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The Chemistry of Batteries for Electric Vehicles

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Abstract: ***The paper discusses the ongoing research in electric vehicle battery types. The report presents the chemistry engineering challenges of Lithium-ion, Solid-state batteries. The last section highlights Tesla's '4680 battery' and its potential to replace solid-state batteries.***

1. INTRODUCTION

Our world is seeing increasingly many catastrophes due to global warming. As a result, the need to develop environmentally friendly technology. One technology that has been at the forefront of this revolution has been the development of Electric Vehicles. However, there are many technical challenges for Electric Vehicles to become mainstream.

The heart of the Electric Vehicle is its battery. Technical improvements in battery can solve mileage, storage capacity, and charging time. Hence, it is imperative to understand and mitigate the engineering impediments by studying the battery's Chemistry.

2. WHAT ASPECTS OF BATTERIES ARE IMPORTANT IN ELECTRIC VEHICLES?

Smartphones have been an essential tool in our daily lives. With Smartphones playing many roles such as – email, messages, social media, schedule planner, GPS, and many more – a long battery life with minimal charging time, size, shape are significant research areas.

Similarly, electric vehicles are slowly becoming like our phones: an essential part of modern life. An electric vehicle takes a few hours to charge with the current technology.

In India especially, where there is always a crowd at petrol stations, it would not be feasible for electric vehicles to take a long time to charge. Hence, the storage capacity of batteries must improve.

Various companies like Tesla have been working on improving the Chemistry of modern batteries, and in some cases, even creating new kinds of batteries to improve their storage capacity.

In addition to the long battery life, charging time also has to be reduced and another area of research.

Types of Batteries: Lithium-ion batteries are the most used with nickel-metal hydride batteries (although significantly less than lithium-ion).

1. Lithium-ion battery

2. Nickel-metal hydride battery

3. Lead Acid Battery

4. Ultracapacitor

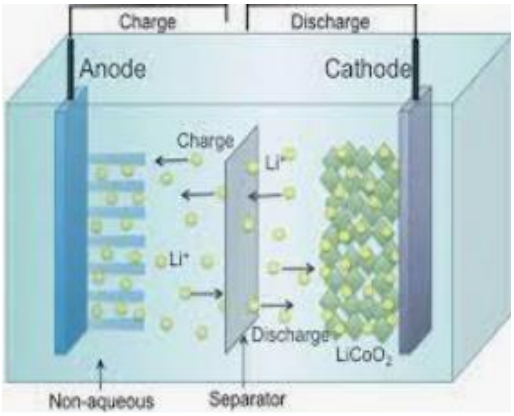
Chemistry and Working of Lithium-ion battery[1]:

Lithium ions move via an electrolyte from a negative to a positive electrode[2] in a rechargeable lithium-ion battery. It moves in the opposite direction during charging.[3]

A lithium-ion battery consists of a cathode, separator, electrolyte, and two current collectors. The negative electrode is carbon-based, and the positive electrode is usually a metal oxide because they allow for intercalation (the ability of molecules to allow the easy passage of ions in and out of their structures). A lithium salt in organic salt is an example of an electrolyte.[4]

Like most batteries, this works on the movement of ions. Lithium-ion batteries don't use elemental Lithium because Lithium is very reactive in its elemental form. Therefore, lithium-metal oxide, such as lithium-cobalt oxide LiCoO2, which supplies the lithium-ions, is usually used.

A redox reaction takes place in a lithium-ion battery.



Reduction: (cathode): $CoO_2 + Li^+ + e^- \rightarrow LiCoO_2$

Oxidation: (anode): $LiC_6 \rightarrow C_6 + Li^+ + e^-$

Redox reaction: $LiC_6 + CoO_2 \rightleftarrows C_6 + LiCoO_2$

Discharging and Charging: During discharging, positively charged lithium ions move from the anode to the cathode through the electrolyte and deposit once they reach the electrode. The electrons, however, move from the anode to the cathode. The opposite process takes place during charging. Studies suggest Lithium-ion batteries are suitable for Electric Vehicles.[5] Since

[1] Ref: Lead Acid vs. Lithium Ion (LiFePO4), Smart Charger July 19, 2019; https://smartercharger.com/blogs/news/lead-acid-vs-lithium-ion-lifepo4

[2] Ref: 2600mAh Battery: Working, Specifications, Application Circuit, and Other Useful Knowledge; https://www.wellpcb.com/2600mah-battery.html

[3] Ref: Outline some methods for obtaining ultra-high orientation in polymers (e.g. Kevlar); https://www.bartleby.com/questions-and-answers/outline-some-methods-for-obtaining-ultra-high-orientation-in-polymers-e.g.-kevlar./e787bca6-d7e6-40f7-853a-dc99dbacb484?v=2&mrasn=800265.994143.qv7X6EFV

[4] Ref: Cause of LG's battery fires rumored to be found (updated) Sean Graham, Feb. 12th 2021, https://electrek.co/2021/02/12/cause-of-lg-battery-fires-rumored-to-be-found/

[5] Ref: Motiv Power Systems to offer BMW batteries on electric chassis for commercial vehicles; ByFleet Equipment Staff, Jan 28, 2019, https://www.fleetequipmentmag.com/motiv-power-

they have the highest charge density of any similar system, lithium-ion batteries can supply a large amount of electricity without a high weight. Lithium is among the most electropositive elements and light versus other metals.

3. ADVANTAGES AND DISADVANTAGES OF LITHIUM-ION BATTERY[6]:

Advantages:

- **High energy density:** Lithium-ion batteries supply large amounts of energy without much weight. Electric vehicles also need battery technology with a high energy density.
- **Cell voltage:** Each lithium-ion cell produces 3.6 volts. Being higher than most batteries, the voltage of each lithium-ion cell is higher, requiring fewer cells in many battery applications.
- **Self-discharge:** Lithium-ion cells have one of the lowest rates of self-discharge
- **Low maintenance, no requirement for priming, variety of types available**

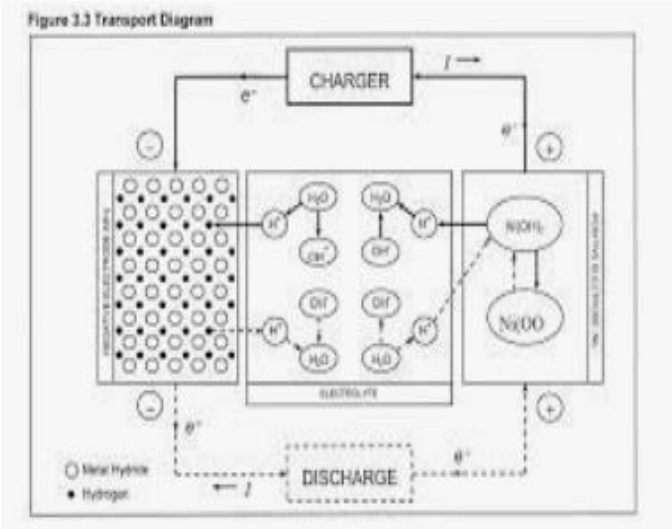
Disadvantages:

- **Protection required:** Lithium-ion batteries require protection from being overcharged and discharged within safe limits. Therefore, they require protection circuitry incorporated to ensure that they are within safe operating limits.
- **Aging:** Overcoming aging is a research topic with the emergence of li-ion technology
- **Transportation**
- **Cost**

Chemistry and Working of Nickel-Metal Hydride (NiMH)[7]:

Nickel metal hydride battery is a rechargeable battery with a positive plate with nickel hydroxide and a negative plate made up of primarily hydrogen-absorbing alloys, fine separator fibers, alkaline electrolyte, a sealing plate, and metal casing. Ni-Cd batteries have a similar structure[8].

In a nickel-metal hydride battery, the hydrogen movement is from the positive electrode to the negative electrode and reverses while discharge, with no role for the electrolyte during the process.[9] As a result, the electrolyte does increase nor decrease.



It follows a **redox** reaction.

Positive electrode: $Ni(OH)_2 + OH^- \rightleftarrows NiOOH + H_2O + e^-$

Negative electrode: $M + H_2O + e^- \rightleftarrows MH_{ab} + OH^-$

Redox reaction: $Ni(OH)_2 + OH^- \rightleftarrows NiOOH + H_2O$

Where M is hydrogen-absorbing alloy and MH_{ab} is absorbed hydrogen.

Lithium batteries replace Nickel-Metal Hydride batteries used in earlier generation electric and hybrid-electric

systems-to-offer-bmw-batteries-on-electric-chassis-for-commercial-vehicles/

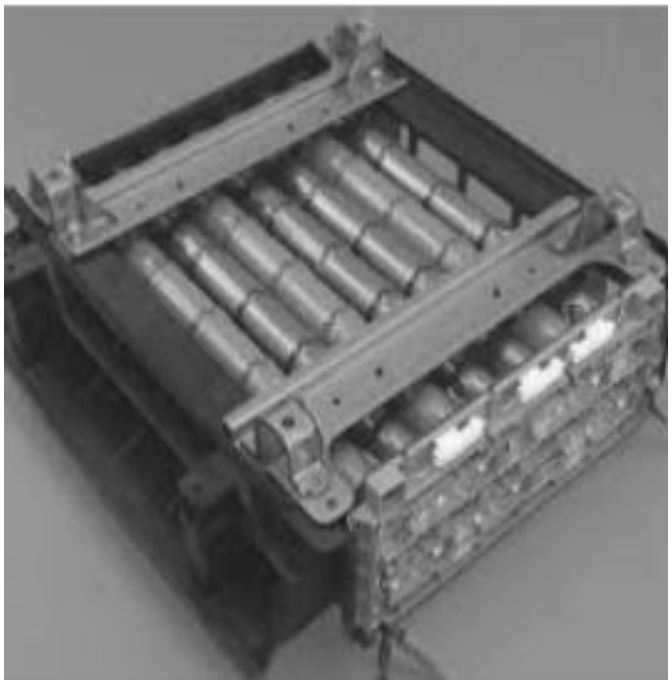
[6] Ref: Pros and Cons of Lithium Ion Batteries; BSLBATT Mar 30,2020; https://www.lithium-battery-factory.com/pros-and-cons-of-lithium-ion-battery/

[7] Ref: Best Ebike Battery: What Technology Type Of Battery Should I Get? https://www.onlybicycle.com/best-ebike-battery/

[8] Ref: Methods and apparatuses for power generation in enclosures; Inventors: Gregory M. Quist David A. Drake https://www.patentsencyclopedia.com/app/20080258694

[9] Ref: Discuss the construction and working of nickel- metal hydride battery; https://eduladder.com/viewquestions/3746/Discuss-the-construction-and-working-of-nickel--metal-hydride-battery

vehicles. Still, they remain in use in hybrid vehicles, e.g., the 2020 Toyota Highlander.



Advantages and Disadvantages of Nickel Metal Hydride Batteries:

Advantages:

- 30% more capacity than a standard NiCad battery. And less memory than the NiCad battery.
- Fewer Periodic exercise cycles.
- With fewer toxic metals, the NiMH is "environmentally friendly."

Disadvantages:

- The number of cycles: The NiMH rated only 500 charge/discharge cycles.
- The heat generated during charge: The NiMH generates considerably more heat during charge and requires a complex algorithm for full-charge detection
- Self-discharge: The self-discharge of the NiMH is not good as it loses a large percentage of its capacity in the first 24 hours.

Recent Developments in Solid State Battery:

The low adoption of Electric Vehicles so far is that their engineering is inferior to the existing internal combustion engine vehicles (ICEV). The main issue is that electric vehicles have lower mileage per unit, higher vehicle price, longer charging time vs. time refueling at petrol or diesel station, bigger battery size and weight than internal combustion engine vehicles.

The main problem is the type of battery used in electric vehicles. Although the lithium-ion battery is among the superior available options, its shortcomings contribute towards the overall technical shortcomings of Electric Vehicles versus ICEV. The drawbacks of a lithium-ion battery are its capacity and safety.

Lithium-ion batteries currently have a safety risk of damage due to swelling caused by temperature change or leakage caused by external force since they use liquid electrolyte solution. A solid-state battery with a solid electrolyte displays higher stability with a solid structure, and potentially better safety as it tends to maintain its shape should the electrolyte get damaged.[10]

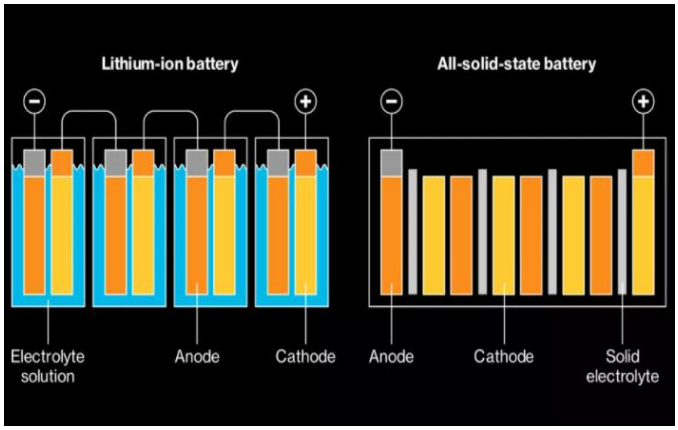
To achieve higher battery capacity, researchers suggest increasing the number of batteries. However, practically, it occupies more space, making the electric vehicle heavier and more expensive.

Alternatively, to solve the above technical issues, a second and more feasible method is to develop Solid-State batteries with a higher energy density than lithium-ion batteries. As the electrolyte is not a liquid, explosion risk is mitigated and occupies lesser space, allowing for more capacity.

Chemistry and Working of Solid-State Batteries:

A solid-state battery uses solid electrodes and solid electrolytes. The solid electrolytes include oxides, sulfides, phosphates, polyethers, polyesters, nitrile-based, polysiloxane, polyurethane. Battery performance also depends on electrolyte types used. Ceramics are suitable for rigid battery systems due to their high elastic moduli, while low elastic moduli of polymers make them fit for flexible devices.

[10] *Ref: What is a Solid Sate Battery? https://www.samsungsdi.com/column/technology/detail/56462.html?listType=gallery*



The working of a solid-state battery is similar to that of a lithium-ion battery.

The cathode and anode of a battery consist of electrically conductive material. In between the electrodes, the lithium ions move through the electrolyte between the electrodes, producing current. The battery charges when ions move from the cathode to the anode and produce current. And ions move from the anode to the cathode, that is, in the reverse direction, the battery discharges and provides current to the load.[11]

Engineering Challenges of a Solid-State Battery:

- **Cost:** Solid-state batteries are expensive to manufacture, and the current processes make it challenging to scale, requiring expensive vacuum deposition equipment. As a result, the high costs are currently preventing widescale consumer usage. It was estimated in 2012 that, based on technology available at that time, a 20 Ah solid-state battery cell would cost US$100,000, and a high-range electric car would require between 800 and 1,000 of such cells.

- **Interfacial resistance:** High interfacial resistance between a cathode and solid electrolyte has been a long-standing problem for all-solid-state batteries.

- **Temperature and pressure sensitivity:** Currently, solid-state batteries require low temperatures for optimal performance. Research to improve battery performance at higher temperatures is necessary to achieve optimal performance standards.

- **Interfacial instability:** The interfacial instability of the electrode-electrolyte has always been a severe problem of solid-state batteries. After solid-state electrolyte contacts with an electrode, the chemical side reactions at the interface usually produce a passivated interface, which affects the diffusion of Li^+.

Tesla's Innovation that Could Remove the Need for Solid-State Batteries:

On October 25th, 2021, Elon Musk, the founder of Tesla, tweeted: "Bye-bye solid-state batteries!"

Tesla announced the creation of a "4680 battery," claiming a "100-fold increase in battery production" by the year 2030, thanks partly to the new battery type's cylindrical architecture.

The cylindrical battery cell has a certain threshold for thermal runaway. The advantages of cylindrical battery cells are that the capacity of a single unit is low, and the heat release of a single electrical runaway is not easy to spread. Also, the arc-shaped surface suppresses the heat transfer between the batteries to a certain extent.

Chemistry and Working of 4680 Battery

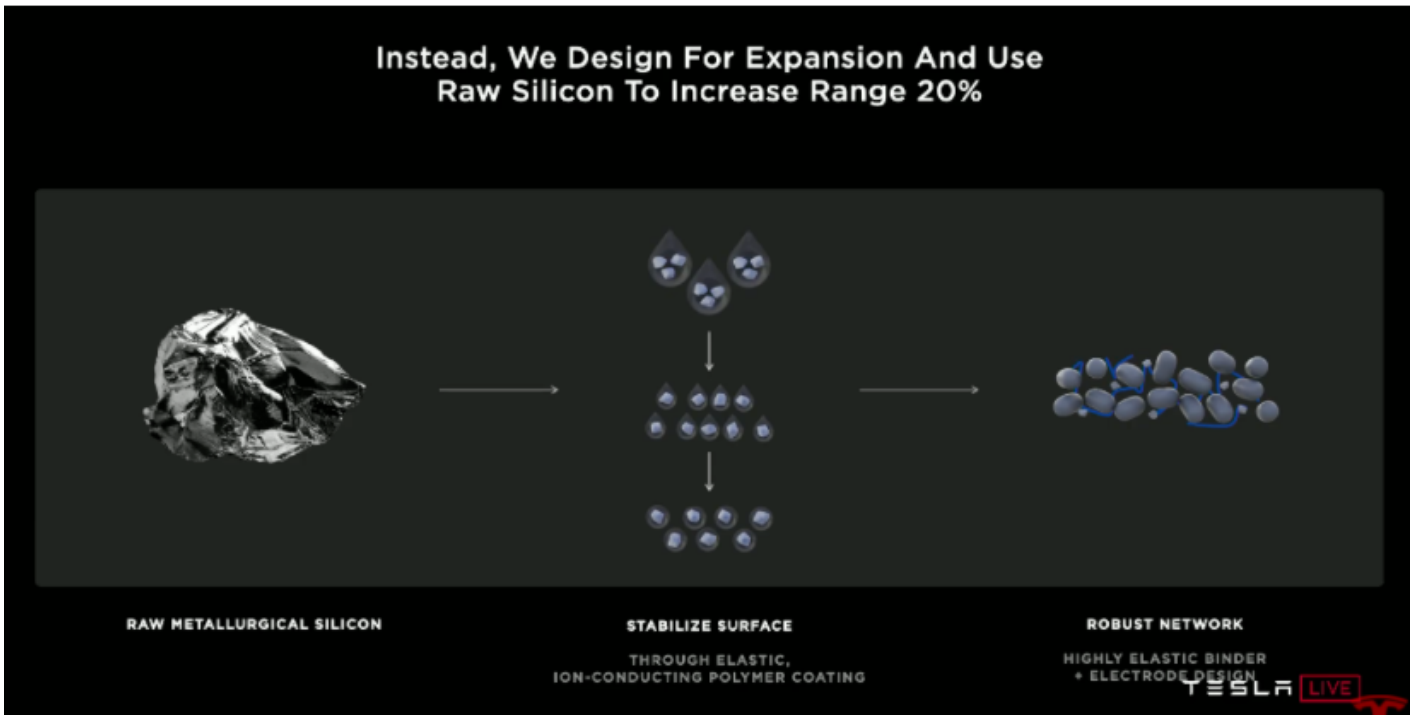
Tesla's batteries currently use Silicon. However, its physical properties make it challenging to use at higher volumes, as Silicon expands four times when charged with Lithium.

[11] *Ref: https://studiousguy.com/solid-state-battery-working-principle-uses-advantages/*

Tesla began experimenting with raw Silicon to solve the problem. Using raw Silicon, an abundant material on Earth lowers the cost and stabilizes the surface with an elastic ion-conducting polymer coating.

It also allows for a higher percentage of Silicon to be used in the cells. The result is a cheaper cell that also boasts higher capacity, which increases the range of their vehicles by an additional 20%.

The cells are also cheaper, with a 5% cost reduction at the battery pack level.



4. CONCLUSION

Several technology advancements in developing a battery for electric vehicles are underway to align costs, technology, safety, weight, and size to make it commercially viable for broad adoption.

The battery is the heart of the electric vehicle, and Chemistry is the heart of the battery. Advancements in the Chemistry of materials, such as making solid-state batteries that can work in higher temperatures reducing the leakage of lithium-ion batteries, enable the broad adoption of electric vehicles.

Although the interest in electric vehicles is increasing steadily, it remains an area requiring further research in form, cost, versatility, and stability. The future is bright as multidisciplinary engineering research for overcoming battery shortcomings for Electric Vehicles is progressing rapidly.

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