Safe Practice for Lead Acid and Lithium Batteries

Document Prepared By: Spring 2016 Course Staff
ECE 445: Senior Design Project Laboratory
Last Revised: April 13, 2016

I. Introduction

Hello senior designers! If you are reading this document, you are probably planning on designing a project using some form of battery! Batteries are a great way to store energy for later use in portable devices or backup systems. One often overlooked problem with batteries is that they are dangerous. Additionally, different batteries are dangerous for different reasons. In this document, we will challenge students to justify why they need a battery, introduce dangers inherent to all batteries, explain the dangers that are unique to two common types of batteries (lead-acid batteries and lithium batteries), present some suggestions for charging batteries, and end with a discussion of the ECE 445 procedures for minimizing the risks of projects involving batteries.

II. Do You Need a Battery?

Due to the danger, the course staff would like to stress that students should ***avoid batteries if at all possible and use the very nice voltage supplies that are provided at every single lab bench***.

III. Dangers Inherent to all Batteries

To prevent runaway current, your batteries must always be stored in a secure location with the terminals covered by insulating material to ensure that there is absolutely no way that a short circuit can present itself. Both of these battery chemistries are capable of delivering unbelievably high currents (>5000A) and will overheat and possibly ignite (lead acid via ignition of evaporating hydrogen and lithium via decomposing cathode and eventual exposure to oxygen) if they become too hot. Additionally, proper ventilation should be allowed such that any gas can dissipate itself. If your circuit requires a battery, you must be able to demonstrate that your circuit will not have any conditions where a failure results in a short circuit.

IV. Unique Dangers of Lead Acid, SLA, Gel Mat, etc. Batteries

Lead acid batteries are the same types of batteries in your car. They are very high capacity and capable of outputting tremendous amounts of current at a reasonably low voltage. As the name implies, they are full of lead (bad) and acid (also bad). What's worse, the acid inside of a non-SLA or non-Gel Mat battery is in a liquid form and these batteries have valves to allow vapors to evaporate from the battery, meaning they pose a severe risk of spewing acid everywhere (VERY bad). For these reasons, if your project involves a lead-acid battery of any type, you will be *REQUIRED* to find the Material Safety Data Sheet (MSDS) and data sheet for your battery before you can acquire the battery and you must keep this documentation with you at all times in the laboratory. If possible, it is advised that students purchase a battery with protection against chemical spills (SLA is typically the most effective for student projects relating safety and cost) in order to minimize the risk of chemical leakage occurring.

V. Unique Dangers of Lithium-Ion, Lithium Iron Phosphate, etc. Batteries

Lithium batteries are the type of batteries found in your mobile phones and laptops. They are generally smaller and lighter than comparable capacity lead acid batteries, but they are also *substantially more flammable*. Unlike the lead acid battery where cell damage typically translates to reduced capacity, cell damage in a lithium battery translates to *a particularly nasty chemical fire*. Lithium Iron Phosphate batteries tend to be somewhat more fire resistant on account of different cathode material; however, they are still extremely flammable. For this reason, if you elect to use a lithium battery in any capacity, you will be required to complete additional fire safety and fire extinguisher training before proceeding with the course. Additionally, you will be required to incorporate some circuit to prevent your battery cell voltage from decaying below 3.0 $\frac{V}{cell}$ (2.5 $\frac{V}{cell}$ for $LiFePO_4$) or exceeding 4.2 $\frac{V}{cell}$ (3.65 $\frac{V}{cell}$ for $LiFePO_4$). Any charge or discharge tests must be performed while the battery is inside of one of the specially design lithium safety bags and any protection or charging circuits must be approved by your TA **AND** one of the power-centric TAs before they are so much as tested on a breadboard. These procedures are in place in order to protect you, others, and the brand new ECEB from being reduced to a smoldering pile of ashes. ***IF YOUR BATTERY BEGINS TO SWELL, FEEL HOT OR MAKE FUNNY NOISES: disconnect the battery IMMEDIATELY and place it in a battery bag FAR AWAY FROM FLAMMABLE STUFF. You should then report the issue to your TA and a power-centric TA IMMEDIATELY either in person or via a phone CALL to dispose of the battery as soon as possible.***

Swollen Battery = Time Bomb

There are several ways to damage a lithium cell. They include:

- Over charge
- Over discharge
- Over current (charge or discharge)
- Excessive heat
- Internal or external short circuit
- Mechanical abuse

Always check the battery specifications before purchasing or using them!
To minimize the risk associated with lithium batteries, the following precautions should be followed:

- Written work instructions and checklists should be generated for testing procedures
- Remove jewelry that may accidentally short circuit the terminals
- All dented batteries should be disposed of immediately (Contact your TA AND Casey Smith (217)-300-3722; cjsmith0@illinois.edu))
- Cover all metal work surfaces with insulating material
- Batteries should be transported in non-conductive carrying trays
- Always ensure the the open circuit voltage is within the acceptable range for your battery

VI. Charging Lead-Acid Chemistry Batteries

Charging a lead-acid battery is a non-trivial task. The course staff strongly suggest that if you must build a charger, you use some kind of integrated circuit (IC) solution. Additionally, you must familiarize yourself with the battery's charge characteristic and maximum charging current. Lead-acid batteries are inherently safer than lithium chemistry batteries. While an overcharge or overdischarge will cause extreme damage to your battery, the damage will be limited to internal calcification of the plates, reducing your capacity to a fraction of what it originally was. For this reason, ***the course staff strongly suggests that you use a lead-acid type battery if your project requires a battery and is not weight or size sensitive***.

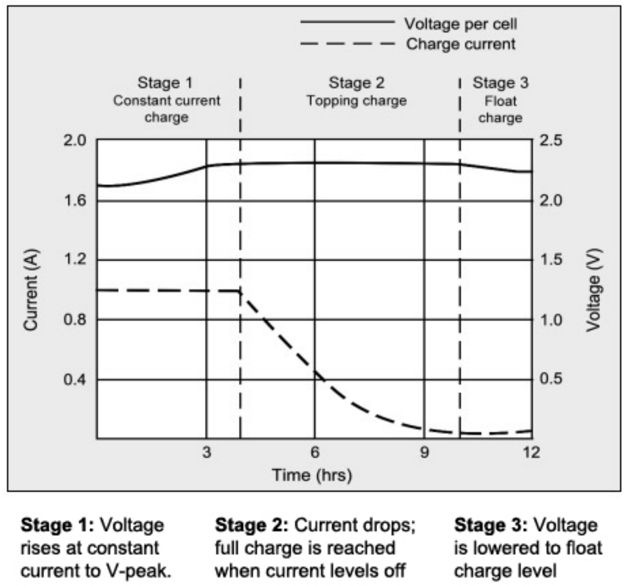

Fig. 1: The Generic Charging Characteristic of a Lead Acid Battery. Source.

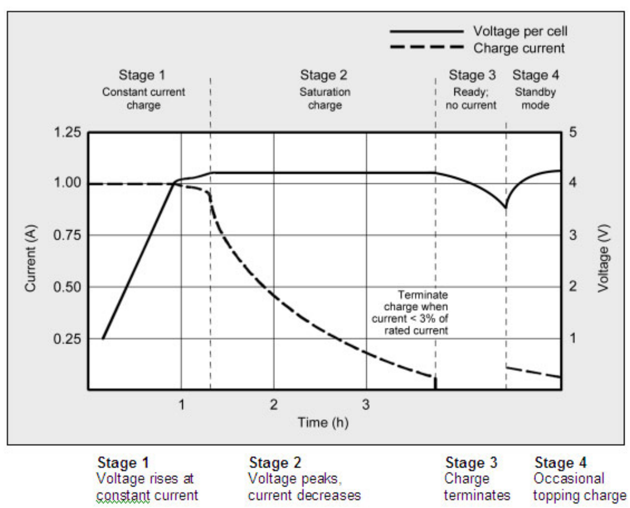

Fig. 2: The Generic Charging Characteristic of a Lithium Battery. Source.

VII. Charging Lithium Batteries

Charging a lithium battery is also a non-trivial task. The course staff continue to strongly suggest that if you must build a charger, you use some kind of IC solution. You must also familiarize yourself with the charge characteristic and maximum charge current. *Any circuitry you design that involves a lithium battery must be approved by your TA* ***AND*** *one of the power-centric TAs before they are so much as tested on a breadboard.* As an addition, it is important to note that batteries, which we can model as ideal voltage sources, charge with ideal current sources. Having an ideal current source and voltage source in parallel with the load is fine! Problems arise if we instead have two voltage sources in parallel. Any mismatch in the voltage will break KVL, which leads to a sudden rush of current from one source to the other in order to try and balance the voltages. This is a very unstable and hazardous methodology, therefore we always charge our batteries with current driving sources.

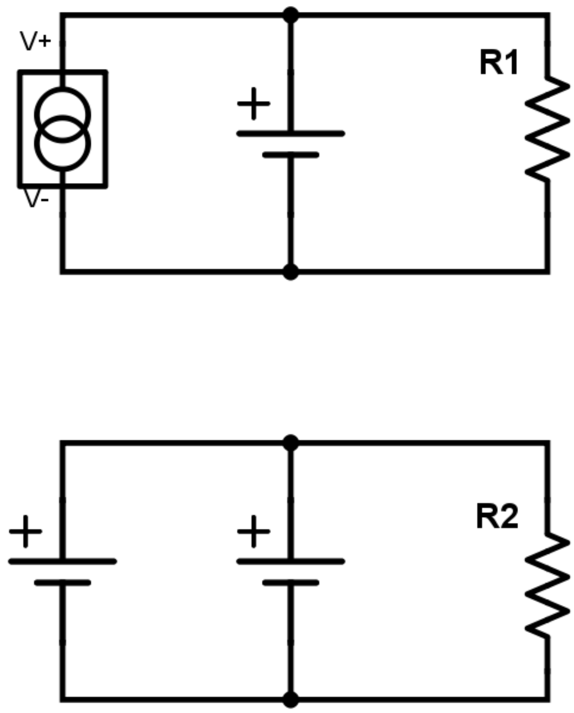

Fig. 3: Top: the proper way to think of charing your battery. Below: a risky way to do so.

VIII. Charging Suggestions and Testing Requirements

If possible, we strongly suggest purchasing and incorporating a fully featured charging suite if your project requires batteries. Those must meet rigorous safety standards in order to be sold in the USA. If this is not possible for any reason (your project is cost sensitive because it is for the developing world, you are using solar panels to charge a battery, etc.), we strongly suggest using an integrated circuit solution. As a last resort, you may attempt to design your own charging circuit. Regardless of the route you choose to take, due to the inherent danger of charging these batteries, everything must be approved by your TA and one of the power-centric TAs before you even bring your design to the breadboard. Once your charging design has been approved, its functionality must be validated to your TA in a demonstration before the battery is connected to the system. Initial testing of the charging circuit with the battery connected should be done in the senior design lab with a TA present and proper protective and emergency equipment easily accessible.

TABLE I: A Short Table of Suggested Charging ICs. (Google is Your Friend)

Chemistry	**Suggestions**
1S-2S Lithium	MAX1551/5, LM317 (see datasheet)
3S+ Lithium	LT1505, LT1512, LM317 (see datasheet)
Lead Acid	LM317 (see datasheet), LTC4020, LT3652

IX. ECE 445 Procedures

1) Justify to the course staff that your project requires a battery.
2) Determine the appropriate chemistry for your project. Spill-resistant lead acid is vastly preferred.
3) Obtain safety documents:
   a) If you are using a lead-acid battery: obtain the MSDS and battery data sheet.
   b) If you are using a lithium battery: obtain additional fire safety and fire extinguisher training
4) In this order:
   a) If your project allows for it: search for a commercially available charger.
   b) Search for ICs that will perform the entire charge algorithm for you.
   c) AS A LAST RESORT: Design your own charging circuit.
5) Simulate your circuit in SPICE, even if you plan to use a charging IC.
6) Have your TA and a power-centric TA review and approve your design.
7) Build your design on a breadboard and validate functionality to your TA before attaching a battery.
8) If using a lithium battery, place it in one of the lithium battery bags whenever charging or discharging the battery.
9) To be done only in the senior design lab with a TA present and with protective and emergency equipment easily accessible: connect a battery to your circuit.
10) If your circuit behaves correctly, congratulations! You are done. If not, close is NOT close enough and you will have to return to Step 4.

If a problem occurs in your circuit:

1) Shut off power
2) Locate problem before power is restored
3) If circuit breaker is tripped, report to ece-eshop-repairs@illinois.edu to reset
4) If help is needed, contact Casey Smith ((217)-300-3722; cjsmith0@illinois.edu) or the electronics shop for assistance
5) If the situation is an emergency, **call 911**

A. *Emergency Procedures*

- If a lead acid battery spills: use the Battery Acid Spill Kit located in the back of the lab to clean the spill. Contact Casey Smith and your TA immediately.
- If a lithium battery explodes, **call 911** and evacuate the area.
- If a lithium battery ignites, **call 911** and extinguish it with either of the fire extinguishers located in the lab. They are both rated to extinguish electrical fires and should be at your bench whenever you are actively working with your batteries. Contact Casey Smith and your TA immediately.
- If a lithium battery swells, feels hot to the touch, or makes funny noises but does not ignite, keep the battery in the bag and contact Casey Smith and your TA immediately. The battery cannot be left unattended until it has been properly disposed of.

By signing below, you acknowledge that you have read this document and agree to follow the ECE 445 Course Staff's guidance regarding high capacity batteries and will complete all necessary safety training and adhere to the guidelines set forth in this document as well as additional guidelines as the course staff deems necessary.

______________________________ ________________________

Print Name Date

______________________________ ________________________

Signature Date

TABLE II: History of Revision

Revision	**Date**	**Authors**	**Log**
A	3/19/2016	Lenz	Creation
B	3/28/2016	O'Kane	Additonal Information, General Revision
C	3/29/2016	SP16 Staff	Collaborative Revisions
D	4/7/2016	Salz	General Revision