Lithium Battery

Guidance

Date: 03/09/23

Applies To:

This Guideline applies to users of lithium-ion (Li-ion) and lithium polymer (LiPo) cells and battery packs by anyone on the University of Michigan (U-M) Ann Arbor, Flint, and Dearborn campuses, and other University owned properties (e.g. Biological Station, Pellston, MI; Stinchfield Woods, Pinckney, MI; Camp Davis, Jackson, WY).

The U-M supports the safe use of Li-ion and LiPo batteries in the course of research and educational activities and other endeavors in the pursuit of the University's mission. This document provides guidance for the safe use and handling of these types of batteries under normal and emergency conditions on U-M properties and off U-M properties for U-M sanctioned events.

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DEFINITIONS

Anode: the negative electrode typically made with a graphite active material coated onto a metal (usually copper) foil current collector.

Aqueous Vermiculite Dispersal Extinguisher (AVD): AVD is an aqueous dispersion of chemically exfoliated vermiculite. It is applied to lithium battery fires as a mist, extinguishing them and preventing the propagation of the fire.

Battery capacity (Ah or Amp-hour): The rated Coulombic capacity of the cell. The unit is Amp hour, multiply by 1000 for milliamp hour. The rated capacity is measured at a specified discharge rate, typically 0.2C or 0.3C. The actual capacity obtained in use will depend on temperature, discharge rate, and battery state-of-health (calendar and cycle life, discharge and charge duty cycle and conditions).

Battery Management System (BMS): Battery management systems are critical to the safe operation of lithium-ion battery packs. The system protects against the following: over-charge, over-discharge, and excessive currents and temperatures. The BMS protects the pack from exceeding upper and lower voltage and temperature limits. It will also limit current as a function of temperature. Charging rates typically decrease below 0^{o}C. The BMS also estimates pack SOC and available power and communicates this to the device controller. The BMS may also be responsible for providing cell balancing.

If the device controller or human operator does not respond to the BMS request to lower power or stop operation the BMS should disconnect the pack by opening the contactor or relay to the pack or blowing an in-line fuse.

BMS systems can have multiple configurations depending on the application, i.e., central control board with sense (V, T) leads to each cell or central master board with distributed boards with electronics for monitoring multiple cells.

Battery Pack: An assembly of cells that are connected in series and/or parallel. Each battery pack contains only one type of cell. Connecting cells in parallel increase the pack capacity (ampere hour, Ah) and in series the pack voltage.

C-rating: A dimensionless way of expressing discharge and charge rates which allows the rate capabilities of different cell designs and chemistries to be compared. For example the discharge time of a 1Ah cell at different C-rates (0.1C = 10h, 0.5C = 2h, 1C = 1hr, 2C = 30min, 5C = 12min). For a 2Ah cell, the currents are doubled but the discharge times would be the same. Cells designed for high energy may have continuous discharge rates of 1C to 2C with pulse rates up to 5C. In contrast, high power cells may have continuous rates of 5-10C and pulse rates in the 50-70C range. For a given cell capacity, i.e., 5Ah, the discharge current for a given C-rate would be the capacity value times the C-rate.

Cathode: the positive electrode typically made with a metal oxide (LiMO2, where M= Ni, Mn, or Al) or a phosphor-olivine (i.e., LiFePO4) coated onto a metal (usually aluminum) foil current collector.

Cell: A single primary or secondary battery

Depth-of-Discharge Window (DOD): DOD is defined as 1-SOC. A cell can be discharged 100%, but practically the maximum SOC may be reduced to 95% to 90% and the min SOC may be limited to 5% to 10% to increase cycle life of battery packs (xPyS). The DOD window may be 80- 90%. **Electrolyte:** lithium salt (i.e., typically LiPF6) in a mixture of flammable organic carbonate solvents.

Lithium-Ion cell: A lithium-ion cell is a type of rechargeable battery in which lithium-ions move from the negative electrode to the positive electrode during discharge and back when charging.

Lithium-ion Polymer cells: Same chemistry as lithium-ion cells but the electrolyte is composed of a gel with a polymer host that reduces flammability and prevents leakage of liquid electrolyte from a damaged cell.

Open-Circuit Voltage (OCV): The OCV of a cell is present when the current flow is zero and the internal cell state is at equilibrium. For $LiMO_2$ cathode based cell chemistries, the OCV can be correlated with the cell state-of-charge, SOC (100 x Available Capacity/Total Capacity). The cathode chemistry is the primary factor influencing the shape of the curve, voltage range, and temperature dependence. Iron phosphate cathode materials have a "flat" OCV curve versus SOC similar to nickel-cadmium and nickel metal hydride cell types. The nominal voltage for $LiMO_2$ cathode cells is typically, 3.6-3.7V. This voltage corresponds to a SOC of 50%. The nominal voltage times the cell capacity generally is a good estimate of the cell energy. The OCV for these cells will generally range from 3V (0% SOC) to 4.2V (100% SOC). Cobalt oxide based cells may have maximum voltages up to 4.35V.

Primary (non-rechargeable) lithium metal cells: These cells are not rechargeable. These cells have lithium metal anodes paired with a variety of cathode materials (i.e., MnO_2, CF_x, FeS_2, and $SOCl_2$) and corresponding nominal voltages (1.5V to 3.5V). Depending on the chemistry and application, cells may be available in button and cylindrical form factors.

Pouch cell: The case of the battery is a polymer-aluminum laminate, similar to the material used for potato-chip bags, allowing for light and slender designs.

Secondary (rechargeable) lithium (lithium-ion) cells: These cells are rechargeable. Depending on the quality, design, and operating window these cells typically can be cycled from hundreds to thousands of cycles. The long cycle life is possible because the lithium is not present in metallic form. Lithium is intercalated into the electrode active materials (i.e., graphite – $Li_{1-x}C_6$ and lithium metal oxide – $Li_{1-x}MO_2$) and moves from the anode to the cathode during discharge and from the cathode to the anode when charging in ionic form. Lithium-ion cells are generally available in cylindrical, prismatic, and pouch form factors.

Voltage (V): During discharge or charge "resistances" within the cell lower or raise the OCV.

$$V_{cell} = OCV + I \times DCR \text{ where DCR= DC resistance of the cell, I(+ or -)}$$

During discharge or charge, the resistive losses and the chemical energy (endothermic or exothermic) of the cell will determine the temperature rise or fall in the cell. On discharge, the minimum voltage may be set to 2.75V – 3V. If a cell is severely over-discharged, $V < 2.5V$, the copper substrate of the anode may be dissolved. On charging, the copper in solution may plate out at the cathode forming a bridge or short back to the anode. If the cell is severely over-discharged (duration or number of times) the resulting short can cause the cell to go into thermal runaway. The charge voltage should not exceed the maximum rated voltage, typically 4.2V, otherwise overcharging the cell will damage the cell and possibly force the cell into thermal runaway.

Watt-hour (Wh): A measure of energy. The cell will have a rated energy. The actual energy obtained from the cell will depend on the rate of discharge and the temperature of the cell. As rate increases and cell temperature is lowered the amount of energy obtained will decrease.

RESPONSIBILITY

Principal Investigator (PI) /Student/University Staff

- Implementation of all applicable provisions of this Guideline.
- Obtain and review the battery manufacturer's Safety Data Sheet (SDS), Technical Specification sheet(s) and/or other documents available.
- Perform hazard analysis to understand the various failure modes and hazards associated with the proposed configuration and type(s) and number of batteries used.
- Ensure that written standard operating procedures (SOPs) for Li-ion and LiPo powered research devices are developed and include methods to safely mitigate possible battery failures that can occur during assembly, deployment, data acquisition, transportation, storage, and disassembly/disposal.
- Ensure that at the conclusion of testing the battery assemblies are disposed of properly or left in a safe condition for storage.
- Contact EHS Hazardous Materials Management (HMM) - (734) 763-4568 for shipment of lithium batteries.

U-M Environment, Health, & Safety (EHS)

- Maintain this Guidance.
- Assist in training and communicating safety requirements to university personnel.
- Assist in development and review of SOPs
- Provide waste management (removal of hazardous waste).
- Assist with shipments of lithium batteries.
- Assist in the investigation of incidents involving Li-ion/LiPo batteries.
- Provide incident response.

HANDLING AND USE

When handled correctly, the risk of fire from primary and secondary cells is minimal. Most incidents involving these types of batteries occur from inadvertent mishandling. Examples include: over-charging or discharging, unbalanced cells, excessive current discharge, short circuits, physical damage, excessively hot storage and, for multiple cells in a pack, poor electrical connections.

Best practices for lithium-ion cell/battery use

- Always purchase batteries from a reputable manufacturer or supplier.
- Be sure to read all documentation supplied with your battery.
- Never burn, overheat, disassemble, short-circuit, solder, puncture, crush or otherwise mutilate battery packs or cells.
- Do not put batteries in contact with conductive materials, water, seawater, strong oxidizers or strong acids.
- Avoid excessively hot and humid conditions, especially when batteries are fully charged. Do not place batteries in direct sunlight, on hot surfaces, or in hot locations.

- Always inspect batteries for any signs of damage before use. Never use and promptly dispose of damaged or swollen batteries. Contact EHS HMM - (734) 763-4568 for battery disposal.
- Li-ion batteries assembled to offer higher voltages (over 60 V) may present electrical shock and arc hazards. Therefore, adherence to applicable electrical protection standards (terminal protection, shielding, PPE etc.) is required to avoid exposure to electrical hazards.
- Do not reverse the polarity.
- Do not mix different types of batteries (including new and old) together (e.g. in a power pack).
- Do not open the battery system or modules unless you have appropriate training and permission.
- Do not use the unit without its electronic management system.
- Immediately disconnect the batteries if, during operation or charging, they emit an unusual smell, develop heat, change shape/geometry, or behave abnormally.

Battery charging/discharging

The majority of rechargeable Li-ion/LiPo batteries used for research activities require a conscious effort of supervision during charging and discharging activities. Over-charging can lead to runaway thermal reactions due to the high energy densities and flammable organic electrolytes contained within a given Li-ion/LiPo battery. Li-ion/LiPo battery users should incorporate the following recommendations when charging/discharging these types of batteries:

- Use chargers or charging methods designed for safe charging of cells or battery packs at the specified parameters.
- Never leave a battery pack unobserved during charging. Always stay in or around the charging location so that you can periodically check for any signs of battery or charger distress.
- Disconnect batteries immediately if, during operation or charging, they emit an unusual smell, develop heat, change shape/geometry, or behave abnormally.
- For series packs (2S and above), always balance charge with a charger capable of monitoring the condition of individual cells to prevent individual cells being overcharged.
- The charger and the battery should be located on a heat-resistant, non-flammable, and non-conductive surface.
- It is best practice to charge and store batteries in a fire-retardant container like a high quality Lipo Sack.
- Keep all flammable materials away from the charging area.
- Do not overcharge (greater than 4.2V for most batteries) or over-discharge (below 3V) batteries.
- Make sure that batteries do not exceed manufacturers' recommended operating temperatures during charging or discharging. Use caution if charging a battery that is still warm from usage, or using a battery that is still warm from charging.
- Never parallel charge since chargers cannot monitor the current of individual cells.
- Do not leave batteries connected to chargers after charging is complete.

Transporting

Lithium Batteries or equipment containing lithium batteries are considered "dangerous goods" because they can pose significant safety risks in transportation. Do not ship lithium batteries or equipment containing lithium batteries without appropriate training. EHS can assist with these shipments. Please contact U-M EHS for assistance with shipping of Li-ion batteries or equipment containing Li-ion batteries.

Shippers shall ensure batteries are properly packed, prepared, and communicated to the air carrier to ensure shipments arrive safely. When shipping a Li-ion battery, specific regulations must be followed. Domestic transportation is regulated by the U.S. Department of Transportation (DOT). Internationally, air transportation is regulated by the International Air Transport Association (IATA). Maritime transport is controlled by International Maritime Organization (IMO) whose regulations are contained in the International Maritime Dangerous Goods (IMDG) Code.

- **WARNING: Failure to comply with regulations for shipping hazardous materials can result in significant civil penalties for the shipper of up to $100,000.00 per violation.**

A major risk of shipping lithium batteries is short-circuit of a battery or inadvertent activation while in transport. All batteries should be packed to eliminate the possibility of a short-circuit or activation. Please contact U-M EHS for assistance with shipping of Li-ion batteries or equipment containing Li-ion batteries.

To help prepare shipments:

- Ensure batteries cannot come into contact with other batteries, conductive surfaces or metal objects while in transport.
- Pack cells and batteries in fully enclosed inner packaging made of nonconductive material (e.g., plastic bags)
- Ensure exposed terminals or connectors are protected with non-conductive caps or tape or by other similar means.
- Secure batteries by packing them to prevent shifting during transport or loosening of terminal caps.
- Do not use envelopes or other soft-sided packs.

Transporting lithium ion batteries for teaching or research projects between buildings or on campus property are not subject to official shipping regulations.
The following guidance should be followed for transporting:

- Do not transport batteries in a metal box.
- Do not carry in your pocket. Coins, keys or other metallic objects can cause batteries to short circuit.
- Keep away from heat, transport in a container or padded bag to prevent shock if dropped or impacted.
- Do not transport a fully charged battery. The recommended State of Charge (SoC) is 30% or less. Note: this does not refer to your smart devices, computers or lithium ion batteries contained in equipment with an approved battery management system.
- Tape terminals to prevent contact being exposed to short circuiting.

- If contained in equipment, make sure the power is isolated from electronic device, or disconnect the battery.

Battery storage

Proper lithium battery storage is critical for both battery performance as well as for battery safety. Below are recommendations for proper Li-ion/LiPo battery storage:

- Store the battery at temperatures between 5°C and 20°C (41°F and 68°F).
- Li-ion/LiPo batteries should never be stored fully charged. When not in use, store the Li-ion/LiPo battery pack at 60-70% of the pack's rated capacity.
- Remove the battery from a device before storing it.
- It best practice to use a Li-ion/LiPo battery fireproof safety bag or other fireproof container when storing batteries.
- Cell terminals must be protected by non-conductive electrical tape. The approved tape would be electrical tape, packaging tape, or duct tape.
- Storing batteries in a refrigerator may create internal condensation when the battery is brought to room temperature. This condensation could present a hazard when the battery is put into operation.
- It is best to have a reserved area ONLY for Li-ion/LiPo battery storage. It must be a cool and dry place, away from heat sources.
- The ideal surface for storing lithium-ion batteries is concrete, metal, or ceramic or any non-flammable material.
- It is recommended that a smoke detector be located in the battery storage area.
- It is recommended that a class ABC or CO_2 fire extinguisher be located near the storage area. The use of an AVD extinguisher would be the best option if located in the area.

Battery disposal

U-M EHS provides services and oversight to ensure compliance with the regulations pertaining to Li-ion/LiPo battery collection, packaging, and manifesting. The EHS Hazardous Materials Management (HMM) program collects and disposes of Li-ion/LiPo batteries used in laboratories, maintenance areas, construction sites, housing units, and healthcare clinics across campus.

Prior to placing batteries in plastic bucket for disposal, taping of terminals or positive and negative posts will aid in the prevention of any residual energy from the battery from discharging. The use of non-conductive tape like electrical tape, packing tape, or duct tape would be acceptable.

Contact EHS HMM at 647-4568 for proper Li-ion/LiPo battery disposal guidance.

EMERGENCY PROCEDURES

Li-ion/LiPo batteries can pose serious health and fire risks due to their high energy density and flammable electrolyte composition. Batteries that are damaged, over-charged/undercharged, or incorrectly handled can experience thermal runaway leading to venting, leaking, fire, or explosion of the battery pack. Li-ion/LiPo battery users must be aware of these potential hazards along with the correct steps for mitigating any emergency associated with a battery failure.

All unplanned fires and emergencies must be reported to U-M DPSS by dialing 9-1-1 as soon as possible.

Overheating, venting, or leaking battery

When the internal pressure and temperature of a Li-ion/LiPo battery increase faster than the rate at which they dissipate, cell overheating can occur. If the cell does not return to normal operating temperature, venting and/or leaking may occur. The following steps must be followed if a Li-ion/LiPo battery overheats, vents, or leaks:

- If cells are hot, disconnect the charger and remove any external short circuit if present.
- If a cell is venting or smoking, evacuate all personnel from the area. The area should be secured to ensure that no unnecessary persons enter.
- Venting or smoking batteries should be placed in steel self-closing can.
- If leaking material is present, do not touch it. Contact EHS Hazardous Material Management..
- Do not approach the cell until it reaches room temperature. The cell temperature can be checked using a remote device (i.e. infrared thermometer).
- If a remote device is not available, do not handle the cell for a period of at least 24 hours.
- As soon as the cell reaches room temperature, contact EHS HMM at 647- 4568 to have the damaged battery removed from the working area as hazardous waste.

Battery cell explosion

If excessive internal pressure causes the battery to explode, a research area could fill up with dense smoke. This smoke could cause irritation to the respiratory system, eyes, and skin. The following steps must be followed if a Li-ion/LiPo battery explodes:

- The research area must be evacuated, and the area should be secured to ensure that no unnecessary persons enter.
- Activate the nearest fire alarm pull station.
- **Call U-M DPSS at 9-1-1 as soon as possible.**
- Contact EHS HMM at 647-4568 for proper hazardous waste disposal guidance.

Battery fire

In case of any emergency: U-M Police Department (UMPD) Emergency 9-1-1

In the event that a Li-ion/LiPo battery experiences a thermal runaway, flammable vapors may be released which could lead to a fire. **Those trained to operate a fire extinguisher may do so if it can be done safely.** Proper fire extinguishers for a Li-ion/LiPo battery fire include ABC (dry powder), foam (noncombustible), or AVD extinguisher where available. Smothering the fire with sand or sodium bicarbonate is also an alternative. After the fire has been extinguished, water should be used to prevent re-ignition. The following steps must be followed during a Li-ion/LiPo battery fire:

- All researchers in the area must be evacuated.
- Activate the nearest fire alarm pull station.
- Only attempt to extinguish the fire if it can be done safely.
- Use the proper fire extinguisher - ABC (dry powder), foam (noncombustible), or AVD extinguisher where available.
- When using the fire extinguisher, locate yourself between the exit and the fire.
- Toxic fumes can be emitted during a Li-ion/LiPo fire. Exit the area immediately if heavy smoke is noted.
- If the fire is successfully extinguished, pour water over the battery to cool it off and prevent re-ignition if this can be done so safely.
- Report ALL unplanned fires regardless of size to UMPD Emergency at 9-1-1.

Incident reporting

It is vital that you report all incidents and near-misses in the laboratory involving Li-ion/LiPo batteries. A "Near-Miss" is an unplanned event, condition, or behavior that did not result in injury but had the potential to do so.

All work-related illnesses and injuries in all departments at U-M must be reported to WorkConnections immediately (within 24 hours). The WorkConnections website is a great resource for all issues related to illness and injury.

The following information can help instruct you where and how to report an incident. If in doubt about whether or not to report an incident, it is better to err on the side of caution and report the event. There are no repercussions for reporting incidents or near misses.

- Injuries or illnesses: Work Connections Illness or Injury Report Form
- Near misses, fires/explosions, property damage, injuries, or illnesses Incidents relating to research: EHS Incident and Near Miss Report Form