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State of Charge Analysis in a Vanadium Redox Flow Battery using an UV-Vis-based Calibration Model

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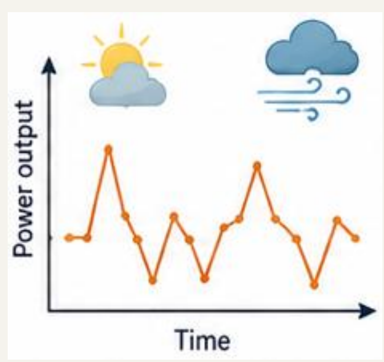
INTRODUCTION

Why VRFB?

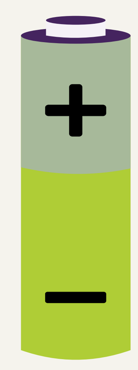
CLIMATE CHANGE → **RENEWABLE ENERGY SOURCES** → **INCONSISTENT & UNPREDICTABLE** → **ENERGY STORAGE SYSTEMS** → **VANADIUM REDOX FLOW BATTERY (VRFB)**

- Rising global T

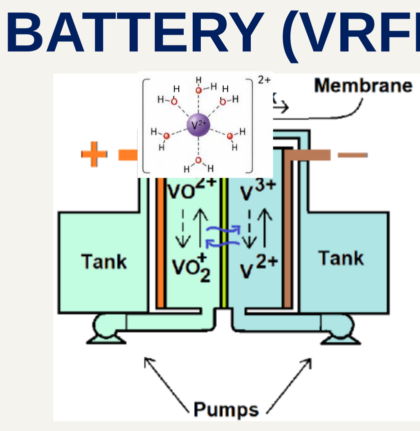
- Inexhaustible supply



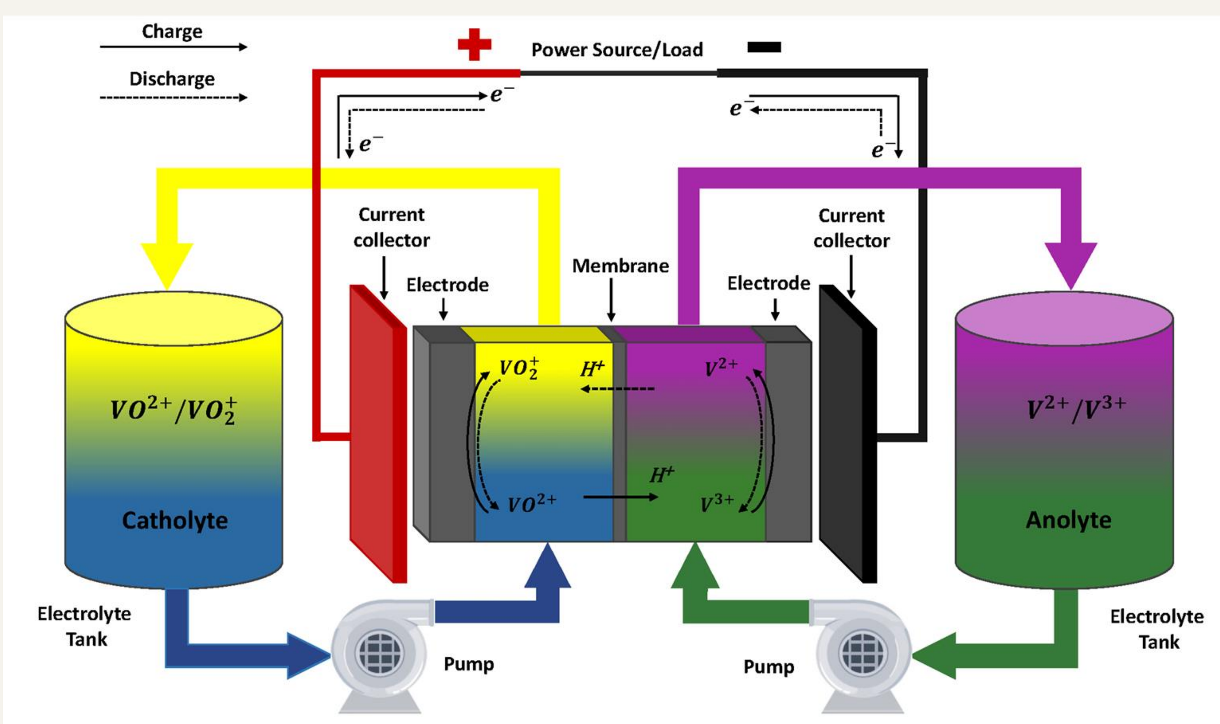
- Intermittent nature



- Balance supply & demand



- Scalable & safe
- Long cycle life



VANADIUM

- By-product of steelmaking industry

Why SoC?

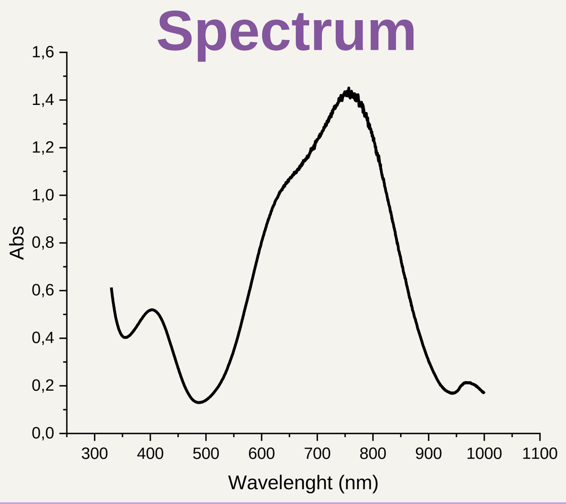
State of Charge (SoC) is a key parameter for understanding battery performance & efficient energy management

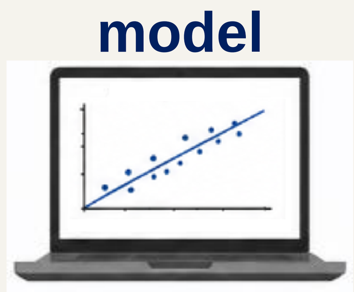
Lit: [Puleston, T. et al. Modelling and Estimation of Vanadium Redox Flow Batteries: A Review. Batteries 2022, 8, 121.]

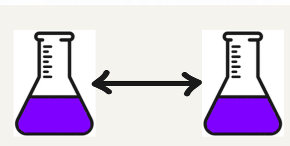
OBJECTIVE

To develop and apply a UV-Vis calibration model for determining vanadium species concentrations and estimating SoC during VRFB operation.

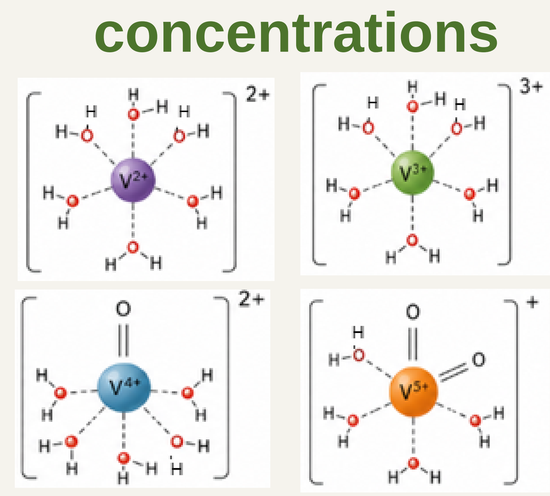
❶ Unknown UV-Vis Spectrum ❷ Calibration model ❸ Vanadium species concentrations ❹ SoC determination







50 mM ⟷ 160 mM



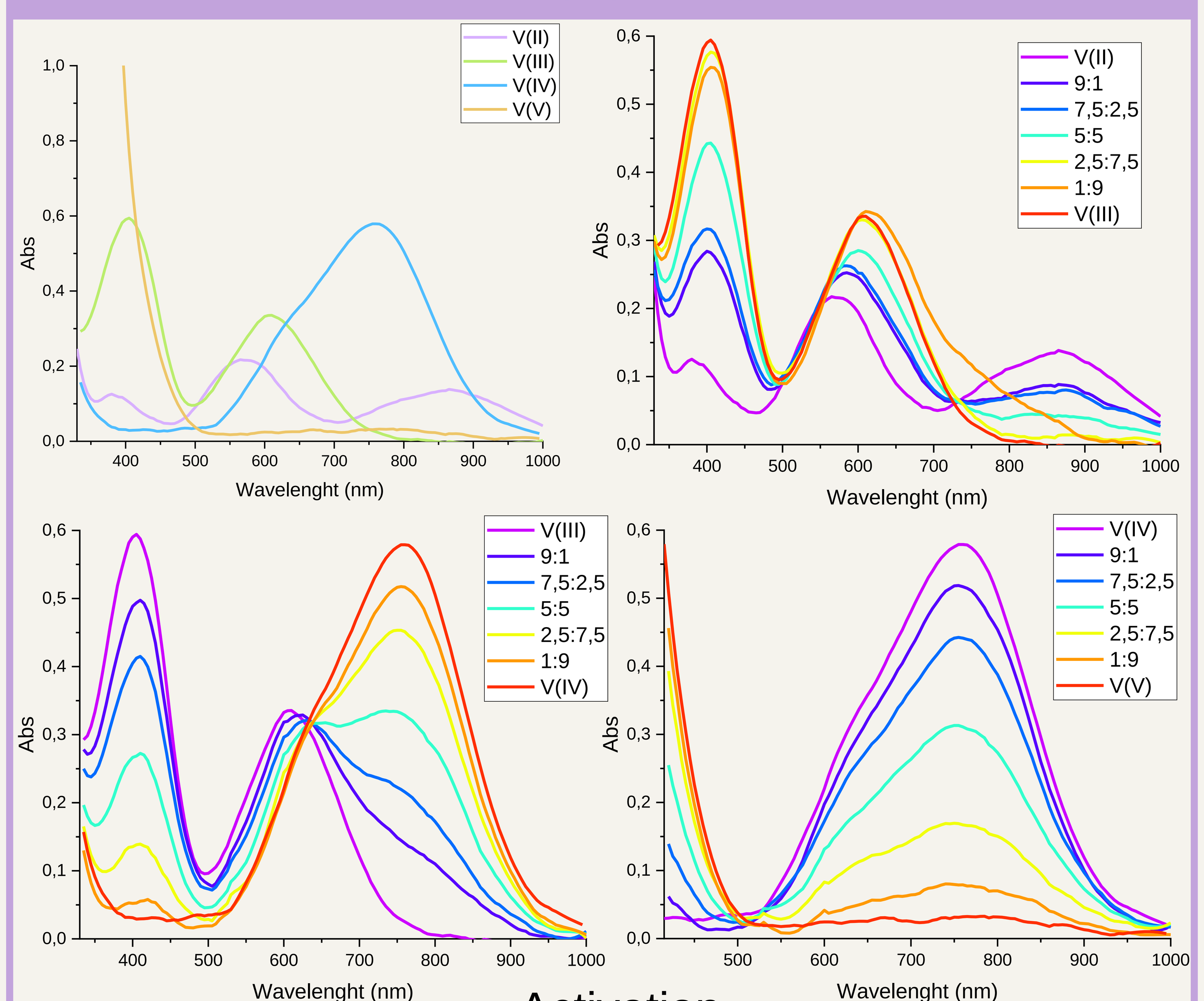
$$SoC^- = \frac{c_{V^{2+}}}{c_{V^{2+}} + c_{V^{3+}}}$$

$$SoC^+ = \frac{c_{VO_2^+}}{c_{VO^{2+}} + c_{VO_2^+}}$$

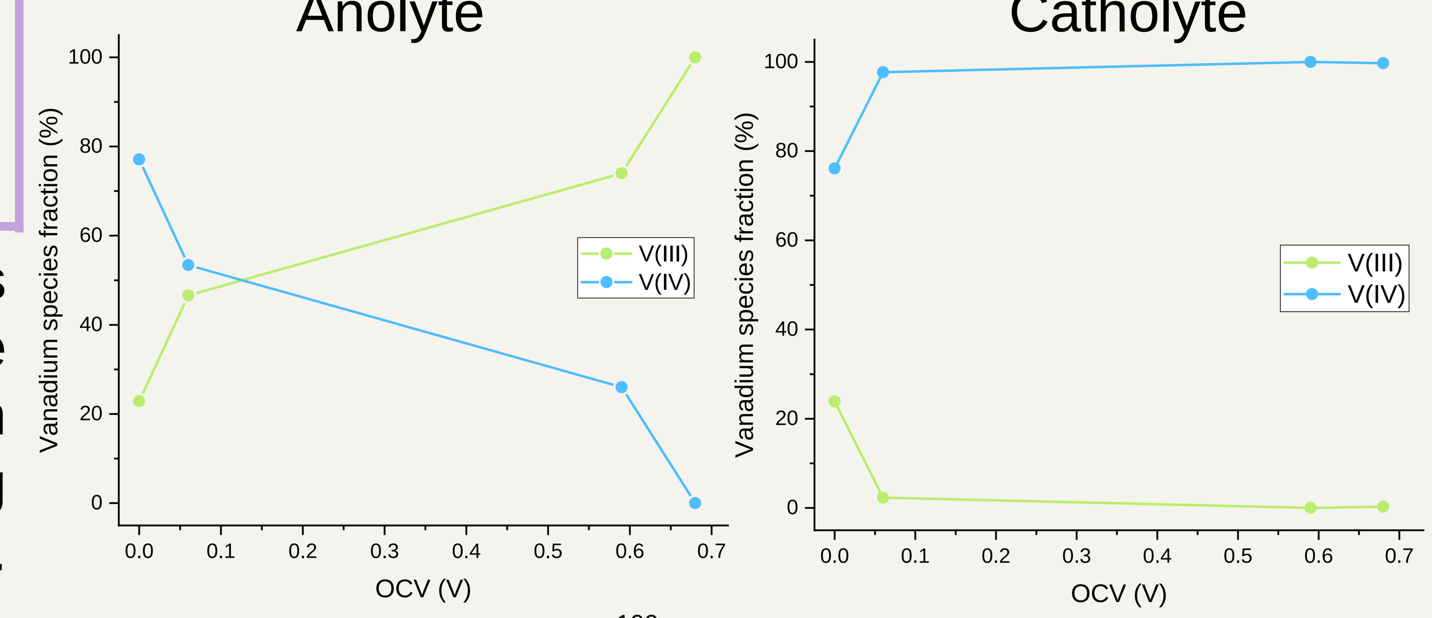
PREPARATION

- V(II), V(III), V(IV) & V(V) prepared in 4 M H_2SO_4 at 2 concentration levels: 50 mM & 160 mM
- Binary mixtures: V(II)/V(III), V(III)/V(IV), V(IV)/V(V)
- Ratios: 1:9, 2.5:7.5, 5:5, 7.5:2.5, 9:1

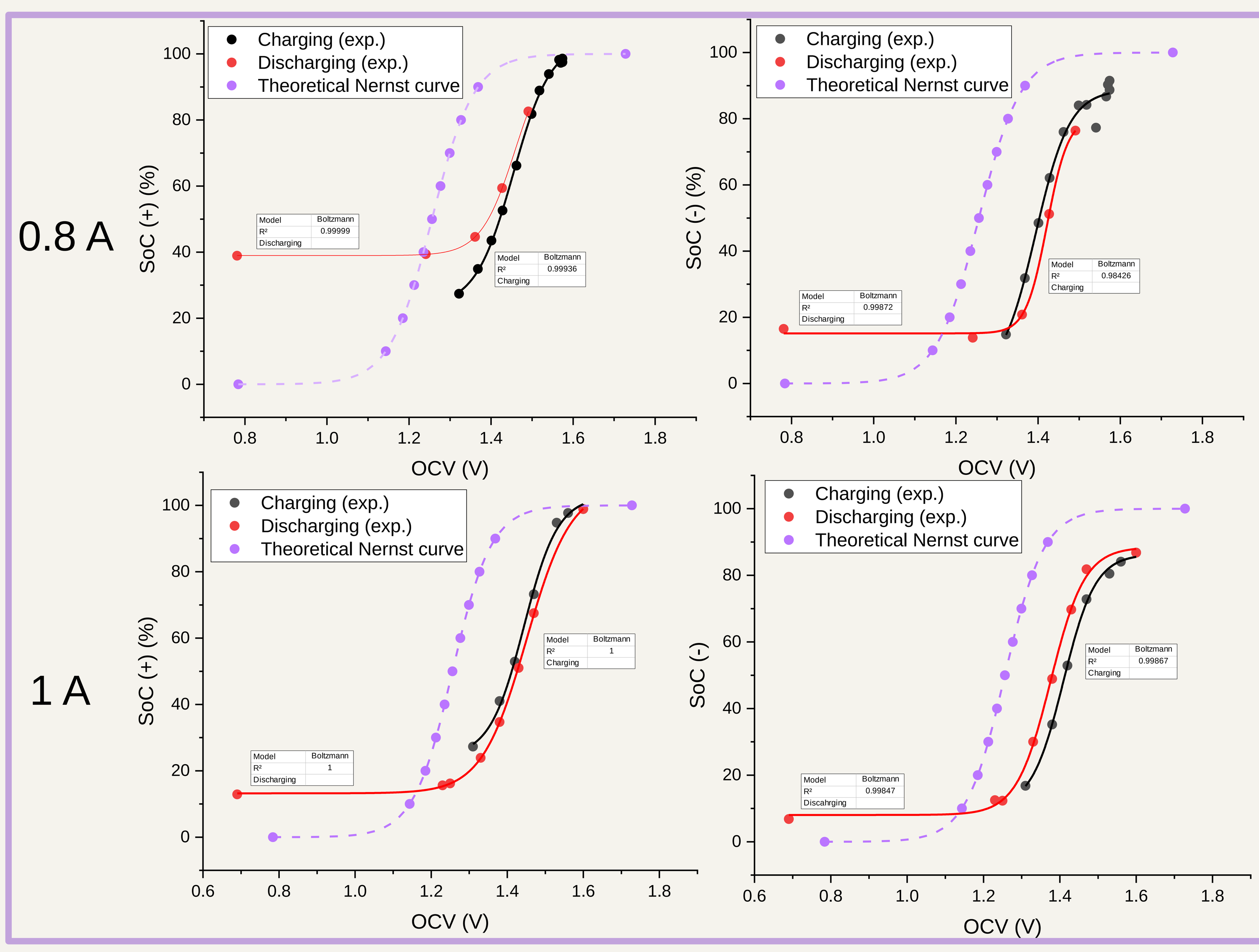
RESULTS

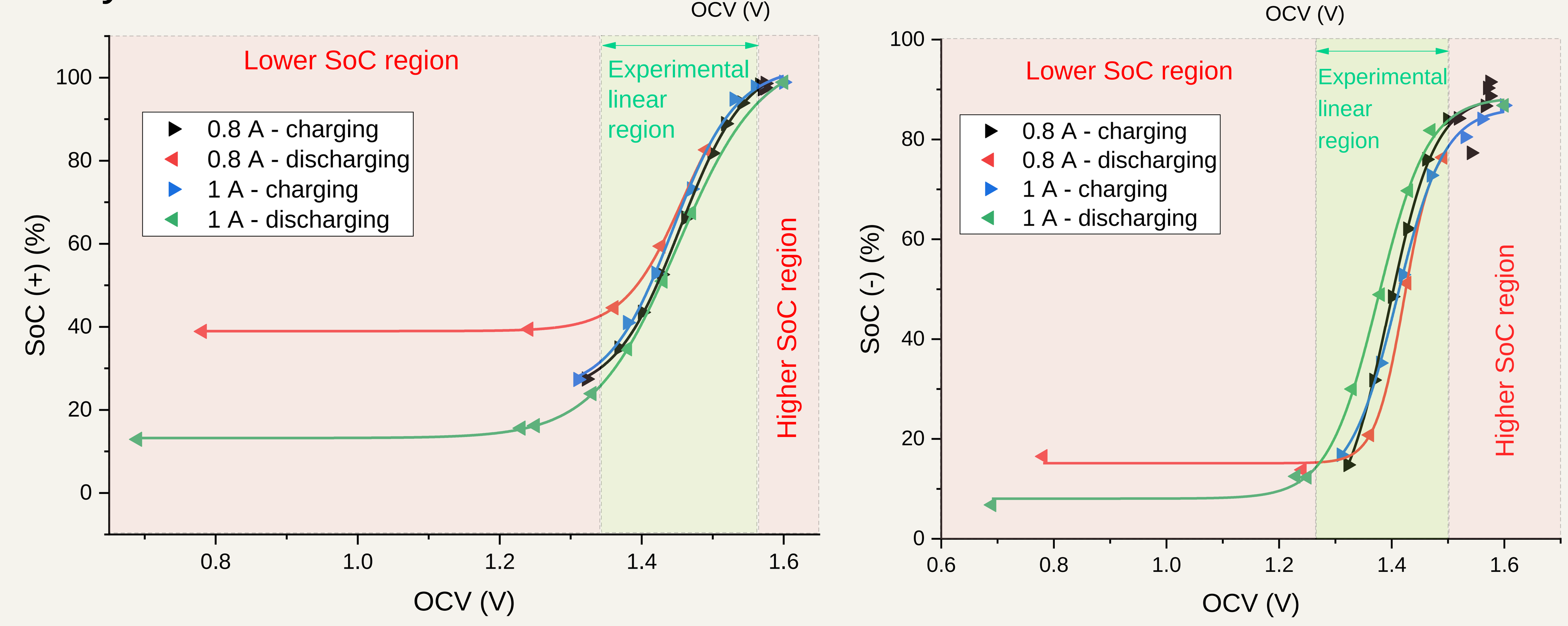


Activation



Vanadium species evolved in the expected direction in both half-cells during electrolyte activation.





SoC–OCV profiles obtained at 0.8 and 1 A showed comparable behaviour, with a distinct experimental linear region and deviations at lower and higher SoC.

CONCLUSION

- The UV–Vis calibration model enabled determination of vanadium species concentrations & independent SoC estimation
- Vanadium species evolution during electrolyte activation followed the expected trend in both half-cells
- Similar SoC–OCV profiles were obtained at 0.8 & 1 A with non-linear behaviour towards the limits of the investigated SoC range
- The identified linear SoC–OCV region provides a basis for further optimisation of VRFB operating voltage limits
- UV-Vis spectroscopy shows strong potential for real-time, non-invasive SoC monitoring in VRFB systems

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