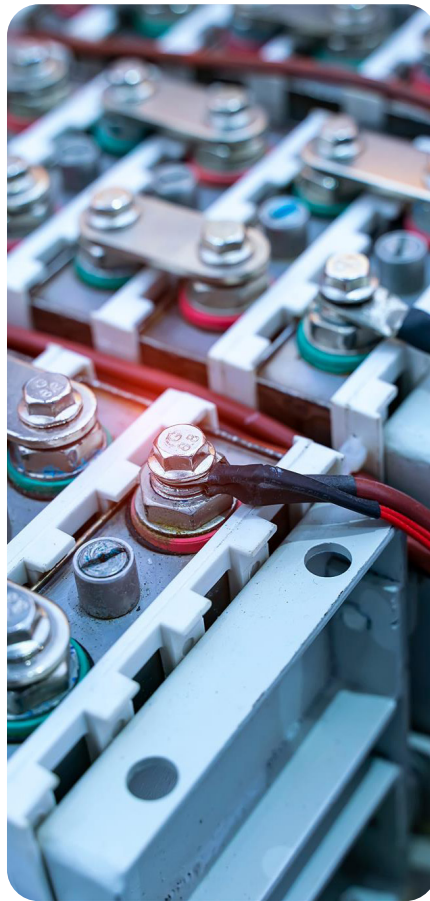

The Science of Fire and Explosion Hazards from Lithium-Ion Batteries

An introduction to lithium-ion battery construction, thermal runaway and potential hazards.



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Introduction

Lithium-ion battery-powered devices play an increasing role in every aspect of our lives – phones, laptops, toothbrushes, power tools, electric vehicles, scooters and bikes. They are even being deployed at a massive scale to improve the resilience of our national electrical grid.

Despite many advantages, a significant safety drawback is the possibility that these batteries can overheat, catch fire, and in extreme cases, cause explosions.

Fires involving various lithium-ion battery-powered products have been increasing at an alarming rate and have resulted in numerous injuries and fatalities. Even when the initial cause of a fire is not the lithium-ion device, the involvement of lithium-ion batteries can increase the intensity and magnitude.

Recently, a high-profile fire in Manhattan involving lithium-ion batteries injured almost 40 people. The fire was one of more than 500 caused by lithium-ion batteries in the United States since 2021.



E-mobility device went into thermal runaway and caused a fire (FSRI)

In 2022, a high-profile fire in New York involving lithium-ion batteries injured almost 40 people. The fire was one of more than 500 documented incidents caused by lithium-ion batteries in the United States since 2021. Although, this number is likely higher because lithium-ion battery fires are not yet captured by the national fire incident reporting system.



Lithium-ion battery post thermal runaway (FSRI)



Firefighters rescue victims trapped in fire caused by a Li-ion battery (FDNY)

These incidents drive the need to better understand the physical phenomena that determine how hazards develop during lithium-ion battery incidents and develop strategies to mitigate the associated risks.

This resource will focus on the foundational research conducted to date, including lithium-ion battery components, thermal runaway and how fire and explosion hazards can develop.



Smoke from e-mobility device, signifying the battery is in thermal runaway (FSRI)

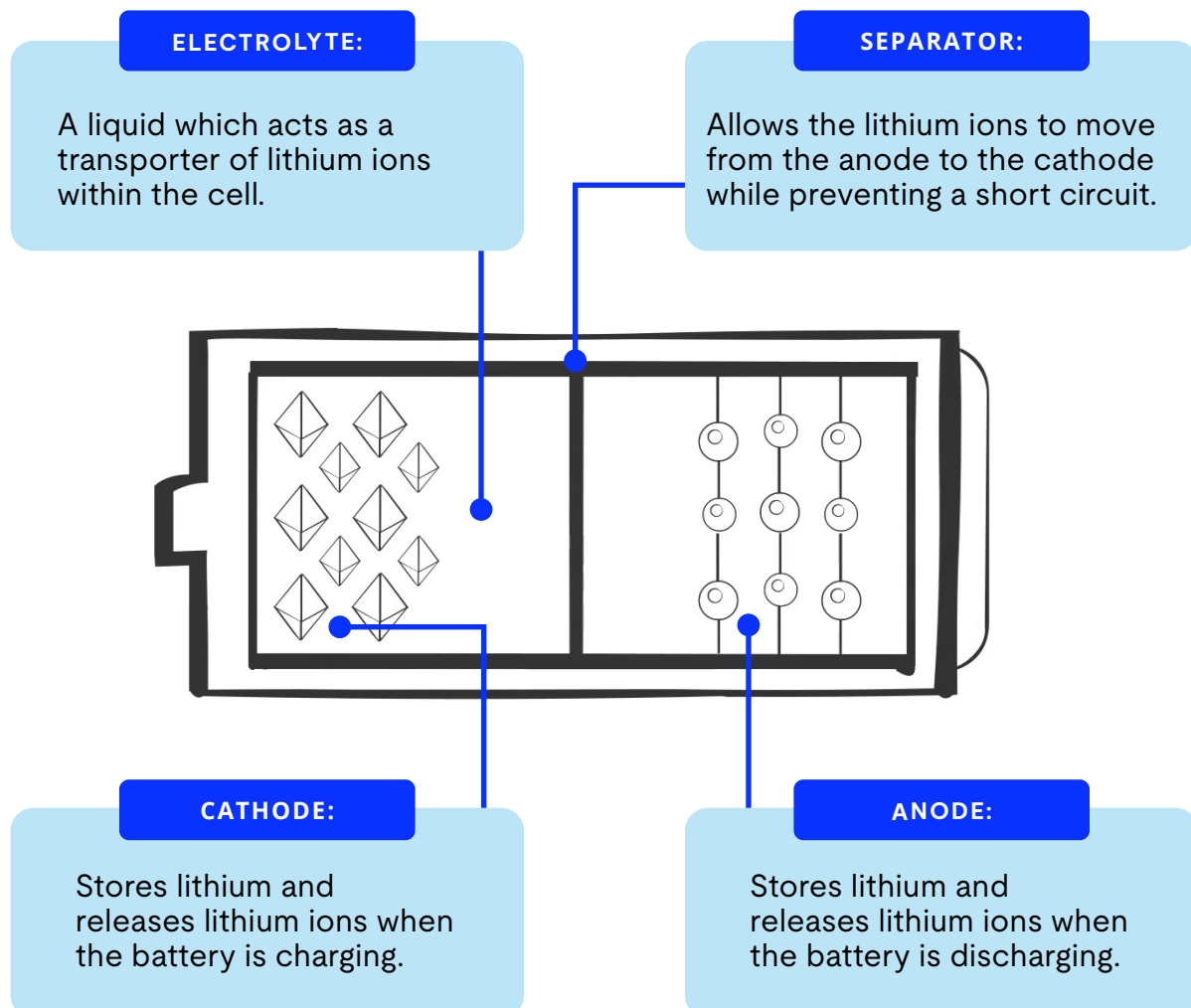
Components of a Lithium-Ion Cell

A lithium-ion cell is composed of four primary components - the anode, cathode, separator and electrolyte. The components work together in the cells to provide an electrical current to devices we use on a daily basis.

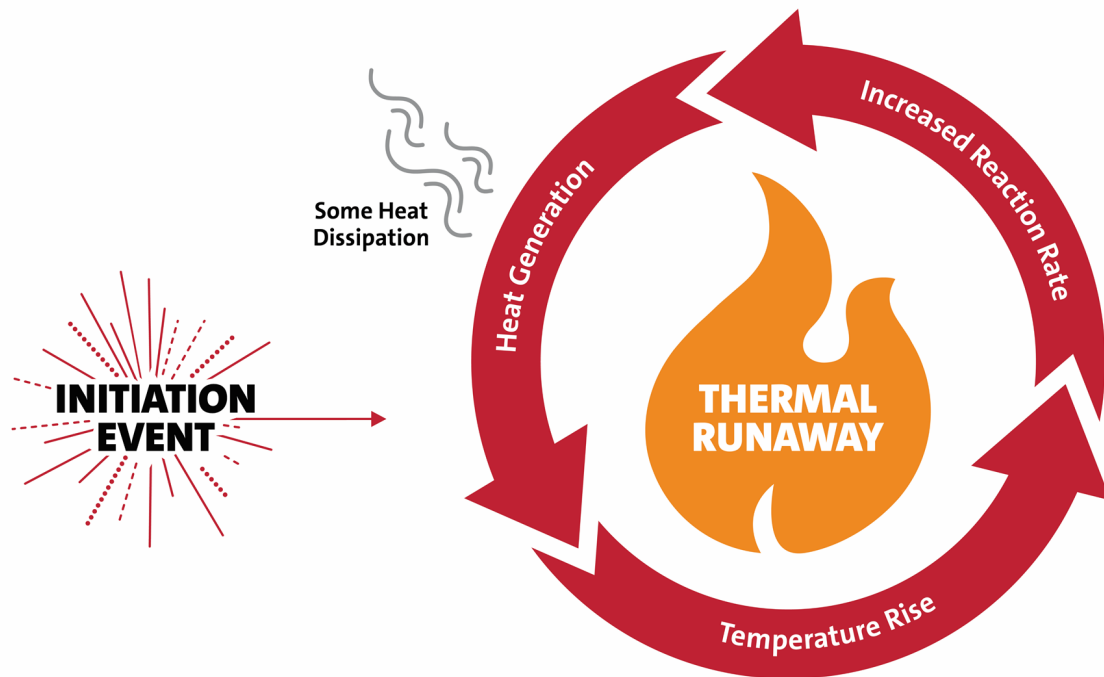
Lithium is stored in the anode and cathode. Depending on whether the battery is charging or discharging, the lithium will move from the anode to the cathode

or vice versa. The electrolyte, a liquid, transports the lithium ions through the separator creating free electrons and, thus, electrical potential.

For example during discharge, lithium ions move from the anode to the cathode and free electrons are created in the anode. These free electrons create a an electrical potential, which enables an electrical current to move through a powered device.



Thermal Runaway



Thermal runaway is a phenomenon in which a lithium-ion cell enters a state of uncontrolled self-heating. Thermal runaway often begins when the heat generated within a cell exceeds the heat dissipated to its surroundings.

If the cause of excessive heat generation is not remedied, the condition will worsen. The elevated heat causes chemical reactions that further release thermal energy. High enough temperatures can cause distortion or melting of the separator, which can cause an internal short circuit.

The rapid thermal energy generation during an internal short circuit is typically the tipping point after which thermal runaway occurs. Internal cell temperatures will continue to rise, increasing the rate of the chemical reactions and creating a feedback loop.

The rise in temperature in a single cell will transfer heat to other cells. Propagation of thermal runaway can occur when these cells are heated enough to also go into thermal runaway, and the process may continue throughout a battery pack.

Different types of abuse can destabilize the otherwise stable chemical system that makes up the lithium-ion cell. Most of these different types of abuse can stress the separator, which can cause an internal short circuit. The heating from the internal short circuit can cause exothermic chemical reactions that lead to thermal runaway.



ENVIRONMENTAL

Means of thermal runaway include excessive heat, charging in a cold environment, and chemical exposure such as exposure to salt water.



MECHANICAL

Means of thermal runaway include dropping, crushing, indenting, shocking, vibrating, impacting, or penetrating a cell such that mechanical stress causes separator failure.



ELECTRICAL OVERCHARGE

Occurs when a cell is charged above the specified voltage, which causes an exothermic reaction at the cathode, which leads to separator failure and, ultimately, thermal runaway.



ELECTRICAL OVER-DISCHARGE

Occurs when a cell's voltage falls below the discharge voltage limit governed by the cell design, which causes copper to dissolve from the anode and create paths for a short circuit.



EXTERNAL SHORT CIRCUIT

Can heat the cell through Joule or resistance heating to temperatures that initiate thermal runaway due to a high discharge current.



DESIGN AND MANUFACTURING

Issues include loose parts, electrode misalignment, burrs, tight tolerances, and contamination which can eventually cause short circuits leading to thermal runaway.



AGING

Refers to destabilization of lithium-ion cells as they are exposed to degradation mechanisms such as rapid charging, use, and storage at high and low temperature extremes.

A basic description of the thermal runaway process is as follows:

1

Excessive heat is generated in the lithium-ion cell. The protective layer covering the anode begins to break down. This is an exothermic reaction, so the temperature of the cell increases.

2

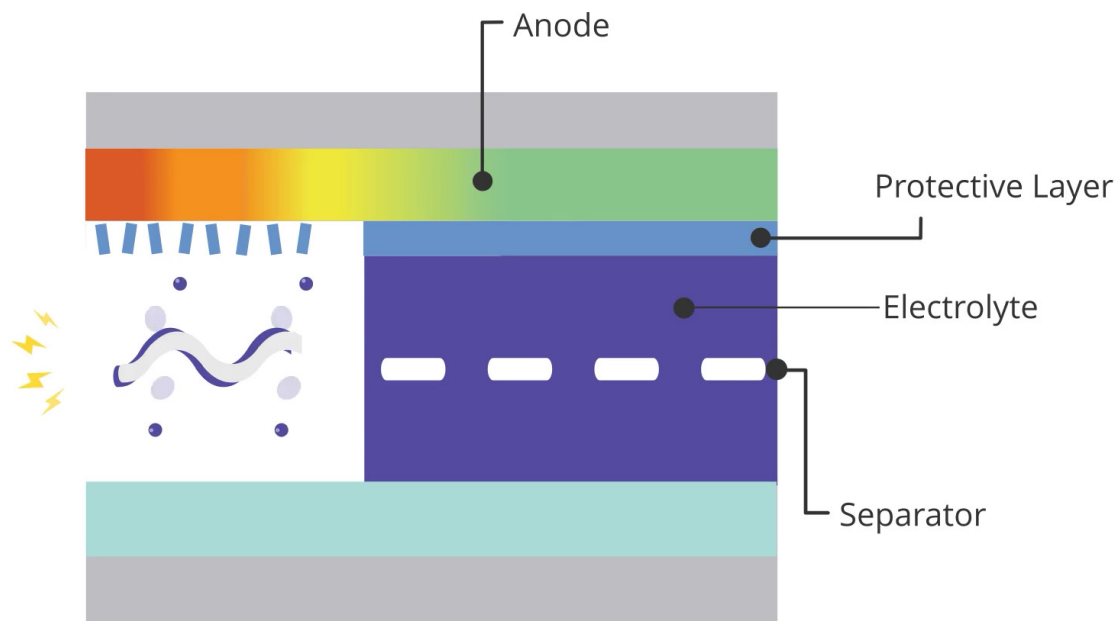
As the temperature of the cell increases, the electrolyte starts to break down, releasing additional thermal energy. Eventually, the separator begins to melt.

3

As the separator becomes compromised, an electrical short may be possible. The electrical short adds even more heat to the system.

4

Eventually, the cathode will begin to break down. This releases heat and bound oxygen, which can react with products from thermal decomposition and contribute to the combustion reaction that may occur once the cell catches on fire.



[View this animation.](#) (FSRI)



Ongoing Research

While battery research has been conducted for decades, increasing lithium-ion involved fire incident frequency has resulted in increasing focus on lithium-ion battery fire safety research. Fire Safety Research Institute, part of UL Research Institutes, is actively involved in two areas of battery-related research.



Firefighter looks on fire damage as result of an e-mobility device (FSRI)



Fire damage as a result of an e-mobility device fire (FSRI)

First, to better understand the potential consequences associated with thermal runaway in large battery packs in residential applications, FSRI is researching the [impact of battery fire involvement in residential fires on fire dynamics](#) and the development of potential explosion hazards.

Secondly, FSRI is conducting experiments to better understand the development of [hazards from e-mobility device thermal runaway](#) in living spaces and means for mitigating those hazards.

Call to Action

Understanding lithium-ion cell construction, thermal runaway and its causes, and the associated potential hazard scenarios can help you reduce the chance of lithium-ion battery-powered devices going into thermal runaway, and reduce the severity if thermal runaway occurs.

FSRI has created a detailed online training that provides a deeper understanding of the information shared in this document. [The training is available for free through our Fire Safety Academy.](#)



Lithium-ion batteries from e-mobility devices which caused a fire (FDNY)



Science of Fire and Explosion Hazards in Lithium-Ion Batteries

[Take the online training](#) (FSRI)

FSRI also recommends the [resources available from FDNY Smart](#) for immediate guidance.

Battery technologies and the safety science addressing battery hazards continue to evolve. Stay connected with FSRI to learn more as we share updates from our research and collaborative work with FDNY and other partners.

