

# Safety hazards and solutions of lithium-ion batteries

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**Abstract.** The invention and application of lithium-ion batteries (LIBs) have significantly impacted modern life. LIBs operate on the same principle as all secondary electrochemical cells, primarily relying on the movement of lithium ions between the positive and negative electrodes. Reversible energy release and storage are achieved through controlled redox reactions. LIBs are widely used in contemporary society due to their high energy density, long service life, and low self-discharge rate. However, LIBs also present certain safety risks. For instance, during charging and discharging, as well as when the battery's exterior experiences a collision, temperatures can reach dangerous levels, leading to thermal runaway, fire or explosion. Enhancing the safety of LIBs has become increasingly important. This research examines the various origins of safety issues associated with LIBs, discusses the existing methods to address these problems, and outlines relevant international regulations with examples. By understanding these measures and safety testing methods, potential accidents can be reduced, thereby protecting the lives and property of consumers. It is anticipated that these efforts will stimulate improvements in LIBs safety, foster the development of more efficient LIBs, enhance consumer confidence in LIBs technology, and promote the healthy growth of related industries.

**Keywords:** Lithium-ion batteries; Safety; Thermal runaway; Material modification.

## 1. Introduction

With global warming, green travel has become a focal point of attention. Lithium-ion batteries (LIBs) are characterized by their high energy density, long cycle life, and lack of memory effect. Their significant potential for environmental sustainability is attracting increasing interest. In modern life, many scientific and technological products rely on LIBs, including smartwatches, laptops, and electric or hybrid vehicles). As technology advances and costs decrease, the application of LIBs in energy storage systems and renewable energy is becoming increasingly widespread. The production and demand for LIBs continue to grow globally, particularly in new energy vehicles and energy storage technologies, indicating a broad application prospect. However, the limited safety features of LIBs significantly hinder their development. In recent years, incidents of explosions and fires have led to the recall of several tons of LIBs. Additionally, there have been numerous fire incidents associated with commonly used electronics and electric vehicles, prompting researchers to focus more on the safety of LIBs.

The safety of LIBs is influenced by battery chemistry, operating environment, and tolerance for abuse. The instability of the battery's chemical system can lead to internal failures. Key factors that govern the battery's reactions include voltage and temperature. Continuous heat generation and gas production can cause the battery to become uncontrollable, potentially igniting flammable materials or even leading to explosions. Thermal runaway may also result in the casing of the battery cracking, which can cause the electrolyte—a conductive substance—to leak, thereby increasing the risk of fire. This research discusses the exploration of solid electrolytes as alternatives to address the issue of electrolyte flammability. By modifying materials and incorporating anti-overcharge additives, it is possible to reduce the risks of internal short circuits, thermal runaway, and other related problems. Additionally, advancements in battery technology, optimization of battery management systems, and enhanced protective measures for the battery casing can significantly improve the overall safety of LIBs.

Here are some available security testing projects. For overcharge test, this test simulates the potential overcharging of the battery during the charging process. It involves monitoring parameters

such as battery voltage and temperature. The safety performance under overcharge conditions is closely related to the charge rate, and overcharging is conducted at various electrical rates to determine the extreme rate and voltage at which failure occurs. For overplay test, this test simulates the overdischarge of the battery during discharge and evaluates the battery's stability. For short circuit test, this test involves directly connecting the positive and negative terminals of the battery to simulate a short circuit. It observes changes in parameters such as current, voltage, and temperature. For puncture test, this test uses a sharp object to pierce the battery, simulating the extreme scenario of the battery being punctured. It evaluates the battery's safety, particularly when sharp objects remain inside the battery. For squeeze test, this test mimics how a battery reacts when subjected to squeezing forces, evaluating its stress resistance and overall safety. For heat abuse test, in this test, batteries are exposed to high temperatures to assess their performance under extreme thermal conditions. Batteries tend to expand at elevated temperatures and may explode, as their heat release rate often exceeds the cooling rate. This can lead to electrolyte decomposition and reactions at the electrode-electrolyte interface. This research discusses in detail several key factors affecting the safety of LIBs, the causes of safety risks, and the feasibility of potential solutions, while also considering future developments [1].

## 2. Security concerns

There are several reasons for the failure of LIBs, which may include defects in the battery design or manufacturing process, as well as environmental factors and the use of improper methods. The main reasons for these failures are discussed.

### 2.1. Overcharging and overdischarging

When the charging process reaches the normal upper limit voltage, lithium ions ( $\text{Li}^+$ ) are extracted from the cathode material, leading to instability in the cathode and an excessive lithium in the anode. Overcharging results in the decomposition of the electrolyte at the cathode interface and a significant increase in total internal resistance, a reaction that gradually raises the battery temperature. The principle of overdischarge is similar to that of overcharge. During excessive discharge,  $\text{Li}^+$  is continuously released from the anode, causing the copper (Cu) collector of the anode to dissolve and form  $\text{Cu}^{2+}$  ions. Upon recharging, the reverse reaction can produce copper dendrites, which may lead to an internal short circuit [1].

### 2.2. Internal short

Internal short circuits can be caused by a variety of factors, including short circuits between copper and aluminum collectors, foreign objects, diaphragm failure, inadequate isolation or insulation of electrodes within the battery, poor manufacturing processes, external pressure on the battery wall, and lithium dendrite growth. Internal short circuits can lead to increased self-discharge, gas generation inside the battery, and displacement of the internal electrodes [2].

### 2.3. Thermal runaway

Thermal runaway refers to the rapid increase in local or overall temperature within a battery, where heat cannot be dispersed effectively, resulting in significant chemical changes. These changes can be triggered by external high-temperature environments, electrical abuse, and other factors. Thermal runaway occurs in three stages, beginning with the overheating of the battery system. Overheating may result from overcharging, excessive ambient temperatures, or internal short circuits caused by design flaws or battery defects. Penetration by sharp external objects, high-voltage charging, collisions, crushing, the formation of lithium dendrites, and defective separators can all contribute to the development of internal short circuits. The accumulation of heat and the release of gas mark the onset of the second stage. As the temperature rises, oxygen accumulates within the battery. Once a critical level of oxygen and heat is reached, the battery can ignite. The electrolyte in LIBs is organic

and highly flammable. In the third stage, if the battery reaches a certain temperature, it can lead to a fire or explosion [1].

#### **2.4. Electrolyte problems**

Electrical decomposition, deterioration, or leakage of the electrolyte can lead to diminished battery performance or even failure. Excessive consumption of the electrolyte to release gas, or the cathode material to release oxygen, can result in increased battery pressure, potentially causing the aluminum packaging film to burst or leading to other issues. Aluminum is commonly used in LIBs cathode fluid collection. The electrolyte is highly corrosive to aluminum, and over prolonged cycles, the corrosion and dissolution effects can result in the diffusion of aluminum fragments, the deposition of dendritic aluminum, and the separation of active materials, among other issues [2].

#### **2.5. Material failure**

The failure of essential components, including the positive electrode material, negative electrode material, electrolyte, and fluid collector, can result in diminished battery performance or complete failure. For instance, structural failure of the positive electrode material, excessive growth of the solid electrolyte interphase (SEI) on the negative electrode surface, decomposition of the electrolyte, and degradation of the micropores in the diaphragm at elevated temperatures can all contribute to these issues [3].

#### **2.6. Design and manufacturing defect**

There may be flaws in the design and manufacturing of batteries. For example, the electrode capacity may be insufficient, and leakage or gas expansion can occur due to weak seals and poor internal connections. Additionally, contamination, cracks, and uneven diffusion can arise during the production process. Localized high temperatures in the diaphragm and excessive internal resistance are also concerns. Furthermore, the proportions of active substances in the positive and negative electrodes does not be balanced, and the composition of the electrolyte can be unstable. Lastly, defects in the battery terminals can contribute to overall performance issues [4].

#### **2.7. Poor usage environment and improper use**

Batteries used in harsh environments, such as extreme heat, humidity, vibration, or impact, are prone of failure. For instance, during a collision, a significant amount of heat is generated. Each battery consists a shell and a gel roll, which can sustain damage when subjected to external forces. The partition board may become damaged after being compressed and deformed due to these external pressures [1]. The user may not be using the device correctly according to the instructions, or they may not be using the original charger. Charging the device at excessively high or low temperatures can lead to battery failure.

### **3. Mitigation strategies**

#### **3.1. Materials modification**

By enhancing the properties of battery materials, the anti-overcharge capability of batteries can be significantly improved. For instance, material coating technology can be employed to increase the stability of both cathode and anode materials, enhance endurance, and minimize the side effects associated with charging. The olivine structure of  $\text{LiFePO}_4$  is a widely used active cathode material, known for its stability at temperatures up to 400 °C and has excellent cycling properties [5]. Additionally, the anode and separator can be protected by directly coating them with ceramic powder, which offers high-temperature resistance (stable at 400 °C), strong tensile strength, and other characteristics [6]. Solid-state electrolytes can also serve as alternatives to traditional liquid electrolytes, there reducing the risk of electrolyte leakage. The primary types of solid electrolytes

include non-polar ceramic electrolytes and solid polymer electrolytes. Their superior structure and thermal stability significantly decrease the likelihood of internal short circuits, as well as the risks of fire and explosion of in batteries.

### 3.2. Adding anti-overfilling additives

Specific additives are incorporated into the electrolyte, which can be categorized into REDOX pair additives and shutdown additives based on to their distinct functions. The former provides reversible protection against overcharging, while the latter permanently disables battery operation. A REDOX pair is an electrolyte additive that generates reversible oxygen ions, offering built-in protection for the battery to help balance the charge and prevent overcharging. For instance, a highly soluble (0.6 M) 1,4-dialkoxybenzene shuttle molecule that can endure 500 overcharge cycles at a 100% overcharge rate was demonstrated, providing remarkably long-lasting overcharge protection [7]. There are two types of shutdown additives. One that releases gas to activate the current interrupt device, and the another that polymerizes to inhibit ion transport in the electrolyte. These additives are commonly used in consumer electronics and children’s toys [8].

### 3.3. Intelligent management system

Set a protection voltage value in the integrated advanced battery management system (BMS). Various critical parameters of the battery can be monitored in real time. When the battery voltage reaches or exceeds this protection voltage value, the BMS will limit the charging speed or automatically power off the system. The BMS employs big data analytics and artificial intelligence algorithms to predict battery health and enhance early warning of potential safety hazards. The BMS includes functions such as battery monitoring, battery balancing, safety and protection, state estimation, heat management, and more [9]. As shown in Fig. 1, the battery health predictor is a key component of the BMS, providing predictions for residual battery life and capacity decay [10]

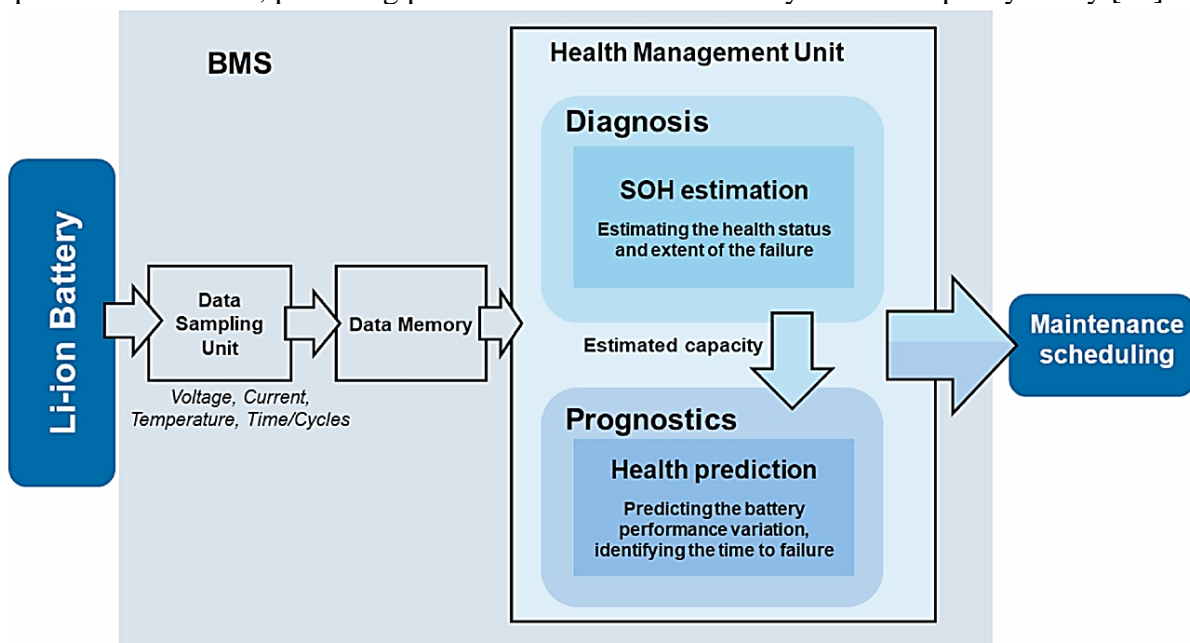
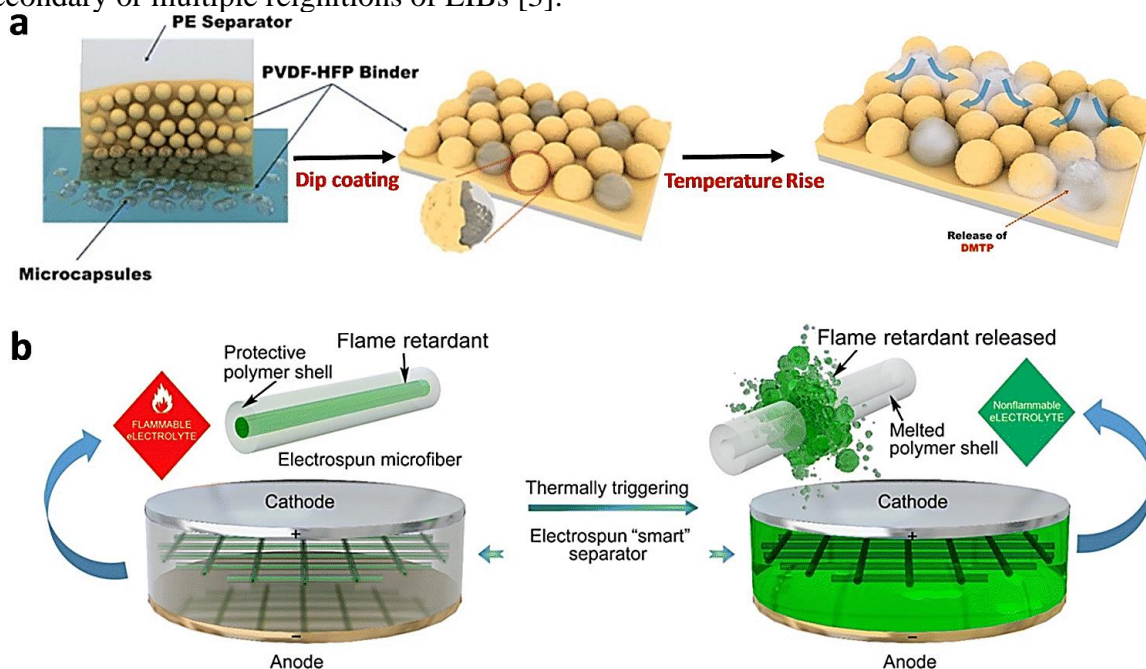


Fig. 1 BMS health diagnostics and prognostics algorithm framework [10].

### 3.4. Strengthening of shell protection

High-temperature, corrosion-resistance, and high-strength materials are utilized as raw materials for the production of battery shells. These materials enhance the protection level and improve waterproof and dustproof performance. For instance, an N-H microcapsule fire extinguishing agent is applied to the outer surface of the aluminum-plastic film of LIBs (Fig. 2). This agent can rapidly

reduce the battery temperature from 800 °C to 30 °C within 15 seconds, effectively inhibiting the risk of secondary or multiple reignitions of LIBs [3].



**Fig. 2** Building safe LIBs. (a) Schematic for the coating of microcapsules on a PE separator by the PVDF-HFP binder. (b) Structure of core-shell structure microfibers [3].

### 3.5. Strict production standards

It can establish a robust international standard for battery production, enforce string quality control measures during the manufacturing process and implement a comprehensive management and penalty system to ensure compliance with factory safety standards. Furthermore, regulations stipulate that all stationary energy storage systems, LMT batteries and electric vehicle batteries must be equipped with a battery management system that provides parameters for battery health and life expectancy. Additionally, the regulations introduce new requirements regarding hazardous substances, carbon footprint and durability.

### 3.6. Innovations in charging technology

It can design fast and safe charging technologies, such as wireless charging and adaptive charging. In the square aluminum shell batteries produced by Ningde Era, the design of the overcharge protection device (OSD) and current interruption device (CID) serves as universal anti-overcharge method. Once the voltage exceeds the specified limit, the system pauses for 5 minutes before resuming charging. If the target voltage is not met, the process is repeated. This technology can increase the charge by an additional 10 to 15 percent while avoiding side reactions and prolonging battery life.

### 3.7. Standardize recycling and safety education

It can regulate battery recycling technologies, methods, and environmental standards. For example, it can enhance the battery recycling system and encourage consumer participation, and ensure the safe, efficient, and environmentally friendly treatment and resource recovery of waste batteries to minimize environmental pollution. It can utilize media, online platforms, and other channels to promote knowledge about the safe use of battery, increase public awareness of safe practices and reduce the incidence of accidents.

## 4. Conclusion

The safety concerns associated with LIBs primarily revolve around issues such as overcharging, over-discharging, internal short circuits, thermal runaway, electrolyte leakage, and material failure. Research indicates that the resistance to overcharging can be enhanced through material modification. Incorporating various anti-overcharge and flame-retardant additives can bolster the internal protection of the battery while also improving its external waterproof and impact-resistant capabilities. Furthermore, optimizing the intelligent management system and employing innovative charging technologies can enhance the monitoring of battery voltage and temperature, thereby extending its service life. These measures have significantly improved the safety of LIBs to some extent. However, regarding the market application potential of LIBs, current advancements are insufficient. There is a pressing need to develop new materials with superior properties and to implement more effective battery management systems to achieve strategic safety. For instance, a short circuit within a battery can lead to a rise in temperature. The replacement of traditional liquid electrolytes with solid electrolytes greatly mitigates the risk of short circuits and associated incidents such as fires and explosions. Nevertheless, the performance of solid electrolytes is considerably lower than that of liquid electrolytes, making it crucial to find a balance between safety and performance—a topic likely to gain prominence in the future. It is anticipated that with the ongoing advancements in LIB technology, lithium-ion batteries will find widespread applications across various sectors, including the aviation industry.

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