processes within the battery. The components in the circuit model correspond to different aspects of battery behaviour, such as voltage, resistance, capacitance, and diffusion processes. The model parameters are typically determined through experimental characterization.

The most common equivalent circuit model for batteries is the Randles circuit, which includes a resistance representing the electrolyte and electrode resistance, a capacitor accounting for double-layer capacitance, and a Warburg element to capture diffusion processes. The equivalent circuit model can be used to simulate the battery's voltage response, impedance, and other electrical characteristics under various operating conditions.

Equivalent circuit modelling is relatively simple, computationally efficient, and allows for the analysis of transient and steady-state behaviour. However, it may not capture all the complexities of the battery's electrochemical processes and can have limitations when applied to more advanced battery chemistries.

Life Modelling: Life modelling focuses on predicting the aging and degradation of batteries over time, considering factors such as capacity fade and cycle life. These models help estimate the expected lifespan of a battery and identify factors that contribute to degradation.

Life modelling often involves empirical or semi-empirical approaches that use historical data to establish relationships between battery aging and factors such as operating conditions (temperature, current, voltage), state of charge, cycle depth, and cycling frequency. These relationships are then used to predict the battery's degradation over time.

Various life models exist, including empirical models like the Arrhenius model, which relates battery aging to temperature, and the Peukert model, which estimates capacity loss based on discharge current. More advanced models may incorporate additional factors, such as calendar aging or the effects of different charge and discharge protocols.

Life modelling helps manufacturers and users understand the expected lifespan of a battery under specific operating conditions, optimize battery usage and charging strategies, and develop maintenance or replacement plans.

Both equivalent circuit modelling and life modelling provide valuable insights into battery behaviour and performance. Equivalent circuit modelling aids in understanding electrical characteristics and transient response, while life modelling focuses on predicting degradation

and estimating battery lifespan. These modelling approaches complement each other and contribute to the overall understanding and management of battery systems.

ENVIRONMENTAL CONCERNS IN BATTERY PRODUCTION

Battery production, especially for lithium-ion batteries, raises several environmental concerns throughout the manufacturing process. Here are some key environmental considerations associated with battery production:

Raw Material Extraction: The extraction of raw materials required for battery production, such as lithium, cobalt, nickel, and graphite, can have significant environmental impacts. Mining activities can result in deforestation, habitat destruction, soil erosion, and water pollution. Some mining practices, particularly in regions with lax regulations, may involve unsafe working conditions and human rights concerns.

Energy Consumption: Battery production requires a substantial amount of energy, primarily for the manufacturing of battery components, electrode fabrication, and assembly. Depending on the energy source, this can contribute to greenhouse gas emissions and air pollution. Efforts are being made to increase the use of renewable energy in battery manufacturing to reduce the carbon footprint.

Chemical Usage and Waste Management: Battery production involves the use of chemicals, including solvents, electrolytes, and binders. Improper handling and disposal of these chemicals can lead to water and soil contamination. Adequate waste management practices are necessary to minimize environmental impacts and ensure the safe disposal or recycling of hazardous materials.

Water Usage: Battery production requires significant water consumption, particularly in processes like electrode coating and washing. Water scarcity in certain regions can be exacerbated by high-demand industries like battery manufacturing. Efficient water management practices, including water recycling and conservation measures, can help mitigate the environmental impact.

Recycling and End-of-Life Management: Batteries have a limited lifespan and eventually require proper disposal or recycling. If not handled appropriately, batteries can release toxic substances into the environment, leading to soil and water contamination. Establishing effective recycling infrastructure and promoting responsible disposal practices are critical for minimizing the environmental impact of battery waste.

Supply Chain Considerations: Battery production involves complex global supply chains that can span multiple countries. Ensuring responsible sourcing practices, transparency, and adherence to environmental regulations throughout the supply chain is crucial to mitigate environmental concerns associated with battery production.

RECYCLING OF BATTERIES

Battery recycling is the process of recovering valuable materials from used batteries to prevent environmental pollution and promote resource conservation.

Used batteries are collected through various channels, including dedicated recycling centres, drop-off points, retail stores, and recycling programs. It is essential to separate different battery chemistries (e.g., lithium-ion, lead-acid) as each requires specific recycling processes. Collected batteries undergo sorting to separate different types and chemistries. This step ensures that batteries are processed correctly and prevents cross-contamination during recycling. Before further processing, batteries are discharged to eliminate any remaining electrical charge. Discharging prevents potential safety hazards during handling and recycling operations. In some recycling methods, batteries are mechanically shredded into smaller pieces. This step helps expose the internal components for subsequent separation. Different recycling techniques, such as hydrometallurgical and pyro metallurgical processes, are employed to separate battery components. These methods involve the use of chemical solutions, high temperatures, or mechanical processes to extract valuable metals from the battery cells. Valuable metals like lithium, cobalt, nickel, lead, and others are recovered from the battery components. These metals can be reused in the production of new batteries or other applications, reducing the need for raw material extraction. The recycling process also focuses on managing and treating hazardous materials found in batteries, such as acids, electrolytes, and toxic substances. These materials are treated and disposed of properly to prevent environmental contamination. Battery recycling facilities must adhere to environmental regulations and quality standards to ensure proper handling, storage, and disposal of materials. Compliance with these standards helps minimize the environmental impact and ensures the safety of workers and surrounding communities. In addition to metal recovery, some batteries can undergo refurbishment or reconditioning processes for reuse in secondary applications. These include repurposing batteries for energy storage systems, grid stabilization, or other non-critical applications where the battery's capacity may not meet the original specifications.

Battery recycling plays a vital role in reducing the environmental impact of batteries, conserving valuable resources, and minimizing the need for raw material extraction. By recovering and reusing metals, proper disposal of hazardous materials, and adopting environmentally responsible practices, battery recycling contributes to a more sustainable and circular economy.

UNIT 5

BATTERY MANAGEMENT SYSTEM

INTRODUCTION TO BATTERY MANAGEMENT SYSTEM

A Battery Management System (BMS) is an essential component in modern battery systems, particularly for rechargeable batteries such as lithium-ion batteries. It is responsible for monitoring, controlling, and protecting the battery throughout its operation. Here's an introduction to the Battery Management System:

The BMS continuously monitors various parameters of the battery, including voltage, current, temperature, and state of charge (SOC). This real-time monitoring provides valuable information about the battery's performance, health, and safety. In multi-cell battery packs, the BMS ensures that each cell operates at an optimal voltage level. Cell balancing helps maintain uniform charge/discharge across cells, maximizing the overall capacity and lifespan of the battery pack. The BMS employs algorithms and models to estimate the SOC of the battery, providing an indication of the remaining charge or energy available. Accurate SOC estimation is crucial for effective battery management, efficient energy utilization, and preventing overcharging or deep discharging. The BMS tracks the battery's SOH, which represents the battery's degradation and capacity loss over time. It utilizes various techniques, such as coulomb counting, impedance spectroscopy, and voltage-based methods, to estimate the battery's health and predict its remaining lifespan. The BMS ensures the safety of the battery system and prevents hazardous situations. It incorporates protective measures such as overvoltage protection, under voltage protection, overcurrent protection, and temperature monitoring. These safeguards help prevent overcharging, over-discharging, excessive heating, and other potentially dangerous conditions. The BMS monitors the temperature of the battery cells and pack to prevent overheating, which can degrade battery performance and pose safety risks. It may activate cooling systems, such as fans or liquid cooling, to maintain optimal operating temperatures. The BMS facilitates communication between the battery system and external devices or systems. It provides data on battery parameters, SOC, and SOH to the user interface or connected applications. The BMS also allows for control functions, such as regulating charge and discharge rates or implementing specific battery management strategies. The BMS detects and diagnoses faults or abnormalities in the battery system. By analysing deviations from expected behaviour, it can identify potential failures and trigger appropriate actions, such as isolating faulty cells or generating system alarms. Additionally, the BMS can provide early warning signs or predictions of potential future issues, enabling proactive maintenance and replacement planning.

CELLS AND BATTERY

Cell:

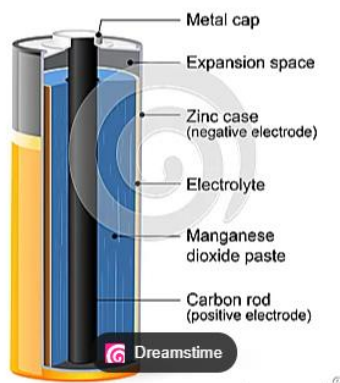
A cell is the basic building block of a battery and consists of three key components: two electrodes (anode and cathode) and an electrolyte.

The anode is the electrode where oxidation occurs during discharge, releasing electrons. The cathode is the electrode where reduction takes place during discharge, accepting electrons.

The electrolyte is the medium that allows ion transport between the electrodes, facilitating the electrochemical reactions.

When a cell is connected to an external circuit, a chemical reaction takes place, resulting in the flow of electrons from the anode to the cathode, creating an electric current.

Dry cell battery



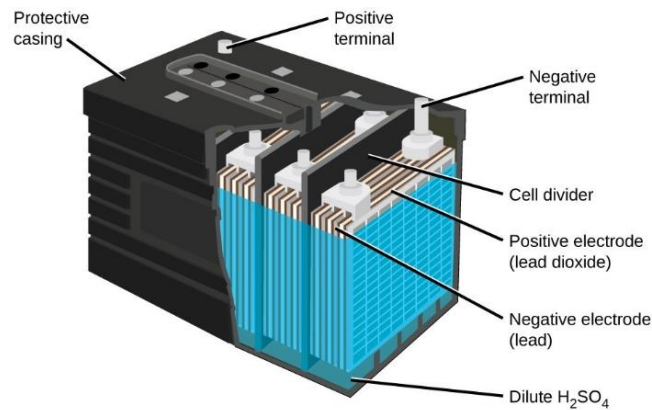
Battery:

A battery is a collection of multiple cells connected in series or parallel to provide a higher voltage, capacity, and power output than a single cell.

Cells within a battery pack are typically housed in a common casing and may share a common electrolyte reservoir.

Batteries can be categorized based on their chemistry, such as lithium-ion, lead-acid, nickel-metal hydride (NiMH), or alkaline, each with different characteristics and applications.

The performance of a battery is determined by its voltage, capacity (amount of stored energy), discharge rate, cycle life, and other factors.



NOMINAL VOLTAGE AND CAPACITY

Nominal Voltage: The nominal voltage of a battery refers to the average voltage value associated with a particular battery chemistry or type. It serves as a standardized representation of the battery's voltage for practical purposes. The nominal voltage is typically mentioned on battery labels and specifications to provide a general indication of the voltage level.

Some common nominal voltages for different battery types are:

Lithium-ion (Li-ion) batteries: 3.6V or 3.7V per cell

Lead-acid batteries: 2V per cell for single cells, 12V for a 6-cell battery pack

Nickel-metal hydride (NiMH) batteries: 1.2V per cell

Alkaline batteries: 1.5V per cell

It's important to note that the actual voltage of a battery can vary depending on its state of charge, load conditions, and other factors. The nominal voltage provides a reference point but may not reflect the precise voltage at a specific moment.

Capacity: Battery capacity refers to the amount of electrical energy a battery can store and deliver over a given period. It is typically measured in ampere-hours (Ah) or milliampere-hours (mAh). Capacity indicates the total charge a battery can hold, which determines how long it can power a device or system before requiring recharging.

Battery capacity is often mentioned along with a discharge rate or time period. For example, a battery might be rated at 2000mAh capacity at a 1C discharge rate, meaning it can deliver a current of 2000mA (2A) for one hour before reaching its specified capacity limit.

Higher capacity batteries generally provide longer runtime or higher energy storage capabilities. However, it's important to consider the specific application's power requirements and the trade-off between capacity and other factors like weight, size, and cost.

Battery capacity can also be expressed in watt-hours (Wh) by multiplying the capacity (in Ah) by the nominal voltage (in V). This provides a measure of the total energy storage capacity of the battery.

Both nominal voltage and capacity are crucial factors to consider when selecting batteries for different applications. Understanding these specifications helps ensure compatibility and optimal performance in various devices and systems, ranging from small consumer electronics to electric vehicles and renewable energy storage solutions.

C RATE

C rate" typically refers to the rate at which a battery is charged or discharged. It is a measure of the current flow relative to the battery's capacity.

In general, the C rate is calculated by dividing the charging or discharging current by the battery's capacity. For example, if a battery has a capacity of 1000mAh and it is charged at a current of 500mA, the charging C rate would be 0.5C (500mA/1000mAh). Similarly, if the same battery is discharged at a current of 200mA, the discharging C rate would be 0.2C (200mA/1000mAh).

The C rate is often used to determine the safe and efficient charging or discharging limits for batteries. Different types of batteries have different recommended C rates, and exceeding these rates can lead to reduced battery life, overheating, or other safety concerns.

It's worth noting that the term "C rate" can also be used in other contexts, such as in financial or credit rating systems.

ENERGY AND POWER

In the context of a Battery Management System (BMS), energy and power play important roles in monitoring and managing the performance of batteries. Here's how energy and power are relevant in a BMS:

Energy: The BMS needs to measure and track the energy stored in the battery. This helps in determining the state of charge (SoC) and state of health (SoH) of the battery. SoC represents the amount of energy remaining in the battery as a percentage of its total capacity. SoH indicates the overall health or degradation of the battery over time. By accurately measuring and estimating the energy, the BMS can provide information about the remaining battery life and optimize battery usage.

Power: Power monitoring is crucial for the safe operation of batteries. The BMS continuously measures the power flowing into and out of the battery during charging and discharging processes. Monitoring power helps to ensure that the battery operates within safe limits and prevents excessive currents or temperatures that could lead to damage or failure. The BMS can implement power limits or control strategies to manage the power flow and protect the battery from adverse conditions.

Additionally, the BMS uses energy and power information to perform various functions, including:

Balancing: In multi-cell battery systems, the BMS ensures that each cell is charged and discharged evenly, preventing cell imbalances. Balancing circuits or algorithms can adjust the energy flow between cells to maintain their equalization.

Thermal management: Energy and power data assist the BMS in monitoring and controlling the temperature of the battery. By regulating the power flow and implementing cooling or heating measures, the BMS helps maintain the battery within safe temperature limits, which is crucial for its performance and lifespan.

Predictive modelling: By analysing energy and power patterns, the BMS can develop predictive models to estimate battery behaviour, anticipate degradation, and optimize charging and discharging strategies.

CELLS

Cells generate electricity and also derives chemical reactions. One or more electrochemical cells are batteries. Every cell has two terminals namely:

Anode: Anode is the terminal from where the current flows in from out i.e. it provides an incoming channel for the current to enter the circuit or the device.

Cathode: Cathode is the terminal from where the current flows out i.e. it provides an outgoing current flow from the circuit or the device.

Learn more about Electric Charge here in detail

There are two simplest ways for cell connectivity are as follows:

Series connection: Series connection is the connectivity of the components in a sequential array of components.

Parallel connection: Parallel connection is the connectivity of the components alongside to other components.

Cells in Series Connection

In series, cells are joined end to end so that the same current flows through each cell. In case if the cells are connected in series the emf of the battery is connected to the sum of the emf of the individual cells. Suppose we have multiple cells and they are arranged in such a way that the positive terminal of one cell is connected to the negative terminal of the another and then again the negative terminal is connected to the positive terminal and so on, then we can that the cell is connected in series.

Equivalent EMF/Resistance of Cells in Series

If E is the overall emf of the battery combined with n number cells and E_1, E_2, E_3, E_n are the emfs of individual cells.

Then $E_1 + E_2 + E_3 + \dots E_n$

Similarly, if r_1, r_2, r_3, r_n are the internal resistances of individual cells, then the internal resistance of the battery will be equal to the sum of the internal resistance of the individual cells i.e.

$$r = r_1 + r_2 + r_3 + r_n$$

Cells in Parallel Connection

Cells are in parallel combination if the current is divided among various cells. In a parallel combination, all the positive terminal are connected together and all the negative terminal are connected together.

Equivalent EMF/Resistance of Cells in Parallel

If emf of each cell is identical, then the emf of the battery combined with n numbers of cells connected in parallel is equal to the emf of each cell. The resultant internal resistance of the combination is,

$$r = (1/r_1 + 1/r_2 + 1/r_3 + \dots + 1/r_n)^{-1}$$

ELECTROCHEMICAL AND LITHIUM ION CELL

Electrochemical cells are devices that convert chemical energy into electrical energy through electrochemical reactions. One type of electrochemical cell is the lithium-ion cell, which has become widely used in various applications due to its high energy density and relatively low self-discharge rate. Here are some details about electrochemical cells and lithium-ion cells:

Electrochemical Cells: Electrochemical cells consist of two electrodes (anode and cathode) immersed in an electrolyte solution. The electrodes are made of materials that undergo reversible chemical reactions, allowing for the flow of electrons and ions. The chemical reactions at the electrodes generate an electric current that can be used to power electronic devices.

Lithium-ion Cells: Lithium-ion (Li-ion) cells are a specific type of electrochemical cell that utilize lithium ions as the primary charge carriers. Li-ion cells typically consist of a graphite anode, a metal oxide cathode, and a lithium salt electrolyte. During charging, lithium ions move from the cathode to the anode through the electrolyte, where they are stored within the anode's structure. During discharging, the lithium ions move back to the cathode, generating electrical energy.

RECHARGABLE CELL

A rechargeable cell, also known as a secondary cell or rechargeable battery, is an electrochemical cell that can be recharged multiple times by reversing the chemical reactions that occur during discharge. Unlike non-rechargeable or primary cells, which are typically used once and then discarded, rechargeable cells are designed to be reused, offering a more

sustainable and cost-effective power solution. Here are some key details about rechargeable cells:

Rechargeable Chemistry: Rechargeable cells employ various chemistries, each with its own advantages and characteristics. Common rechargeable cell chemistries include:

Nickel-Cadmium (Ni-Cd): Ni-Cd cells have been widely used in the past but are less common today due to their lower energy density and the environmental concerns associated with cadmium.

Nickel-Metal Hydride (Ni-MH): Ni-MH cells provide a higher energy density than Ni-Cd cells and are commonly used in applications such as portable electronics, power tools, and hybrid vehicles.

Lithium-Ion (Li-ion): Li-ion cells offer high energy density, low self-discharge rates, and no memory effect. They are extensively used in portable electronics, electric vehicles, renewable energy storage, and many other applications.

Lithium-Polymer (Li-Po): Li-Po cells utilize a flexible polymer electrolyte, which allows for different form factors and packaging options. They are commonly used in slim and lightweight devices like smartphones and tablets.

Lead-Acid: Lead-acid cells are widely used in applications such as automotive starting batteries and backup power systems due to their relatively low cost and robustness.

CHARGING AND DISCHARGING

Charging and discharging are fundamental processes that occur in batteries and other energy storage devices. Here's an overview of charging and discharging:

Charging: Charging refers to the process of replenishing the energy stored in a battery or energy storage device. During charging, an external power source is used to provide electrical energy to the battery, allowing it to store energy for later use. The charging process involves converting electrical energy from the external source into chemical potential energy within the battery.

Discharging: Discharging is the opposite of charging. It is the process of releasing the stored energy from the battery, making it available to power devices or perform work. When a battery is discharged, the stored chemical potential energy is converted back into electrical energy, which can be used to operate electronic devices, power tools, vehicles, or other applications.

Charging and Discharging Characteristics:

Voltage: During charging, the voltage across the battery terminals increases, gradually reaching the desired charging voltage. In contrast, during discharging, the voltage decreases as the battery's energy is consumed.

Current: Charging and discharging involve the flow of electric current. During charging, a higher current flows into the battery, while during discharging, the current flows out of the battery to power the connected load.

Efficiency: Charging and discharging processes are not 100% efficient. Some energy is lost as heat due to resistance within the battery and other components of the charging/discharging circuit. The efficiency of charging and discharging depends on the battery chemistry and the specific charging/discharging system used.

Charging and Discharging Cycles: Charging and discharging cycles refer to the repetitive process of charging and then discharging a battery. Each cycle consists of a charge phase and a discharge phase. The number of charging and discharging cycles a battery can undergo before its capacity significantly decreases depends on factors such as the battery chemistry, operating conditions, and charging/discharging protocols.

Charging and Discharging Systems: Charging and discharging can be performed using different methods and technologies, depending on the type of battery or energy storage device. Common charging and discharging systems include:

Constant Current (CC) Charging: In this method, a constant current is applied to the battery until it reaches the desired voltage or charge level.

Constant Voltage (CV) Charging: Once the desired voltage is reached, the charging current is gradually reduced while maintaining a constant voltage level.

Fast Charging: Fast charging systems deliver higher currents or voltages to charge batteries more rapidly. However, fast charging may generate more heat and could have an impact on battery lifespan.

Discharge Regulation: Discharge regulation systems ensure that the battery voltage remains within a safe operating range during discharging to prevent over-discharge, which can damage the battery.

MODES OF CHARGING

There are different modes of charging used for batteries and energy storage systems, each with its own characteristics and applications. Here are some common modes of charging:

Constant Current (CC) Charging: In this charging mode, a constant current is applied to the battery until it reaches a predefined voltage or charge level. Initially, the charging current is high, allowing the battery to charge quickly. As the battery voltage rises, the charging current gradually decreases to maintain a constant current value. CC charging is commonly used in various applications, including lithium-ion batteries.

Constant Voltage (CV) Charging: Once the battery reaches the desired voltage or charge level, the charging mode switches to constant voltage charging. In CV charging, the charging current is gradually reduced as the battery approaches full charge, while the voltage is

maintained at a constant level. This mode helps prevent overcharging and is commonly used for lead-acid batteries and some lithium-ion batteries.

Trickle Charging: Trickle charging is a low-level continuous charging mode used to maintain the battery's charge when it is not in use. It provides a small current to compensate for self-discharge and keep the battery ready for use. Trickle charging is commonly used for applications like standby power systems, emergency lighting, and small electronic devices.

Pulse Charging: Pulse charging involves charging the battery with short bursts or pulses of high-current followed by a period of rest. This charging mode helps to minimize heat generation and can improve the charging efficiency, especially for certain battery chemistries. Pulse charging is used in various applications, including nickel-cadmium (Ni-Cd) batteries and some specialized rechargeable batteries.

Fast Charging: Fast charging refers to charging batteries at a higher rate than standard charging methods. It aims to significantly reduce the charging time. Fast charging systems typically use high charging currents or voltages to charge the battery more rapidly. However, fast charging may generate more heat and can impact the battery's overall lifespan. Fast charging is commonly used in electric vehicles (EVs) and certain consumer electronics.

Smart Charging: Smart charging involves using advanced algorithms and control systems to optimize the charging process based on battery characteristics, temperature, and other factors. Smart charging systems can adjust the charging parameters dynamically to ensure efficient and safe charging while prolonging battery life. This mode is commonly found in advanced battery management systems (BMS) and chargers for lithium-ion batteries.