LITHIUM BATTERY SAFETY

There are two types of lithium batteries used in the U.S.: Non-rechargeable lithium metal batteries and rechargeable lithium-ion batteries.

Rechargeable lithium-ion batteries are used in many products such as laptops, toys, power tools, appliances, mobility devices (e.g., e-bikes, e-scooters) and electric vehicles.

Lithium-ion batteries store a lot of energy in a small amount of space. When that energy is released in an uncontrolled manner, it generates heat, which can cause flammable and toxic gases to be released.

Follow the guidance below to help prevent fire, injury, and loss of intellectual and other property when procuring, storing, charging, handling, and disposing lithium-ion batteries.

BEST PRACTICES

PROCUREMENT

- Purchase batteries from a reputable manufacturer or supplier.
- Avoid batteries shipped without protective packaging (i.e., hard plastic or equal).
- Inspect batteries upon receipt and safely dispose of damaged batteries.

STORAGE

- Store batteries away from combustible materials.
- Remove batteries from the device for long-term storage.
- Store the batteries at temperatures between 5°C and 20°C (41°F and 68°F).
- Separate fresh and depleted cells (or keep a log).
- Store batteries in a metal storage cabinet, if practical.
- Avoid bulk storage in non-laboratory areas such as offices.
- Visually inspect battery storage areas at least weekly.
- Charge batteries in storage to approximately 50% of capacity at least once every six months.

CHARGERS AND CHARGING

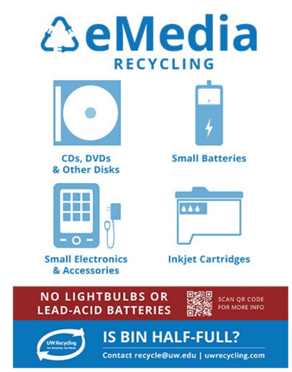
- Never attempt to charge a disposable lithium or alkaline battery.
- Store one-time use batteries separately from rechargeable batteries.
- Charge or discharge the battery to approximately 50% of capacity before long-term storage.
- Use chargers or charging methods designed to charge in a safe manner cells or battery packs at the specified parameters.

- Disconnect batteries immediately if, during operation or charging, they emit an unusual smell, develop heat, change shape/geometry, or behave abnormally. Dispose of the batteries.
- Remove cells and pack from chargers promptly after charging is complete. Do not use the charger as a storage location.
- Charge and store batteries in a fire-retardant container like a high quality LiPo Sack when practical.
- Do not parallel charge batteries of varying age and charge status; chargers cannot monitor the current of individual cells and initial voltage balancing can lead to high amperage, battery damage, and heat generation.
- Check voltage before parallel charging; all batteries should be within 0.5 Volts of each other.
- Do not overcharge (greater than 4.2V for most batteries) or over-discharge (below 3V) batteries.

HANDLING AND USE

- Handle batteries and or battery-powered devices cautiously to not damage the battery casing or connections.
- Keep batteries from contacting conductive materials, water, seawater, strong oxidizers and strong acids.
- Do not place batteries in direct sunlight, on hot surfaces or in hot locations.
- Inspect batteries for signs of damage before use. Never use and promptly dispose of damaged or puffy batteries.
- Keep all flammable materials away from operating area.
- Allow time for cooling before charging a battery that is still warm from usage and using a battery that is still warm from charging.
- Consider cell casing construction (soft with vents) and protective shielding for battery research and experimental or evolving application and use.

DISPOSAL



- Dispose of damaged cells and cells that no longer hold a substantial charge.
- To check the general condition of your cells, charge them, let them rest for an hour, then measure the voltage. If your cells are close to 4.2V, the cells are in good condition.
- Dispose of used batteries by taking them to an eMedia Recycling bin (if less than five pounds) or by requesting a Waste Collection.

EMERGENCIES

IN CASE OF FIRE

1. **Call 9-1-1.**
2. Use a **Class BC** or **Class ABC** fire extinguisher if you are comfortable using one.
    - Do *not* use a Class D fire extinguisher**.**
3. Notify a supervisor and contact EH&S immediately.
    - During EH&S business hours (8:00 a.m. to 5:00 p.m., Monday to Friday) call **(206) 543-7262**.
    - Outside of EH&S business hours, call UW Police at **(206) 685-8973** to reach EH&S on-call staff.

IN CASE OF BATTERY MALFUNCTION

If there is evidence of a **battery malfunction** (e.g., swelling, heating, or unusual odors). be very cautious because it can expel gases that may be flammable and toxic.

If you get close to or touch the battery, use **personal protective equipment,** such as heat-resistant gloves, goggles or safety glasses, and a lab coat.

1. Disconnect the battery (if possible).
2. Remove the battery from the equipment/device (if possible).
3. Place the battery in a metal or other container away from combustibles (if possible).
4. Notify a supervisor and contact UW Environmental Health & Safety (EH&S) to ask for advice on how to proceed.
    - During EH&S business hours (8:00 a.m. to 5:00 p.m., Monday to Friday) call **(206) 543-7262**.
    - Outside of EH&S business hours, call UW Police at **(206) 685-8973** to reach EH&S on-call staff.

BACKGROUND

Lithium batteries have become the industry standard for rechargeable storage devices. They are common to University operations and used in many research applications.

Lithium batteries have higher energy densities than legacy batteries (up to 100 times higher). They are grouped into two general categories: primary and secondary batteries.

- **Primary** (non-rechargeable) lithium batteries are comprised of single-use cells containing metallic lithium anodes. Non-rechargeable batteries are referred to throughout the industry as “Lithium” batteries.
- **Secondary** (rechargeable) lithium batteries are comprised of rechargeable cells containing an intercalated lithium compound for the anode and cathode. Rechargeable lithium batteries are commonly referred to as “Lithium-ion” batteries.

Single lithium-ion batteries (also referred to as cells) have an operating voltage (V) that ranges from 3.6–4.2V. Lithium ions move from the anode to the cathode during discharge. The ions reverse direction during charging. The lithiated metal oxide or phosphate coating on the cathode defines the “chemistry” of the battery.

Lithium-ion batteries have electrolytes that are typically a mixture of organic carbonates such as ethylene carbonate or diethyl carbonate. The flammability characteristics (flashpoint) of common carbonates used in lithium-ion batteries vary from 18 to 145 degrees C.

There are four basic cell designs; button/coin cells, polymer/pouch cells, cylindrical cells, and prismatic cells. (see Figure 1).

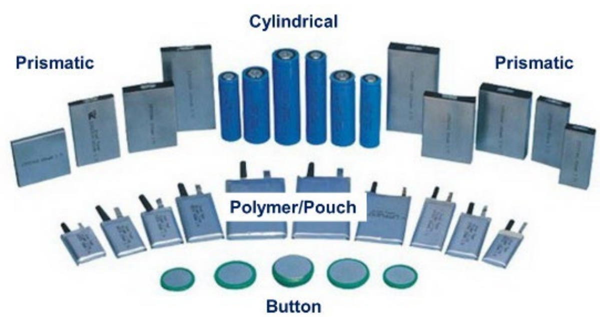


Figure 1. Typical Cell Designs

The most common designs prevalent in academic and research use include polymer/pouch cells typically used in iPods, tablets and cell phones. Cylindrical cells incorporate the similar design parameters that have been the standard for alkaline cells for years (A, AA, AAA, C, and D cells). Prismatic cells are thin, square cells with hard steel cases. Prismatic cells are typically used in cell phones and thin, laptop computers.

Other than cell phones and tablets, most portable electronic/electrical devices operate above the normal operating voltage of single lithium-ion batteries (3.6–4.2V). For such devices, numerous cells connected in packs provide the desired voltage and capacity. Connecting cells in parallel increases pack amperage and discharge capacity while connecting cells in series increases pack voltage. As an example, a 24V lithium-ion battery pack typically has six cells connected in series.

Many battery packs have built-in circuitry used to monitor and control the charging and discharging characteristics of the pack. As an example, circuitry will automatically manage the charging when the pack cells reach 4.2V and/or if the temperature exceeds a preset value. The circuits will shut down the pack if the cells discharge below a preset value (e.g., 3.3V per cell).

The cylindrical cell (identified by “18650”) is similar in size and shape to an AA battery. It is the “workhorse” of the lithium-ion battery industry and is used in a majority of commercially available battery packs. Examples are shown in Figure 2.

Figure 2. Battery and Battery Pack Examples

LITHIUM BATTERY SYSTEM DESIGN

Lithium battery system design is a highly interdisciplinary topic that requires qualified designers. Best practices outlined in IEEE, Navy, NASA, and Department of Defense publications should be followed. Battery selection, protection, life, charging design, electric control systems, energy balance of the system, and warning labels are examples of topics that require thoughtful consideration. Systems designed for mobile applications should apply best practices to ensure appropriate safeguards are in place. Designs should include a hazard assessment that identifies health, physical and environmental hazards, with all hazards appropriately mitigated through engineering and administrative controls. Examples of baseline criteria for system design include:

- Failure scenarios, including thermal runaway should be considered during design and testing so that a failure is not catastrophic.
- Maintain cells at manufacturers' recommended operating temperatures during charging or discharging.
- Size/specify battery packs and chargers to limit the charge rate and discharge current of the battery during use to 50% of the rated value (or less).
- Practice electrical safety procedures for high capacity battery packs (50V or greater) that present electrical shock and arc hazards. Use personal protective equipment (PPE) and insulate or protect exposed conductors and terminals.

LITHIUM-ION BATTERY HAZARDS

Lithium-ion battery fire hazards are associated with the high energy densities coupled with the flammable organic electrolyte. This creates new challenges for use, storage, and handling. Studies have shown that physical damage, electrical abuse such as short circuits and overcharging, and exposures to elevated temperature can cause a thermal runaway. This refers to rapid self-heating from an exothermic chemical reaction that can result in a chain reaction thermal runaway of adjacent cells.

Manufacturer's defects such as imperfections and/or contaminants in the manufacturing process can also lead to thermal runaway. The reaction vaporizes the organic electrolyte and pressurizes the cell casing. If (or when) the case fails, the flammable and toxic gases within the cell are released. The severity of a runaway battery reaction relates to the buildup and release of pressure from inside of the cell. Cells with a means of releasing this pressure (i.e., pressure relief vents or soft cases) typically produce less severe reactions than cells that serve to contain the pressure and rupture due to high pressure (i.e., unvented cylindrical cells). As a result, the cell construction can be a major variable pertaining to the severity of a battery incident.

The resulting reaction can look anywhere from a rapid venting of thick smoke (i.e., smoke bomb/smoker), to a road flare, to a steady burn, to a fireball to an explosion (Figure 3).

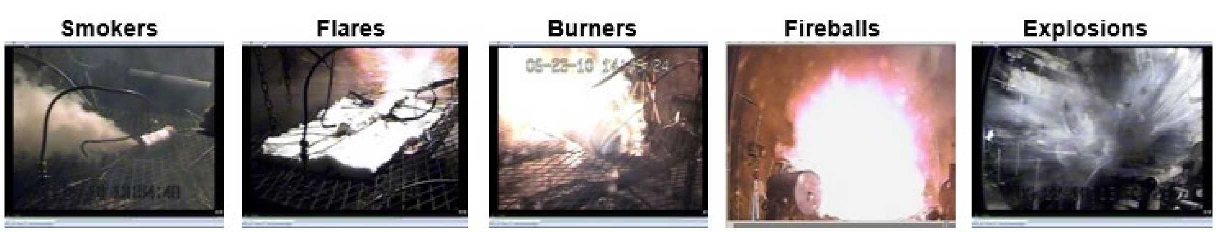


Figure 3. General Battery Reactions

The severity of the reaction is generally a function of a number of parameters including battery size, chemistry, construction and the battery state of charge (SOC). In almost every significant battery reaction, the same hazardous components are produced, flammable by-products (e.g., aerosols, vapors and liquids), toxic gases and flying debris (some burning), and in most instances, sustained burning of the electrolyte and casing material.

During a venting reaction (i.e., no ignition of the vented products), the products consist primarily of electrolyte constituents. For most batteries, the products typically consist of carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2) and hydrocarbons (C_xH_x). These gases are flammable and present fire and explosion risk.

For the burning scenario, the electrolyte burns efficiently producing primarily carbon dioxide (CO_2) and water (H_2O) as the by-products. For most batteries, the products typically consist of CO_2 and water vapor. The burning reaction also tends to liberate the fluorine from the lithium salt (typically $LiPF_6$) dissolved in the electrolyte. The fluorine typically reacts with hydrogen to form hydrogen fluoride (HF). HF production is also proportional to the electrical energy stored in the cell/battery and can result in dangerous concentrations. HF reacts with the water vapor produced during the reaction and/or with the mucus membranes in the human body (i.e., eyes, nose, throat, lungs) and becomes hydrofluoric acid.

ADDITIONAL INFORMATION

Visit the Environmental Health & Safety website for more information on battery disposal/recycling and shipping regulations and procedures.

References

- Battery University
- U.S. Consumer Product Safety Commission – Battery Safety Alerts
- U.S. Consumer Product Safety Commission - Recall List
- IEEE Standard 1679-2010 “IEEE Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications”
- U.S. Naval Academy Lithium Battery Safety Program
- U.S. Navy High-Energy Storage Systems Safety Manual (SG270)
- National Fire Protection Association Lithium Ion Hazard and Use Assessment

Training

NASA: Short course on Lithium-ion battery

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Contact UW Environmental Health & Safety at 206.616.5530 with questions.