Oxford Cambridge and RSA

For issue on or after 13 March 2025

A Level Chemistry B (Salters)

H433/02 Scientific literacy in chemistry

Advance Notice Article

To prepare candidates for the examination taken on Monday 16 June 2025 – Morning

INSTRUCTIONS
- Before the exam, read this article carefully and study the content of the learning outcomes for A Level Chemistry B (Salters).
- You can ask your teacher for advice and discuss this article with others in your class.
- You can investigate the topic of this article yourself using any resources available to you.
- Do **not** take this copy of the article or any notes into the exam.

INFORMATION
- In the exam you will answer questions on this article. The questions are worth 20–25 marks.
- A clean copy of this article will be given to you with the question paper.
- This document has **4** pages.

ADVICE
- In the exam you won't have time to read this article in full but you should refer to it in your answers.

Battery Tech Report: Lithium-Ion vs Vanadium Redox Flow Batteries (VRFB)

Adapted from an article by Duane Hope in Capital 10X interview series, July 26 2022
https://capital10x.com/battery-tech-report-lithium-ion-vs-vrfbs/

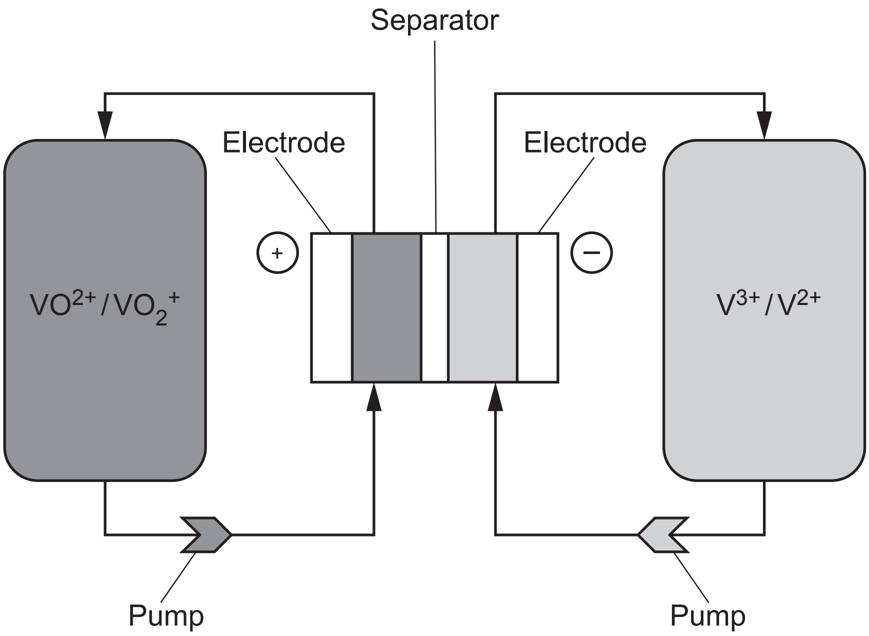
Batteries will play a greater and greater role in the green energy revolution. From electric vehicles to efficient electronics, there are a variety of batteries on the market applicable for various uses, the ubiquitous energy source being the lithium-ion (Li-ion) battery. Vanadium Redox Flow Batteries (VRFB) are a cutting-edge type of rechargeable flow battery, that employs vanadium ions as the active materials.

The unique properties of VRFBs gives manufacturers an edge in certain applications (e.g. utility/grid energy) over other batteries in the space. Below we will lay out the similarities and differences between VRFBs and Li-ion batteries. To illustrate this, let's look at some of the main features and differences between VRFBs and Li-ion batteries.

What are VRFBs and Li-Ion Batteries?

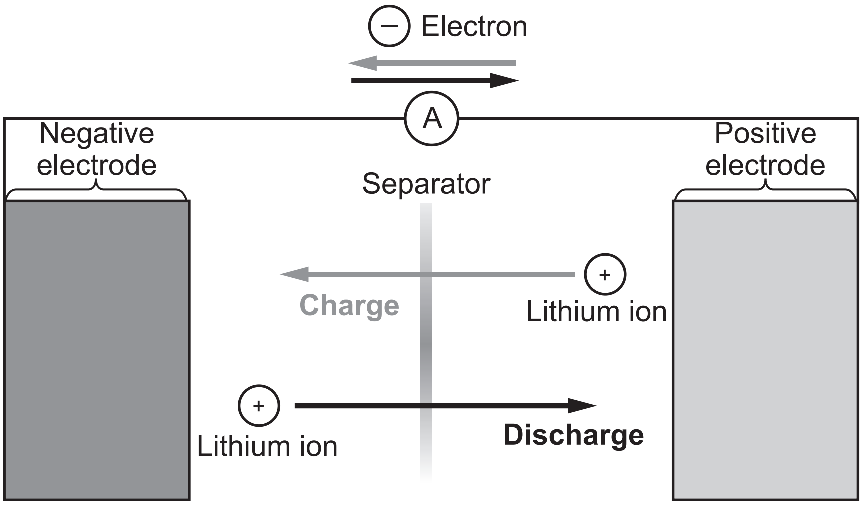
A VRFB consists of an assembly of power cells in which two electrolytes are separated by a proton-exchange membrane. The electrodes in a VRFB cell are carbon based. Both electrolytes are vanadium-based. The electrolyte in the positive half-cells contains VO^{2+} and VO_2^+ ions, while the electrolyte in the negative half-cells consists of V^{3+} and V^{2+} ions. The electrolytes can be prepared by several processes, including dissolving vanadium pentoxide (V_2O_5) in sulfuric acid (H_2SO_4).

Fig. 1 A VRFB



A Li-ion battery is a rechargeable battery made up of cells in which lithium ions move from the negative electrode through an electrolyte to the positive electrode during discharge and back when charging. Li-ion cells use intercalated-lithium compounds as the electrode materials, which are typically graphite as the negative electrodes and metal oxides as the positive electrodes. Li-ion batteries have a high energy density, and low self-discharge.

Fig. 2 A Typical Lithium-Ion Battery



Cells can be manufactured to prioritise either energy or power density. VRFBs have a lower energy density – they are better at delivering a consistent amount of power over significantly longer periods. More importantly, a VRFB can handle far more charge-discharge cycles than a Li-ion battery.

Cell Architecture

Li-ion batteries store all of the components inside the cells which makes them simple and well suited for small devices, such as in laptops and cellphones. They are relatively small and heat up very quickly, one of their strengths being they respond quickly to changes in power demands. Li-ion batteries are also currently the main type used for electric vehicles, because of their unmatched energy density. One of the negatives of using Li-ion batteries for electric vehicles is that they take hours to charge, which can be an inconvenience if there is no charging station available for a travelling driver.

The main drawback to Li-ion batteries for large-scale projects is that hundreds of thousands of cells are needed. This is an inefficient way of storing energy and uses far more materials than a VRFB, since each of these individual Li-ion battery cells can only store a relatively small amount of energy. There is a limit to the amount of active materials that one can hold inside the electrodes, since thick electrodes result in poor performance and shorter lifetimes.

In contrast, VRFBs store their energy in two electrolyte tanks, which are connected to a stack of cells. The electrolyte is the fluid that stores the active materials dissolved in the liquid, and is pumped from the two tanks through the cell stack during the charging and discharging process. The energy capacity of a VRFB can easily be expanded by adding more solution to the tank. This battery design makes it much easier to adapt VRFBs to industrial-scale operations without adding much costs since the tanks can be any size desired. In other words, as the energy capacity of a VRFB increases, the price per kilowatt hour decreases.

VRFBs outperform Li-ion batteries and are a far superior energy storage option for stationary applications, where their feature of storing chemicals in external tanks enables large-scale energy storage from a renewable source during peak-production times and consistent supply when energy production drops below demand.

Energy Capacity

Capacity retention is where VRFBs really stand out. Li-ion batteries decay over time and lose capacity; a well-designed VRFB system can run at 100% capacity forever.

To make up for their capacity loss, Li-ion batteries are built to be oversized at the time of installation, which increases costs to the end user. The average age of a substation transformer is 42 years.

According to Battery University, the capacity of Li-ion cells can drop to 50% after 1200 to 1500 discharges while VRFBs retain 100% capacity for up to 14 000 discharges.

Battery Energy Density & Battery Power Density

Energy is measured in kilowatt-hours (kWh) and is the amount of power (kilowatts, or kW) delivered over a period of time.

Battery energy density measures how much energy a battery can hold compared to its mass. Battery energy density is measured in kWh/kg.

Battery power density is similar but measures how fast the battery can deliver energy. Battery power density is measured in kW/kg.

Li-ion batteries are like coffee cups, which can be readily emptied (high flow rates) but have low storage capacity (low volume).

VRFBs are like water bottles, which can hold large amounts of energy (large volumes). VRFBs can also be designed to deliver whatever ratio of power (flow rate) to energy (volume) one desires for a given application, due to the decoupled and flexible architecture.

Li-ion batteries have higher battery energy densities than VRFBs. However, lower battery energy density is fine for stationary applications where size and weight are less important than in mobile devices or electronic vehicles. VRFBs are ideally suited for long-duration energy storage applications on the electric grid, where capacity, safety and lifespan are far more important than density.

The high energy density and output levels of Li-ion batteries come at a cost – Li-ion batteries contain flammable electrolytes and have a relatively higher hazard than VRFBs. If damaged or charged incorrectly, they can cause damage or fires.

END OF ADVANCE NOTICE ARTICLE