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What toxic chemicals are released in lithium-ion battery fires?

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Abstract

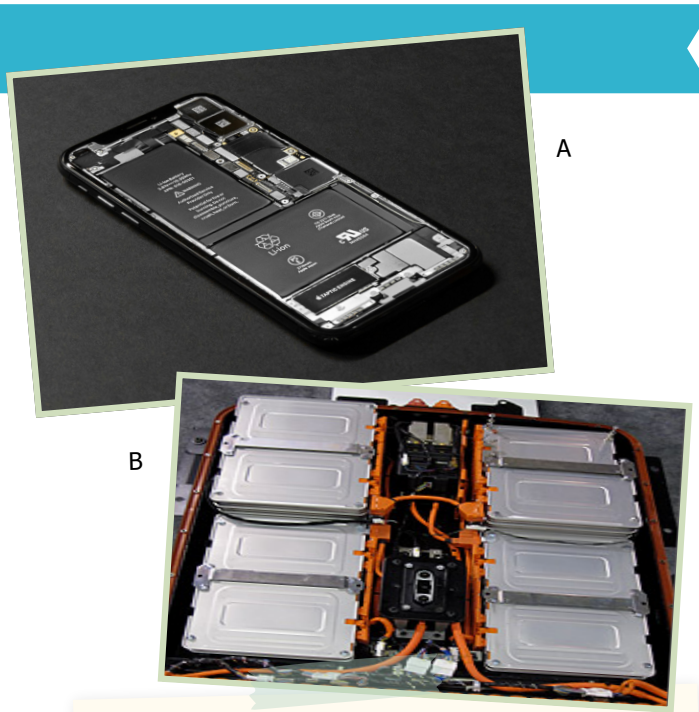
Portable electronic devices are an essential part of life. Cell phones, laptops, and tablets are just a few that we use on the go. What makes these devices portable? They use lithium-ion batteries! Lithium-ion batteries are rechargeable and last a long time. But when a lithium-ion battery overheats (known as thermal runaway), it can result in fire or even an explosion. This releases small particles that people in the area can inhale. We wanted to know how these inhaled particles affect lung cells. We caused several batteries to experience thermal runaway and examined the particles emitted. We collected these particles on special filters. Then we exposed lung cells to these collected particles. We found that lithium-ion batteries release mixtures of toxic gases and particles that may contain heavy metals. We learned that these mixtures cause cell stress and DNA damage if people are exposed to and inhale them. These exposures and associated effects can potentially cause lung injury.

Introduction

Batteries power our world. They store and release energy via chemical reactions. Lithium-ion batteries use lithium and other metals to store energy. Cell phones, laptops, tablets, and even electric vehicles use these batteries. Why? They can store a large amount of energy in a small space. They hold their charge for a long time. They can also recharge quickly, many times over. That is why these batteries are also used to store energy made by renewable energy sources.

But lithium-ion batteries can be dangerous if they experience **thermal runaway**. During thermal runaway, the battery becomes very hot. Then the energy stored in the battery is released suddenly. The result is fire and potential explosions. The batteries also release tiny solid particles known as **particulate matter**. Some of these particulates are large enough to see with the unaided eye. Others are very small.

When you inhale or breathe in particulates, they can hurt your lungs. During a thermal runaway event, people like



A

B

A) A lithium-ion battery in a cell phone.
B) Lithium-ion battery packs used in an electric car.

first responders may breathe in these particles. We wanted to know the health effects of particulate matter and metals released by lithium-ion batteries. We focused on how the particulate matter and metals affect lung cells.

Methods

We tested two different types of lithium-ion batteries. Type A contained lithium, iron, and phosphate. Type B contained lithium, manganese, and cobalt.

We placed the batteries in a chamber. We then heated them to cause thermal runaway. We used probes to measure the number and size of particles. We also analyzed the composition of the particles.

We used a computer model to calculate the amount of particulates that would represent very high or worst-case scenario exposure levels. To achieve this, the model assumed people inhaled the particles through their nose for two hours a day, five days a week, for 52 weeks (one year) or 260 weeks (five years).

Then, we grew lung cells and exposed them to our modeled amount of particulate matter. We exposed Group A cells to the particulates produced by Type A batteries and Group B cells to those made by Type B batteries. We used two doses of particulates from each battery type. The low dose modeled exposure for one year. The high dose represented modeled exposure for five years.

We analyzed the amount of cell stress and **DNA** damage and repair compared to a control group. We determined the amount of cell stress or **oxidative stress** by measuring a molecule known as reactive oxygen species, or **ROS**.

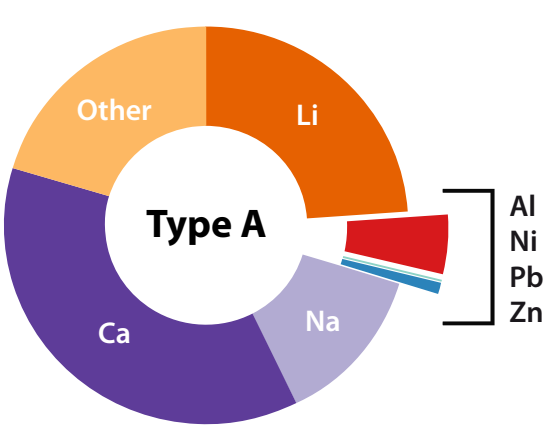
Results

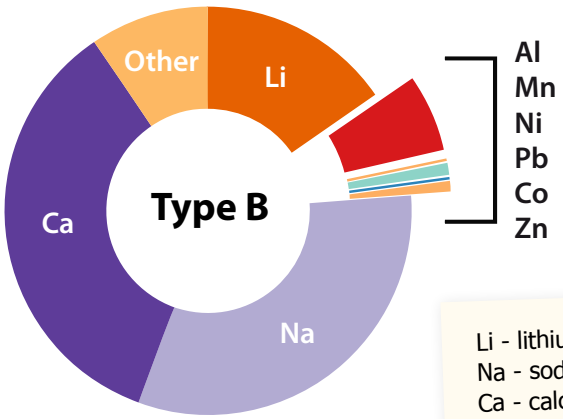
Particulate Characteristics

We learned that the two battery types release similar metals during thermal runaway (see Fig. 1). The main metals released were sodium (Na), calcium (Ca), and lithium (Li). The batteries also released aluminum (Al) and the **heavy metals** nickel (Ni), cadmium (Cd), and lead (Pb). Type B released the heavy metal manganese (Mn)

How does the amount of lithium (Li) and sodium (Na) released by Type A batteries compare to Type B batteries?

What elements do Type B batteries release that Type A batteries do not?





Li - lithium
Na - sodium
Ca - calcium
Al - aluminum
Ni - nickel
Pb - lead
Zn - zinc
Mn - manganese
Co - cobalt

Figure 1: Particulates released by Type A and Type B lithium-ion batteries after thermal runaway.

as well. We found that the Type B batteries had higher particulate concentrations. These particles had a larger average diameter compared to Type A.

Cell Stress

Group A cells produced the same amount of ROS as the control cells at both doses. Group B cells produced more ROS than the control cells when there was a high dose of particulate matter. There was no change in ROS at the low dose.

DNA Damage and Repair

Cells in Group A did not show an increase in DNA damage at either dose. But they did show a decrease in the substances used to repair DNA. This decrease occurred at both doses.

Cells in Group B showed DNA damage at both doses. They also showed a decrease in DNA repair chemicals, but only at the higher dose.

Discussion

We found that emissions from thermal runaway of lithium-ion batteries may cause harmful effects in the body. Both battery types produced particulate matter, including heavy metals. Cadmium and lead are dangerous heavy metals that can cause health hazards.

The Type B batteries released the heavy metal manganese, which can damage the lungs. This might explain why Type B batteries caused more cells to experience stress and DNA damage than Type A batteries did.

Many of the changes we observed in Group A and Group B cells can cause lung disease. Cell stress and DNA damage can cause **inflammation** in the lungs. This inflammation and injury can lead to diseases such as long-term **bronchitis** and **pulmonary fibrosis.**

Our research also showed that battery chemistry is important. Particulate matter from Type A batteries had harmful effects on lung cells. But the particulate matter from Type B batteries caused more harmful effects. This means that the type of battery affects the level of risk that first responders experience. They are often called out to fires and explosions, so their exposure risk is higher.

Conclusion

Thermal runaway in lithium-ion batteries can be dangerous. That is why it is important to use devices with these batteries carefully. Only charge a device with a lithium-ion battery with its own charger. You also want to make sure that the device does not experience temperatures that are very hot.

In addition, never cover a device with a blanket or other items. These items trap heat, making thermal runaway more likely. Lastly, keep charging devices away from pets, as damage from pets can cause thermal runaway.

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Glossary of Key Terms

Bronchitis - a condition caused by inflammation of the cells lining the tubes that carry air to and from the lungs. People who have bronchitis often cough up thick mucus, which can be discolored. Long-term bronchitis is a constant irritation or inflammation of the lining of the bronchial tubes. It is a serious medical condition.

DNA - the molecule that contains genetic information. It is found in every cell.

Heavy metals - metals with a high density that are dangerous to human health. Examples include cadmium, lead, and manganese.

Inflammation - a normal part of your body's response to injuries and infection. It promotes healing and helps you feel better. But inflammation can be harmful if it occurs in healthy tissues or goes on for too long.

Oxidative stress - when your body has too many harmful molecules and they start damaging your cells.

Particulate matter - tiny solid particles and/or liquid droplets that can cause damage to the lungs when inhaled. Liquids are unlikely to be released during thermal runaway.

Pulmonary fibrosis - a lung disease. Patients have scarring and thickening of their lung tissue, which makes it harder for oxygen to enter the bloodstream. Pulmonary fibrosis commonly causes a dry cough, shortness of breath, and other symptoms.

ROS (reactive oxygen species) - a molecule produced by cells when they complete normal functions. When a cell produces a large amount of this molecule, however, it may experience oxidative stress.

Thermal runaway - when a battery overheats, causing a sudden release of energy that results in fire and a potential explosion.

Check your understanding

1. Why are lithium-ion batteries used in many devices?

2. Lithium-ion batteries are commonly used in devices with rechargeable batteries. With a partner, brainstorm a list of items that use rechargeable batteries.

3. Why are we concerned about how thermal runaway will affect first responders?

4. Imagine your community is considering installing large lithium-ion batteries to store energy produced by renewable energy resources. Write a letter to the community council for or against the proposal. Explain your reasoning with evidence.

5. Heavy metals have many health effects, including negative impacts on the lungs. Select one of the heavy metals released during the thermal runaway of a lithium-ion battery. Research this heavy metal and summarize its effects on human health. Share your findings with a partner or the class.