Batteries Introduction

Humans have long relied on batteries for portable energy storage. Batteries allow chemical energy to be stored and later converted to electrical energy for on demand use.

While there are a variety of batteries today, **all batteries consist of three main components:** the positively charged **CATHODE**, a negatively charged **ANODE**, each of which is made from different chemicals (typically metals); and an **ELECTROLYTE**, which separates the two. The electrolyte is a medium that enables the flow of charge between the cathode and anode. When a device is connected to a battery — an electric circuit of any kind — an oxidation reaction occurs between the cathode and anode that creates a flow of charge (electrons) through the device. When electricity is flowing from the battery, electrons are being released from the anode, traveling through the electrolyte substance, and being accepted by the cathode. This flow of ions allows the stored chemical energy to be converted into the desired electrical energy.

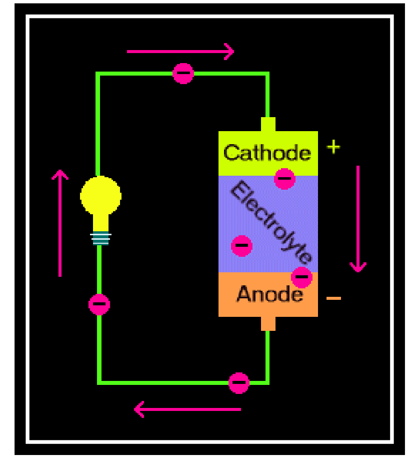


IMAGE CREDIT
http://www.qrg.northwestern.edu/projects/vss/docs/power/2-how-do-batteries-work.html

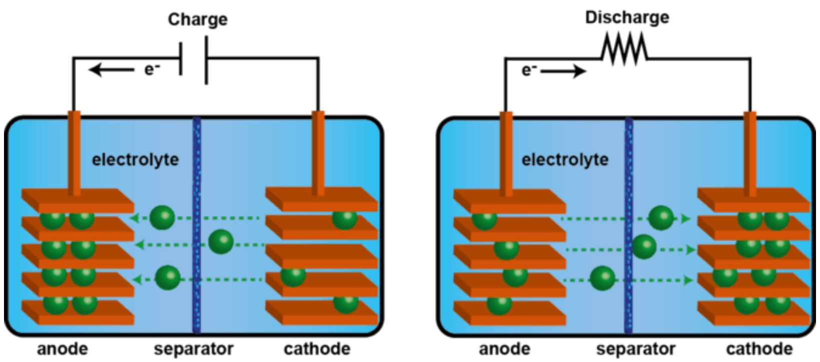
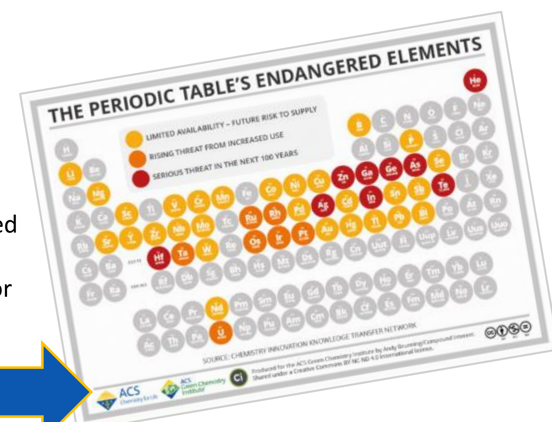


IMAGE CREDIT https://www.iflscience.com/technology/tomorrow-s-battery-technologies-could-power-your-home/

In a typical disposable battery the energy flow only happens in one direction and the battery will continue to produce electricity until it runs out of reactants. However, in rechargeable batteries, the reaction can be reversed allowing electrical energy from an outside source to reverse the flow of ions in the chemical system and recharge the battery.

The disposable batteries we are most familiar with, used in many household devices such as toys and flashlights, are alkaline batteries, named as such for their containing an alkaline electrolyte, **potassium hydroxide**. In these batteries, **zinc** is typically used as the anode and the cathode is **manganese dioxide** (MnO2). While alkaline batteries were a technological improvement from earlier batteries, sustainability related issues still remain. ***Zinc is considered an endangered element with serious concerns about its availability over the next 100 years.*** Since mercury was removed from alkaline batteries, they are now deemed safe enough for disposal in municipal solid waste. However, this means that the zinc in these batteries are not recycled at nearly the rate it could be ii, iii, iv. Alkaline batteries still account for 80% of manufactured batteries in the US and over 10 billion individual units produced worldwide.



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The Lithium-ion Battery: Powering Our High-tech Lifestyle

Over the past 30 years, there has been a shift towards Lithium-ion batteries for portable energy storage. Lithium-ion batteries are used in everything from laptops and cell phones to digital cameras electric vehicles. They typically contain a cathode made of **Lithium** and **Graphite** and an anode made of **Lithium Cobalt Oxide**. **Both Lithium and Cobalt are considered limited in availability with a future risk of supply issues.** This is particularly relevant due to the rate of growth for the electric vehicle market. It is predicted that by 2025, 90% of the lithium-ion batteries will be in electric vehicles v.

While rechargeable lithium batteries have grown in prevalence, they also have their own host of sustainability and technological challenges. Most of the world's Lithium resources are found in Chile, Australia and China. Cobalt is primarily mined in the Democratic Republic of Congo—a country whose mining industry has been widely criticized for human rights violations including the use of child labor.

As a result, many companies are researching replacements for Cobalt vii, viii. Additionally, lithium ion batteries have been known to catch fire if the batteries are punctured or under too much pressure. The lithium in the batteries can react with the water in air and generates sufficient heat to catch fire.

Recycling of Lithium-Ion batteries is not currently widespread, with only a few companies emerging who are able to take them. With most Lithium-ion batteries in cars lasting 8-10 years, the market for recycling them is expected to come into full swing by 2025—with an estimated 11 million tons of recyclable batteries per year ready for recycling by 2030 viii. In addition to the challenges of reclaiming all of the materials in the batteries, it is unknown whether manufacturers will buy these recycled materials.

The Future of Energy Storage: Green and Sustainable Solutions

As chemists and engineers, you have an incredible opportunity to use your technical skills and knowledge to come up with innovative and sustainable solutions to the challenges of portable and larger scale grid power storage. Using green chemistry principles and practices, you are encouraged to use a systems thinking approach to the design of chemicals, processes and products to improve efficiency and reduce negative impacts on human health and the environment by reducing the use of hazardous substances and reducing pollution. Systems thinking challenges you to think about the implications of the choices you make in your experiments within a much broader context and across the life cycle of the process. **For example, when selecting regents, think about where they come from and how they're made. Are they from earth abundant or renewable sources? How are they made? Is it through a hazardous process?**

If so, can alternatives be selected? For more information on green chemistry principles and practices, visit the ACS Green Chemistry Institute design principles page (https://www.acs.org/content/acs/en/greenchemistry/principles.html).

- **With this in mind, can you start to think through some of the sustainability challenges that exist with current energy storage technologies?**
- **What kinds of alternatives to the current battery and grid storage options can you think of?**
- **Using the periodic table on the following page, what are some of the pros and cons of using each of the cathode and anode candidates listed here?**
- **Think about where these elements come from, how are they mined? How are they processed? What are the social and environmental impacts? How do they impact human health? Can they be recycled?**

THE EVOLVING PERIODIC TABLE AND ITS INCREDIBLE ELEMENTS!

ACS PROGRAM-IN-A-BOX ACTIVITY AND DISCUSSION QUESTIONS

Elements that can be used in a battery:

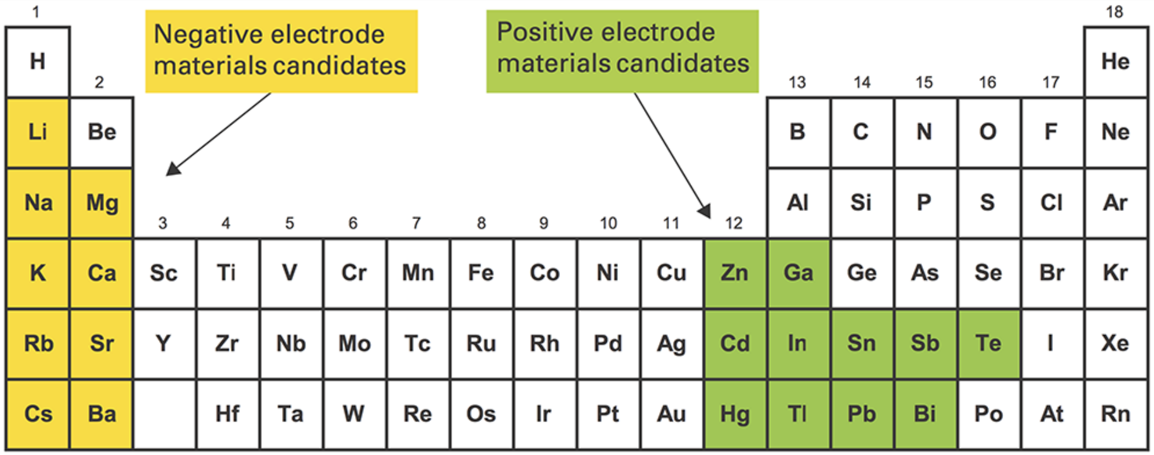

IMAGE CREDIT
http://news.mit.edu/sites/mit.edu.newsoffice/files/styles/news_article_image_top_slideshow/public/images/20151210_battery-molten-metals-figure-2.png?itok=NU-I1SjF

Additional Resources

- https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf
- https://energystoragecenter.mit.edu/
- https://ec.europa.eu/commission/publications/report-critical-raw-materials-and-circular-economy_en

Discussion Questions

- **Which endangered or critical elements are used? What is their purpose in the battery?**
- **What parts of the world do these endangered elements come from?**
- **What socio-economic issues are related to the extraction and processing of these elements?**
- **Can you think of potential alternatives to these elements? What are the sustainability pros and cons of these approaches?**
- **How are these elements recovered or recycled at the end of life? How efficient is this process currently compared to extraction?**

References

i https://engineering.mit.edu/engage/ask-an-engineer/how-does-a-battery-work/
ii https://web.archive.org/web/20111007014825/http://www.epbaeurope.net/documents/NEMA_alkalinelca2011.pdf
iii http://www.epbaeurope.net/090607_2006_Oct.pdf
iv https://web.archive.org/web/20131008081530/
v https://www.ft.com/content/c489382e-6b06-11e7-bfeb-33fe0c5b7eaa
vi https://www.reuters.com/article/us-panasonic-battery/panasonic-plans-to-develop-cobalt-free-car-batteries-idUSKCN1IV14Y
vii https://www.wired.com/story/alternatives-to-cobalt-the-blood-diamond-of-batteries/
viii https://www.ft.com/content/c489382e-6b06-11e7-bfeb-33fe0c5b7eaa