White Paper Article

A Basic Guide To Lithium-ion Battery Risks

Why do we use Lithium-ion batteries?

Lithium-ion batteries are becoming an increasingly popular power source for a variety of different electronic products. Lithium-ion battery technology has evolved providing a very reliable battery of high specific energy (energy per unit mass), high volume energy and long life. Due to these technical advancements, commercial lithium-ion batteries are utilised in a plethora of devices such as:

- Consumer and Electronic Devices
- Medical Devices
- Industrial Equipment

More recently Lithium-Ion batteries have been adopted by electric and hybrid car manufactures due to their superior performance over Lead acid batteries. This has been a key driver for increasing electrified vehicle sales by over 60% since 2012. By 2040 an estimated 560 million electrified cars will be on the road worldwide.

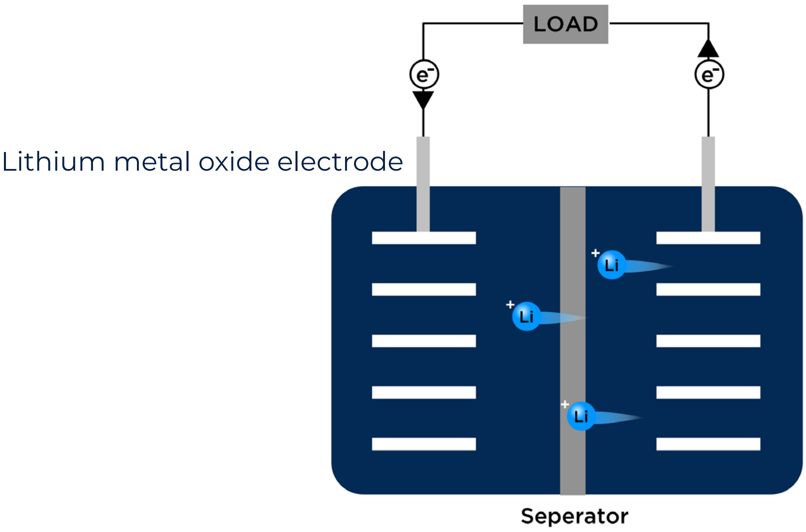
Furthermore, the global use of lithium-ion batteries for Uninterrupted Power Supplies (UPS) and supporting renewable energy is projected to increase over 50 times during the same period. To meet this demand large scale production facilities, known as Gigafactories, are being built across the globe. It is estimated 20 facilities will be required to meet Europe's demand alone.

Whilst the failure/success ratio of lithium-ion batteries is minimal, safety concerns have been raised due to well-publicised incidents of fire and explosions, most recently mobile devices are having issues with battery packs. Given the risk, early detection of defective lithium-ion batteries is imperative. PID (photoionisation detection) is well suited for this purpose, in being highly sensitive to volatile chemicals contained within a Lithium-ion battery.

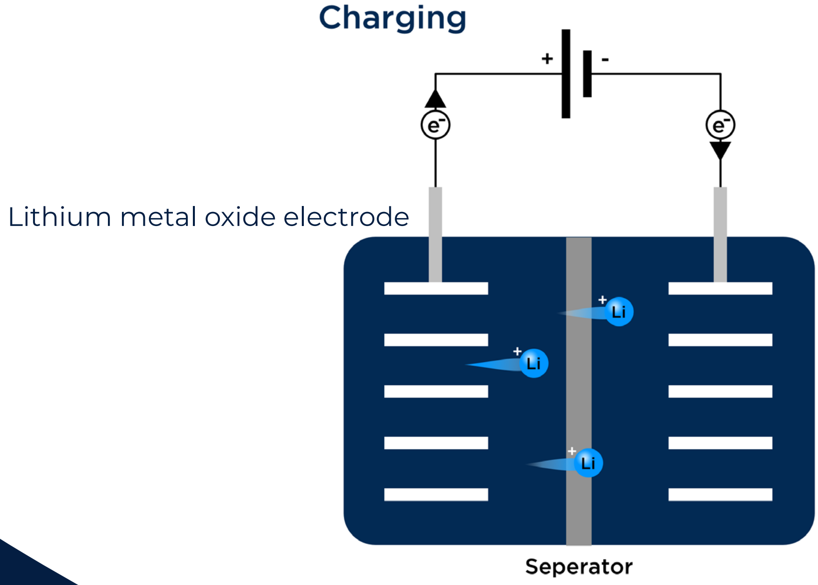
How Lithium-ion batteries work

Batteries are either made from one cell or where higher energy storage is required, multiple cells. The main components of a cell are the cathode, anode, electrolyte and a separator that isolates the two electrodes. On discharge, a lithium metal, impregnated carbon anode releases electrons which move round the electric circuit and simultaneously lithium ions, which enter the electrolyte and move toward the cathode. At the cathode, the ions, and electrons recombine to form a lithium salt (typically $LiMnO_2$ from MnO_2). On charging, the polarity of the electrodes is reversed and exactly the reverse reactions, electron and ion movements take place.

Discharging

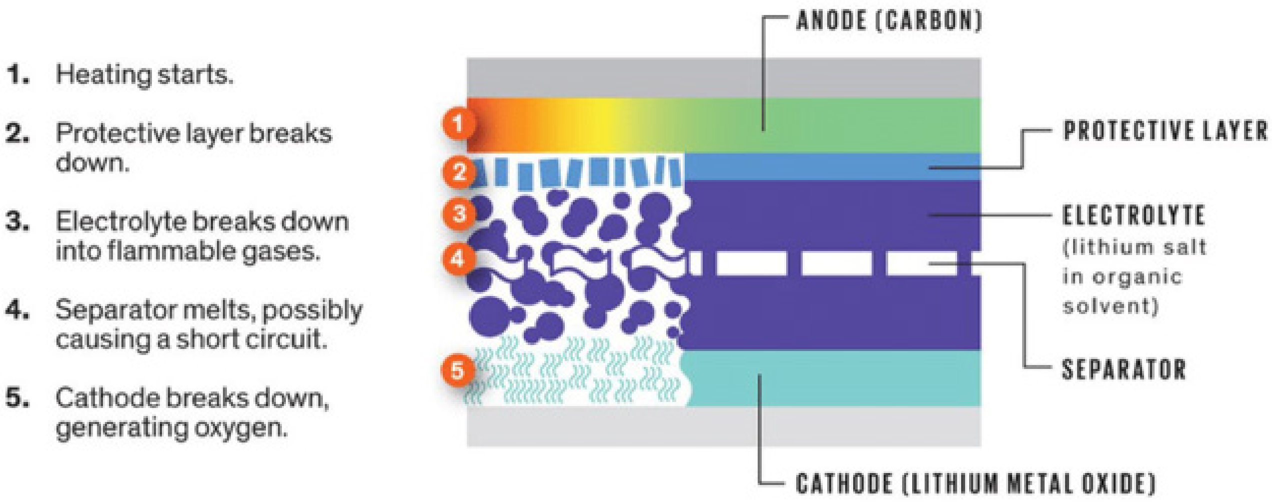


Charging



What is the safety issue with Li-ion batteries?

If a lithium-ion battery is damaged, due to some mechanical stress, short circuit, overcharging or excessive heat, a phenomenon known as thermal runaway can occur. Once a cell reaches approximately 80°C a protective layer on the surface of the anode begins to break down in an exothermic reaction (generating heat) due to the reaction of lithium with chemicals in the electrolyte. When the temperature rises to approximately 110°C the electrolyte starts to break down in another exothermic reaction that generates flammable gasses including methane, ethane, ethylene, and hydrogen. At 125°C the separator melts, allowing the anode and cathode to short circuit generating even more heat. At approximately 140°C the cathode breaks down in another exothermic reaction which generates oxygen, at this point the cell will catch fire completing thermal runaway.



Using PID to identify risks from Lithium-ion batteries

The electrolyte contains, crucially, a mixture of volatile organic compounds (VOCs) which support the ions in solution. If ruptured, the volatiles leak out. It is these volatiles which can be detected by PID. Rapid detection of these allows action to be taken before thermal runaway occurs. The PID response to a particular VOC is identified as a response factor (RF). The RFs for VOCs commonly used in Li ion battery electrolyte are presented in Table 1 (Please see on next page).

Note RF is the ratio of response to isobutylene relative to response to the target VOC so decreases with increasing PID sensitivity.

VOC	Boiling Point °C	RF	Sat. vapour pressure @ 25 °C bar	Prospective maximum response, ppm (IBE)	Measured spike response, ppm (IBE)
Dimethyl carbonate	91	65	0.07	1000	80
Ethyl methyl carbonate	107	18	0.035	2000	240
Diethyl carbonate	127	7.5	0.015	2000	390
Vinylene carbonate	162	3.5	0.0033	1000	480
Butylene carbonate 1,2-	238	18	0.0002	1	10
Propylene carbonate	242	15	0.0002	1	80
Ethylene carbonate	243	>50	0.0003	0.5	<1

Table 1: Evaluation of chemicals used in lithium ion batteries. PID responses in ppm IBE refer to parts per million of isobutylene calibration equivalent. PID specifications are almost universally refer to isobutylene as calibrant. The formulation of the batteries varies considerably but it is likely they will include one or more of the top three most volatile VOCs in the table above.

Battery electrolyte leakage

Battery electrolyte leakage will produce a volatile mix, which depends upon the liquid proportion of each volatile, its volatility and rate of volatilisation. Over time, the more volatile compounds will evaporate from a ruptured battery, leaving a less volatile, less detectable mix. Therefore, rather than using response factors, it is more meaningful to consider the prospective contribution of each volatile. This is tabulated in the penultimate column of the table. In practice, if, for example, a ruptured battery contained 25% diethyl carbonate, then this would contribute a maximum response of 25% x 1000 ppm = 250 ppm.

When using an aspirated detector, the response to the pure vapour is much lower than the prospective response as the instrument entrains the volatile in an air stream which therefore dilutes the volatile. The maximum spike responses obtained from ION Science's Tiger instrument measurement of head space vapour from 25 mL bottles of target volatiles is shown in the last column of the table. Technique is required in leak detection as removing a volatile in the instrument sample stream will cause its vapour pressure to fall.

Typical applications

- Cell and battery manufacturing
- Lithium ion battery product manufacturing lines
- UPS and battery storage monitoring
- Lithium Ion battery recycling
- Vehicle battery monitoring
- Lithium Ion battery transport

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