Battery Safety
Making Peace with Power

A Guideline to the use and storage of portable power sources for Electronic Cigarette Consumers.

Prepared by

CASAA – The Consumer Advocates for Smoke-free Alternatives Association

January 2017

Practical Battery Safety

This guide will discuss how batteries are made, how they work, and what damages them. From this understanding, we can formulate some pretty clear rules to keep us and our batteries living together peacefully.

1. Know your device. Every device has specific power requirements and the batteries for the device should meet or exceed those requirements.
2. Do NOT make modifications to the device, including those which could block any ventilation holes or slots. Those holes or slots remove heat and/or allow venting gas to escape safely.
3. Buy high quality batteries from a known source – cheap batteries and seconds have poor internal quality and could fail sooner.
4. Buy only batteries rated for your device. Beware of re-branded batteries claiming to have 'High Output' - many of these are counterfeit and will fail. If in doubt seek well known brands like Sony, LG, Samsung, etc., and buy from a dealer that knows where they came from.
5. Store batteries in a protective case or sleeve to prevent them from shorting or being damaged. CASAA has battery cases available in our store here.
6. NEVER exceed the rated capacity of the battery – pulse ratings are high stress ratings, **batteries are meant to rest after stress**.
7. Do not drop batteries. If they are dropped they should be inspected **very** carefully. **Any** sign of damage on the outside could mean damage on the inside.
8. Do not subject batteries to extremes of temperature. Leaving them in your car could freeze the electrolyte causing it to crack. Overheating the electrolyte will cause it to dry out prematurely and crack. Cracked electrolyte is a key point of failure for thermal runaway.
9. If, when using a battery, it gets hot, STOP! Batteries may get warm to touch, but they should never get hot. Immediately put the battery in a fire-safe place such as a dry sink or outdoors away from people or pets.
10. Use a quality charger designed for lithium batteries – using cheap chargers can result in overcharging batteries, or charging them too fast. This weakens the separator and causes the electrolyte to dry out and crack making the battery unsafe.
11. Batteries should be replaced after at least 1 year of use – more often under high stress applications like vaping. If you notice that the battery is taking longer to charge, seems warmer while using, or doesn't seem to hold a charge as long, it is time to replace it.
12. **Never use a battery whose wrapper is damaged!** The opportunity for shorts is higher, and damaged wraps may indicate internal damage.

Why Battery Safety?

Batteries have become a part of everyone's daily lives, powering everything from our TV remotes to the cars we drive. Normally we never give them a second thought, until something goes wrong. For most people a dead battery is the only failure they ever encounter. However, sometimes these energy storage devices fail in much more dramatic ways. When that happens, because it is a rare occurrence, it makes news. In a recent survey of reports, researchers cataloged 92 incidents of e-cigarette battery failure from 2012 to 2015 that resulted in physical harm and/or property damage (1). Battery engineers have spent decades understanding just how batteries fail (2) (3). What this presentation will do is condense that knowledge into the practical information that consumers need to know to use batteries, specifically the types of batteries used in electronic vapor products in ways that maximize safety and minimize the risk of harm.

What Are Batteries Anyway?

The batteries used in electronic vapor products are typically lithium ion batteries. These batteries have an excellent storage and discharge capability to power the devices. With this kind of advanced battery, some things need to be understood to use, store, and handle them safely.

The heart of every battery is a careful chemical reaction that takes place between three elements of the battery. This chemical reaction is what produces the power from the battery. The main elements are called the anode (negative), electrolyte (the chemical), and the cathode (positive). These three elements are sandwiched together, a separator is placed on top, and the whole thing is rolled up to form the cylindrical shape we recognize. The following images will illustrate the point (4) (2).

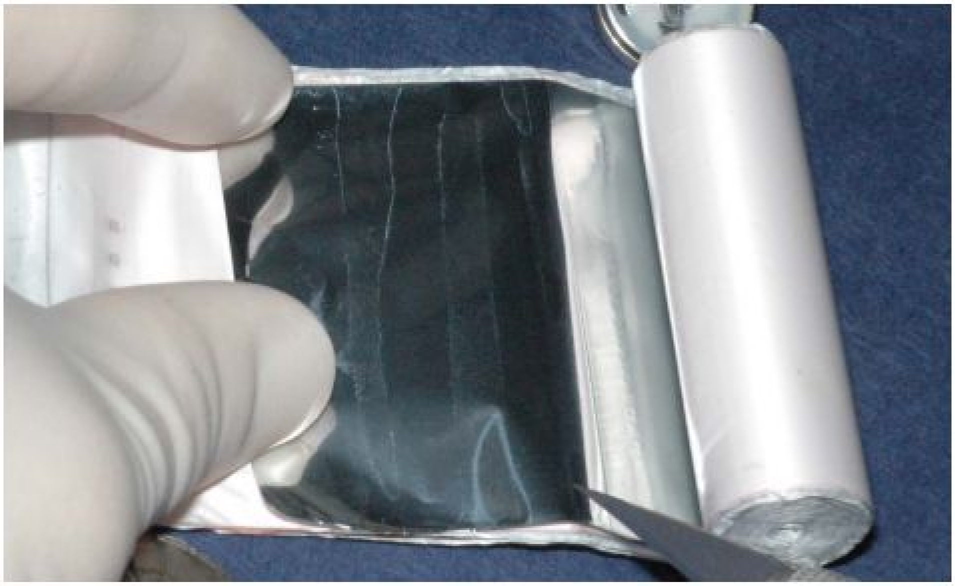

Figure 1 - Battery elements unwrapped (2)

Figure 2 - Layers rolled and placed in casing (2)

As one can see from the images, the layers of a battery are very tightly wrapped. The only thing that is preventing the layers from shorting is the electrolyte and the white plastic layer separating the anode and cathode. So the first clue to safe handling is: *Do NOT allow anything to damage the separator or the electrolyte* (3).

We’re all familiar with the alkaline batteries used in our remote controls. These batteries have a voltage rating of 1.5 volts. Lithium batteries have a voltage rating of 3.6 volts. What makes them different? The key difference is the chemical reaction we spoke of earlier. In most older technologies, the chemical reaction produces just 1.5 volts per cell. The newer lithium ion technology is capable of producing much higher output, up to 4.2 volts. So the chemical reaction determines the voltage (4).

How is the battery capacity determined? Simply put, the larger the surface area of the elements, the larger the capacity of the battery. Capacity is rated in milliamp hours (mAh). The larger the mAh, the more energy the battery can store (4). To get a larger surface area one must make thinner elements and wrap them tighter to fit into the same space. That’s the key difference between, say, a 1500mAh battery and a 3000mAh battery.

What determines how much power a battery can output? The main determination of power is the ability of the elements to pass current to the ends of the battery (4). The thinner the element, the less current it can move without getting too hot and melting the separator or the electrolyte. This is why batteries with less mAh can put out more current, the elements are thicker. There is a tradeoff between surface area of the elements, and the thickness of the elements. If too much current is drawn from a battery the elements will get hot. Remember the first clue about battery safety? *Do NOT allow anything to damage the separator or the electrolyte.* If the separator or electrolyte gets too hot, it gets damaged, and that can lead to a short circuit inside the battery (2). **This is a bad thing to have happen**.

One of the key advantages in using lithium ion batteries is not only their capacity, voltage level, and current delivery, but also the fact that they are rechargeable. Many batteries used in everyday life are called primary cells. Primary cells, like the alkaline batteries, are not rechargeable. Once the chemical reaction is finished, the battery is finished as well (4). lithium ion batteries have chemistry that allows them to be charged. This type of battery is called a secondary cell. This works because passing a small current through the battery will put the electrons in the electrolyte to a state where they can again move between the anode and cathode producing current (4). Each time a battery is discharged and recharged a little bit of the electrolyte loses its ability to be reset. Thus, batteries are rated in number of cycles. These cycles are the number of times the electrolyte can be recharged. If the number of cycles is exceeded, the battery does not perform as well, taking less time to discharge than it did when it was new. More importantly, though, the electrolyte itself begins to dry out and crack, which can cause a short (4) (2) (3). **This is a bad thing to have happen.**

How Batteries Fail

We've talked a little bit about the nature of battery failures from our review of the internals. But how do they end up 'exploding', catching fire, or 'venting'. These are each somewhat related phenomena. The cause of battery failure always boils down to this: *Too much current, too fast, for too long*. The key is what constitutes too much, too fast, and too long.

The first, and most obvious, cause of failure is shorting the battery. A battery can be shorted when too much current is demanded at once. Batteries have a maximum current rating for a reason. Recall our discussion of the element size and thickness and how, if too much current is trying to move through the elements they will get hot. Battery ratings are based on the temperature rise of the cell under test for a given current. Once the temperature rise becomes too large the electrolyte starts to boil and the battery vents the gas. If the condition continues, the battery will short internally and a condition known as thermal runaway begins – gas begins to escape more rapidly, the battery heats up further and, eventually, the gaseous electrolyte ignites and the battery catches fire. If that happens in an enclosed space the pressures build rapidly and the battery and container undergoes 'energetic disassembly'; in other words, it explodes.

The second, and not-so-obvious, cause of failure is disrupting the spacing of the elements, separator, and electrolyte. The most common way this happens is to drop the battery. Most batteries are drop and crush tested to take a certain amount of force before failing. But that doesn't mean they're indestructible, it just means they can handle some force, before they are weakened. Drop the device more than once or twice and you've probably exceeded the force needed to weaken the battery. Recall that if the separator or electrolyte gets damaged the battery will short internally and that leads to the sequence of events above. However, it might not happen immediately. Suppose, instead of direct contact, the electrolyte is thinned in one area, that area will get hotter and the separator and electrolyte will degrade, eventually breaking down and producing a short. Hence the not-so-obvious cause of failure. Unfortunately, unless you can get your batteries CT-scanned after you drop them, you are not going to know if such a condition is looming.

The third, and well hidden cause of failure is the age of the battery. Remember, batteries are rated in charge-discharge cycles. As you approach the end of life, the battery will get a bit warmer each time it is charged, and it won't seem to hold a charge as long. This is because the electrolyte is drying out. **Remember, dry electrolyte cracks easily** and concentrates heat in the separator and electrolyte, causing it to break down. As before, once the separator or electrolyte breaks down the battery will short internally, heat up, vent, and go into thermal runaway.

What To Do When Things Go Wrong

Anyone who uses lithium ion batteries can have a battery fail. The key is knowing the signs of impending failure and acting BEFORE the catastrophic ‘energetic disassembly’ happens.

The first sign of trouble is heat. A battery that is about to fail gets hot as the chemical reaction gets overloaded. Eject the battery in a fire-safe place such as a dry sink or outdoors away from people or pets and let the battery cool if it will. If it will cool off, properly dispose of it immediately. If it continues to heat it is undergoing thermal runaway (see below), protect yourself, your equipment, and any nearby bystanders including pets until the battery remnants are cold.

The next sign of trouble is venting. If your battery vents it will leave moisture and residue behind. Often a battery will vent a little bit if the battery is not rated to handle the load. If you see evidence that the battery has vented, replace the battery with one known to handle the discharge current and properly dispose of the battery that vented.

Finally, if the worst happens and that hot battery isn’t cooling off, get as far away as practical. Thermal runaway takes time to happen, from a few minutes to a half-hour. Be aware of the early signs of failure and take steps to protect yourself, your equipment, and any nearby bystanders including pets. Once a battery is in thermal runaway it cannot be stopped. Wait for the process to finish and the remnants to cool off and dispose of them.

Disposal of batteries should not be in the common trash. Take the battery, in a case or individually wrapped in plastic, to a recycler, or a battery specialist such as Interstate or Batteries Plus. Many hardware stores can also recycle. Google “battery recycling near me” for more information.

Vaping Specific Information

The first part of this paper is applicable to anything that uses lithium-ion batteries. There are a few things that users of vapor products must bear in mind.

First, there is no single type of vaping device. There are those that are all-in-one models that have the battery built in. These range from ‘stick’ batteries to high powered devices. Then there are regulated devices that take external batteries, and unregulated, or mechanical, devices. Each of these has specific requirements that a user must be aware of.

All-in-one models are designed for a particular application, and usually have recommended atomizers, or are part of a kit. Be sure to ask your vendor or consult the instruction manual to find out the maximum power or current the device is rated for and **do not exceed this rating.** Charge these devices as recommended by the manufacturer using their recommended charging equipment.

Regulated devices are, perhaps, the safest devices available but they do have some requirements for the batteries that power them. Consult the instruction manual, or manufacturer for the recommended battery rating, specifically the discharge current. High power devices require high current drain batteries. Here it is important to select a high quality, name brand, battery from a reliable source as there are unscrupulous dealers who are re-wrapping seconds and passing them off as counterfeits. If the device takes more than one battery purchase, charge, and use a complete set of batteries together. Do **not** mix batteries in these devices.

Unregulated, or mechanical, devices are meant for those who fully understand Ohm’s law, and the demands they place on the battery. **There are no safety elements in these devices.** They should only be used by those who are experts in sizing batteries to loads and who are aware of the inherent dangers in their use. Many of the device failures that have been in the media happen to people who are **not** well qualified.

All devices deliver power to an atomizer. The resistance rating of the atomizer determines the amount of current that a device will have to supply to the atomizer for it to function. The table below shows the typical current required for common atomizer resistances. This will serve as a rough guide to the current needed from a single battery. **Do not use an atomizer resistance that exceeds the battery or device discharge current rating under any circumstances!**

Atomizer resistance	**Current draw @ 4.2 Volts**	**Power @ 4.2 Volts**
2.4	1.75 Amps	7.35 Watts
2.0	2.1 Amps	8.82 Watts
1.8	2.3 Amps	9.66 Watts
1.4	3 Amps	12.6 Watts
1.2	3.5 Amps	14.7 Watts
1.0	4.2 Amps	17.64 Watts
0.8	5.25 Amps	22.04 Watts
0.6	7 Amps	29.4 Watts
0.5	8.4 Amps	35.28 Watts
0.4	10.5 Amps	44.1 Watts
0.2	21 Amps	88.2 Watts
0.1	42 Amps	176 Watts

Red - Exceeds rating of most batteries, use only in devices rated for this loads

Yellow - Sub-ohm, use with caution and in device rated for these loads

Green - Safe range for most batteries except some stick types.

Author Information

Bruce Nye, RN – As an embedded systems engineer for 25 years he has designed many products that use stored power technology including life-critical devices for the medical field. He is now a Registered Nurse with 10 years' experience as a trauma/surgical nurse.

References

1. *Electronic nicotine delivery systems: overheating, fires and explosions.* **Rudy, Susan F and Durmowicz, Elizabeth L.** s.l. : Tobacco Control, 2015, Vol. Online First.

2. *Failure Analysis Methodology for Battery Powered Product Incidents.* **Swart, Jan and Slee, Daren.** Austin, TX : IEEE, 2008. Product Compliance Engineering, 2008 Symposium on. pp. 1-6.

3. **Mikolajczak, Celena, et al., et al.** *Lithium-Ion Batteries Hazard and Use Assessment.* National Fire Protection Agency. Quincy, MA : The Fire Protection Research Foundation, 2011. Final Report.

4. **Buchmann, Isidor.** Battery University. *Battery University.* [Online] 2003. [Cited: April 9, 2016.] http://www.batteryuniversity.com.