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VCE Chemistry ¾
Secondary Cells & Connected Cells [2.3]
Workbook

Outline:

Learning Objectives:

- ☐ **CH34 [2.3.1]** - Write Discharge & Recharge Reactions in Secondary Cells
- ☐ **CH34 [2.3.2]** - Identify Factors which Affect Rechargeability & Compare Similarities/Differences between Secondary Cells and Other Cells
- ☐ **CH34 [2.3.3]** - Find Reactions Occurring in Connected Cells

Section A: Secondary Cells

Sub-Section: Introduction to Secondary Cells

Primary Cells

- **Definition:** Cells that [can] / [cannot] **be recharged** and can only produce electrical energy.
- **Energy Conversion:**

$$\textit{Chemical} \rightarrow \textit{Electrical}$$

Secondary Cells

- **Definition:** Cells that [can] / [cannot] **be recharged** and can only produce electrical energy.
- **Energy Conversion:**

$$\textit{Chemical} \rightarrow \textit{Electrical}, \underline{\hspace{8cm}}$$

Discussion: What are some electric appliances which use primary and secondary cells?

Primary Cells	Secondary Cells

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Exploration: Secondary Cell - Phone

- Consider a phone (Secondary Cell).

Scenario #1: When Phone is Being Used

- **Phone battery:** [uses] / [produces] electrical energy.
- **Energy Conversion:** ___________________________________
- **Battery Percentage:** [goes up] / [goes down]
- **Terminology:** ________________________

Scenario #2: When Phone is Being Charged

- **Phone battery:** [uses] / [produces] electrical energy.
- **Energy Conversion:** ___________________________________
- **Battery Percentage:** [goes up] / [goes down]
- **Terminology:** ________________________
- When the phone is being charged, is the **phone battery using** or **producing electrical energy**? What are the energy conversions?

Definition

Discharge & Recharge

Discharge	Recharge
[spontaneous] / [non-spontaneous]	[spontaneous] / [non-spontaneous]
[galvanic] / [electrolytic]	[galvanic] / [electrolytic]

Try some questions!

Question 1

A cell can be considered a secondary cell if:

A. It has a continuous supply of reactants.

B. It can operate at different temperatures.

C. The polarity of the electrodes remains unchanged.

D. It can operate both as a galvanic and electrolytic cell.

Question 2

Which of the following statements best differentiates secondary cells from primary cells?

A. Secondary cells can only discharge energy, while primary cells can both charge and discharge.

B. Secondary cells use non-rechargeable reactions, whereas primary cells use rechargeable chemical reactions.

C. Secondary cells are rechargeable through an external electrical source, while primary cells are not rechargeable.

D. Both secondary and primary cells are designed for single-use applications only.

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Question 3

Which of the following characteristics is unique to secondary cells when compared to typical electrolytic cells?

A. Electrolytic cells are capable of generating electrical energy without an external power source, unlike secondary cells.

B. Secondary cells can convert electrical energy into chemical energy for storage and later use, which is not a function of electrolytic cells.

C. Both secondary and electrolytic cells use electrodes to facilitate a chemical reaction.

D. Electrolytic cells are inherently rechargeable, while secondary cells are not.

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Sub-Section: Secondary Cell Half-Reactions

Misconception

"In a secondary cell, during discharge, the cathode is positive and the anode is negative.

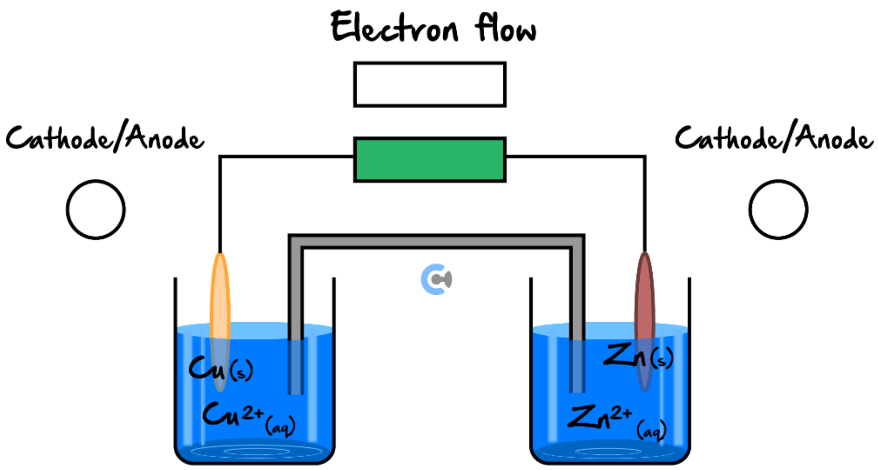
During recharge, the polarities of the two electrodes swap, and the cathode becomes negative while the anode becomes positive."

Exploration: Discharging of a Galvanic Cell

- Consider a galvanic cell containing $Cu^{2+}(aq)/Cu(s)$ & $Zn^{2+}(aq)/Zn(s)$.

Strongest Oxidant	Strongest Reductant

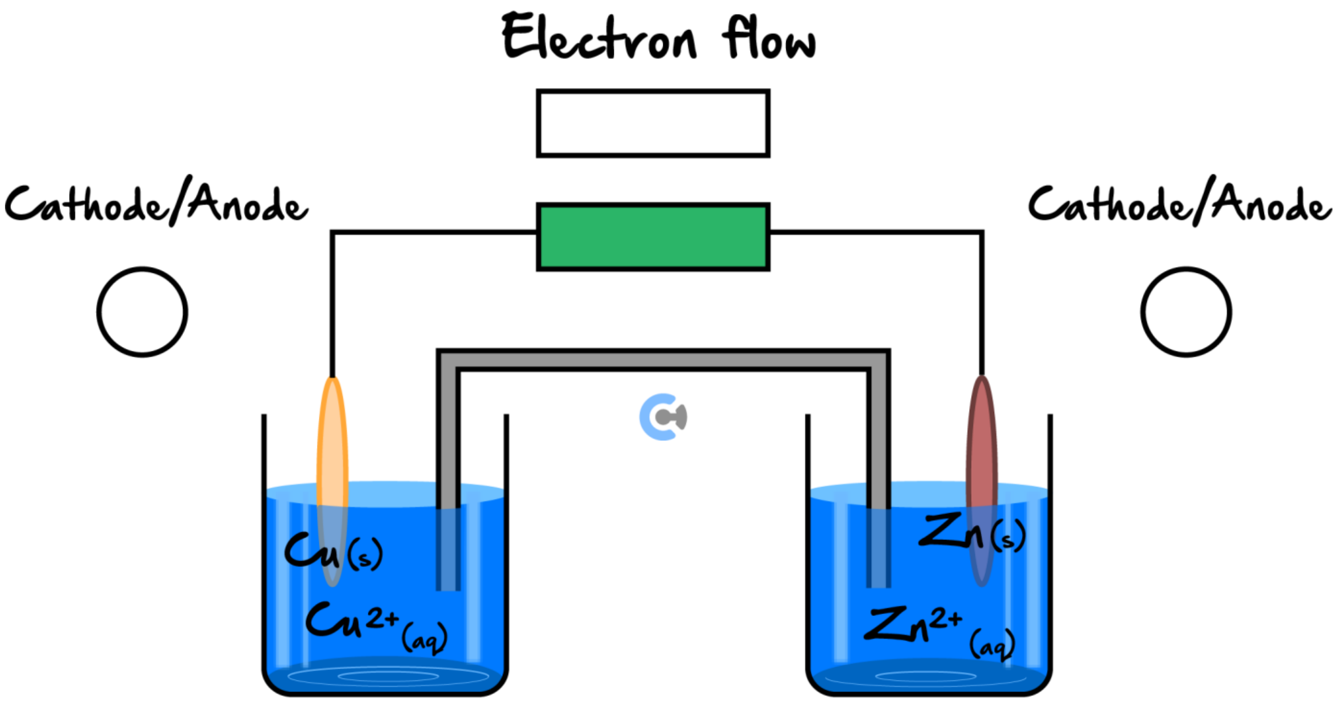
- Discharge Reactions:
  - Reduction: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$
  - Oxidation: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$
  - Overall: $Cu^{2+}(aq) + Zn(s) \rightarrow Cu(s) + Zn^{2+}(aq)$
- Cathode/anode & direction of electron flow: *(Label Below)*



Now, let's consider the opposite reaction!

<u>Exploration</u>: **Recharging of the Galvanic Cell**

- Consider the opposite, where electrical energy is inputted.
- **Recharge Reactions:**
  - **Reduction:** $Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$
  - **Oxidation:** $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$
  - **Overall:** $Cu(s) + Zn^{2+}(aq) \rightarrow Cu^{2+}(aq) + Zn(s)$
- Cathode/anode & direction of electron flow: *(Label Below)*



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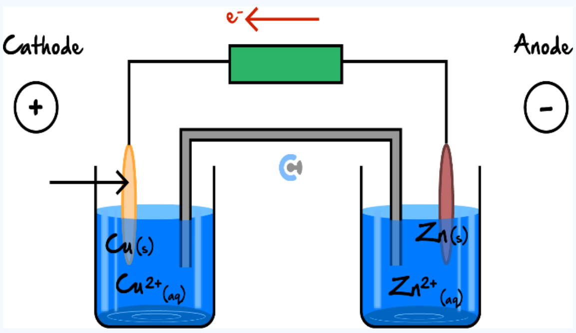
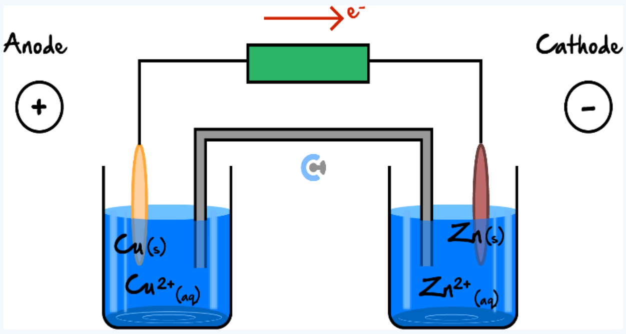
Let's put them both together and see what happens!

Exploration: Comparing the Discharging and Recharging of the Galvanic Cell

Discharge (Galvanic)	Recharge (Electrolytic)
	
Electrons [naturally] / [forced to] flow.	Electrons [naturally] / [forced to] flow.
Electron Flow: [left] / [right]	Electron Flow: [left] / [right]

- **At Left Copper Electrode:**

Process	Discharge (Galvanic)	Recharge (Electrolytic)
Type of Electrode	[cathode] / [anode]	[cathode] / [anode]
Polarity	[positive] / [negative]	[positive] / [negative]

- The type of electrode (cathode/anode) ________________.

  - The left copper electrode switches from **acting** as the __________________ during discharge, to **acting** as the _________________ during recharge.

- The charge/polarity of the electrode (+/–) _____________________________________.

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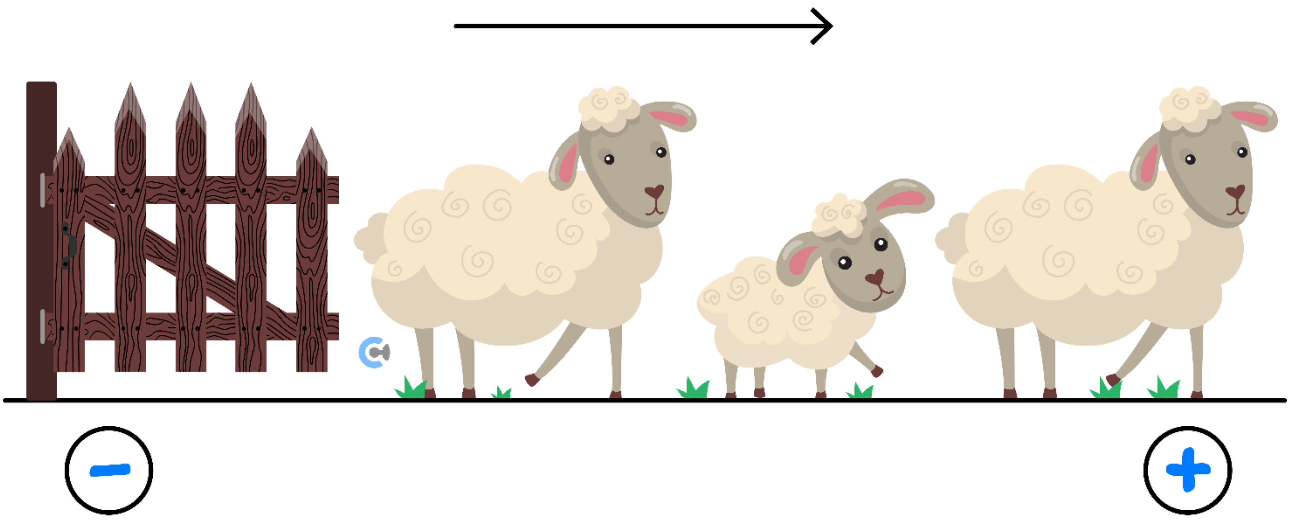
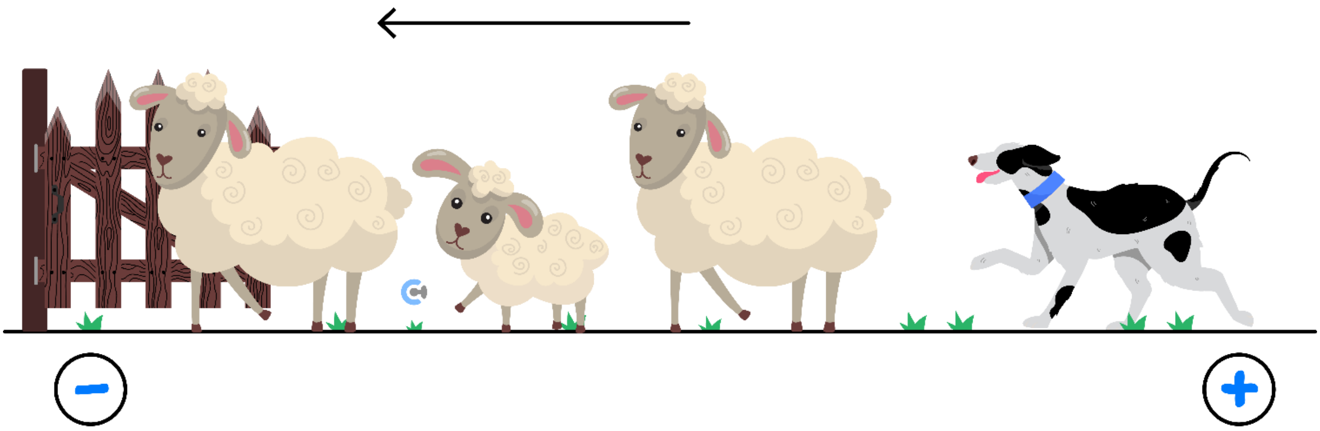
Analogy: Sheep & Dog

- **Discharge**: Sheep running in one way by themselves.



- **Recharge:** Sheepdog forcing them back.



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Definition

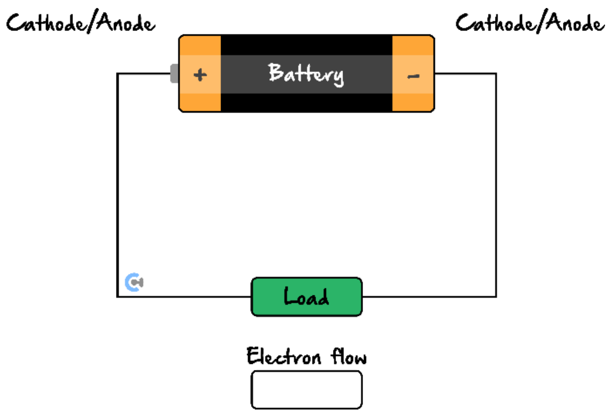
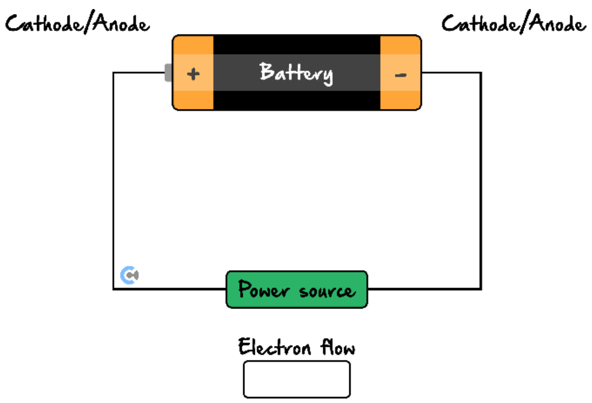
Discharge vs Recharge Electrodes

- The **polarities** of the electrodes [do] / [do not] **swap.**
- The ______________ of the cathode and anode **swap** and the **polarity** of the electrode stays the same.

Electrode	Galvanic	Electrolysis
Positive	[cathode] / [anode]	[cathode] / [anode]
Negative	[cathode] / [anode]	[cathode] / [anode]

Exploration: Battery

- Consider a rechargeable double AA battery secondary cell.

Discharge (Galvanic)	Recharge (Electrolytic)
	

- Notice how the left electrode is always [positive] / [negative].
- Polarities are **literally painted** on the battery. They will never change!

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Let's have a look at the equations a bit more in-depth!

Exploration: Copper-Zinc Battery

- Here are the equations which take place during discharge:

$$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$$

$$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$$

- Cathode/Anode & Polarities during **Discharge**: *(Label on Left Side)*
- Cathode/Anode & Polarities during **Recharge**: *(Label on Right Side)*
- The polarity of the copper electrode during discharge and recharge:________________________

Finding Reactions in Secondary Cells

- Write "RC +/−" and "AO +/−" and arrows showing which way the reaction goes!

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Now, let's have a look at a question together!

Question 4 Walkthrough.

The electrode reactions which occur when the Nickel-Cadmium battery is producing electrical energy are shown below.

$$NiO_2(s) + 2H_2O(l) + 2e^- \rightarrow Ni(OH)_2(s) + 2OH^-(aq)$$

$$Cd(s) + 2OH^-(aq) \rightarrow Cd(OH)_2 + 2e^-$$

Which one of the following correctly shows the type of electrode reaction and the half-cell equation at the negative electrode when the battery is being recharged?

A. Oxidation: $Ni(OH)_2(s) + 2OH^-(aq) \rightarrow NiO_2(s) + 2H_2O(l) + 2e^-$

B. Reduction: $Ni(OH)_2(s) + 2OH^-(aq) \rightarrow NiO_2(s) + 2H_2O(l) + 2e^-$

C. Oxidation: $Cd(OH)_2(s) + 2e^- \rightarrow Cd(s) + 2OH^-(aq)$

D. Reduction: $Cd(OH)_2(s) + 2e^- \rightarrow Cd(s) + 2OH^-(aq)$

NOTE: These equations cannot be found in the electrochemical series, and thus, we need to work with what we're given!

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Your turn!

Question 5

The rechargeable nickel-cadmium cell is used to power small appliances such as portable computers. When the cell is being used, the electrode reactions are represented by the following equations during discharge:

$$NiO_2(s) + 2H_2O(l) + 2e^- \longrightarrow Ni(OH)_2(s) + 2OH^-(aq)$$

$$Cd(s) + 2OH^-(aq) \longrightarrow Cd(OH)_2(s) + 2e^-$$

Which of the following occurs during the recharging of the Nickel-Cadmium cell?

I. Cadmium is deposited on the negative electrode.

II. The pH of the electrolyte increases.

III. The direction of electron flow in the external circuit is from the anode to the cathode.

A. I only.

B. I and II only.

C. II and III only.

D. I and III only.

Question 6

A storage battery used in hybrid cars contains a series of nickel metal hydride cells. MH represents a metal hydride alloy that is used as one electrode. The other electrode is composed of nickel oxide hydroxide (NiOOH).

The half-equations during discharging are:

$$NiOOH(s) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq)$$

$$MH(s) + OH^-(aq) \rightarrow M(s) + H_2O(l) + e^-$$

a. Give the formula of the reductant during discharging.

____

b. Suggest a suitable electrolyte for the battery.

---

c. Write the half equation occurring at the anode during recharging.

---

d. Write a total equation for the battery when it is recharging.

---

e. Would this cell be described as a primary, secondary, or fuel cell? Why?

NOTE: Electrolyte still moves like salt bridge:

$$\textit{Cations} \rightarrow \textit{Cathode}, \textit{Anions} \rightarrow \textit{Anode}$$

Question 7

The reaction below represents the discharge cycle of a standard lead-acid rechargeable car battery.

$$Pb(s) + PbO_2(s) + 4H^+(aq) + 2SO_4{}^{2-}(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$$

During the recharge cycle, the pH:

A. Increases and solid Pb is a reactant.

B. Increases and solid PbO_2 is produced.

C. Decreases and chemical energy is converted to electrical energy.

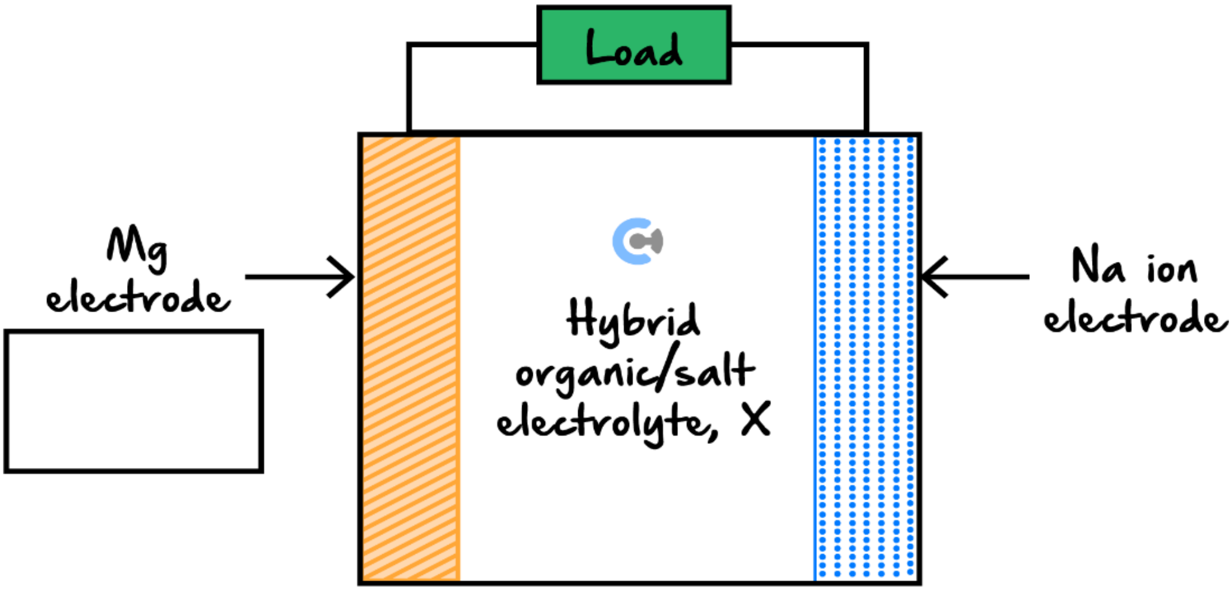
D. Decreases and electrical energy is converted to chemical energy.

Question 8 Additional Question.

Research scientists are developing a rechargeable magnesium–sodium, Mg-Na, hybrid cell for use in portable devices.

The Mg-Na hybrid cell uses magnesium metal and sodium ion electrodes and a hybrid organic/salt electrolyte, X.

A simplified diagram of the rechargeable Mg-Na hybrid cell is shown below.



a. The equation for the overall reaction during **recharge** is:

$$2NaX + Mg^{2+} \rightarrow Mg + 2Na^{+} + 2X$$

Identify the polarity of the Mg electrode when the cell is discharging by placing a positive (+) or a negative (−) sign in the box provided in the diagram above.

b. Write the half-cell equation of the reaction that occurs at the Mg electrode when the cell is **discharging.**

____

c. Write the half-cell equation of the reaction that occurs at the Na ion electrode when the cell is **recharging.**

____

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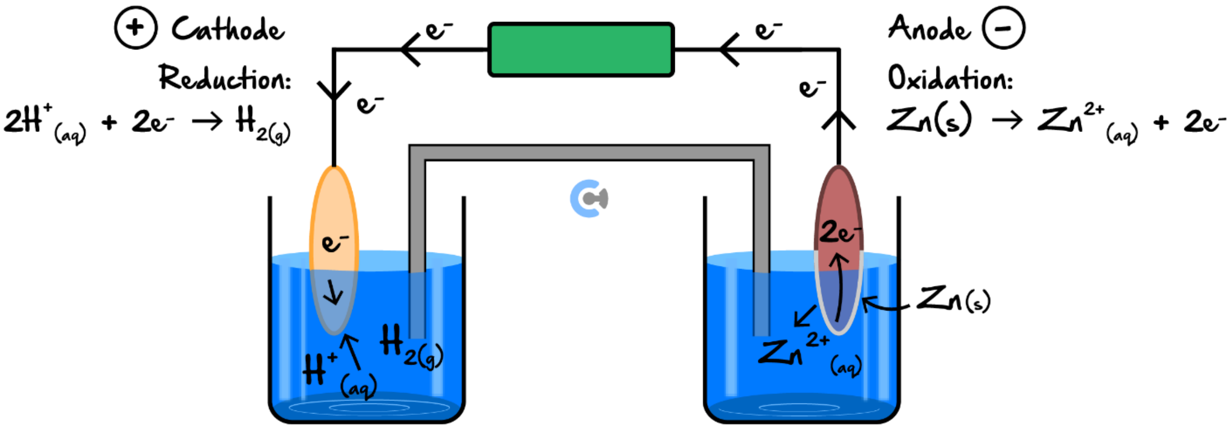
Sub-Section: Rechargeability of Secondary Cells

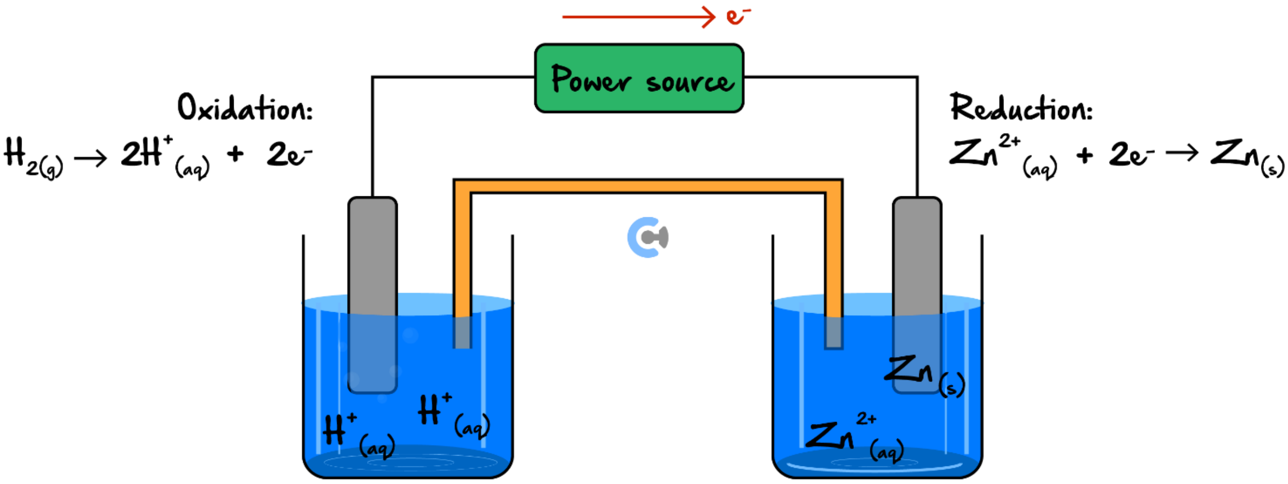
What makes it so that secondary cells can be recharged but primary cells cannot?

Exploration: Rechargeability of Secondary Cells

- Consider a **galvanic cell** containing $H^+(aq)/H_2(g)$ and $Zn^{2+}(aq)/Zn(s)$.



- Discharge Half-Equations:
  - Reduction Cathode: $2H^+(aq) + 2e^- \rightarrow H_2(g)$
  - Oxidation Anode: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$
- Where do the products go? *(Label Above)*
- Consider the **electrolytic cell** which does the opposite.
- Recharge Half-Equations:
  - Reduction Cathode: $Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$
  - Oxidation Anode: $H_2(g) \rightarrow 2H^+(aq) + 2e^-$



- In the reverse equation, reactants are: ____________ & ____________
- Is the $Zn^{2+}(aq)$ present in the cell? Can it react? [Yes] / [No]
- Is the $H_2(g)$ present in the cell? Can it react? [Yes] / [No]
- Rechargeability of this cell: [rechargeable] / [non-rechargeable]
- **Conclusion**: For a cell to be rechargeable, the products must ________________ with the electrodes!
- **Another Requirement for Rechargeability**: Must not participate in ________________.

What are side reactions?

Definition

<u>Side Reactions in Primary Cells</u>

- **Definition**: An unintended chemical reaction which occurs alongside the main reaction.
- **Examples:**
  - **Electrolyte Decomposition:** In dry cells, ammonium chloride, $NH_4Cl(aq)$ decomposes, forming NH_3 and other by-products.
  - **Electrode Decomposition**: Zinc anode in alkaline batteries undergoes irreversible corrosion, forming $Zn(OH)_2(s)$ and $ZnO(s)$.

NOTE: You do not need to know or remember any specific examples of side reactions!

Discussion: What state of matter will remain in contact with the electrode?

[solid] / [liquid] / [gas] / [aqueous]

NOTE: Consider some of the previous questions, and notice how most things are **solid** in state.

$$NiOOH(s) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq)$$

$$MH(s) + OH^-(aq) \rightarrow M(s) + H_2O(l) + e^-$$

Requirement for Rechargeability

- Requirements for rechargeability:
  1. Reactants/Products must remain in contact with the electrode.
  2. Reactants/Products must not participate in side reactions.

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Sub-Section: Lead-Acid Accumulator

Context

- The lead-acid accumulator is the **most common secondary cell** that is **tested by VCAA**.
- **Found in:** ___________________________

Accumulator

- Accumulator is another term for a secondary cell.

Let's have a look at these ideas in the lead-acid accumulator!

Exploration: Lead-Acid Accumulator

- In battery, lead (Pb) exists in **three** oxidation states:

Lead States	Lead Solid $Pb(s)$	Lead sulphate $PbSO_4(s)$	Lead Oxide $PbO_2(s)$
Oxidation State			
State of Matter			

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Let's have a look at the equations together!

Exploration: Lead-Acid Accumulator Half-Equations

- **Electrolyte**: Sulphuric acid $H_2SO_4(aq)$ which contains both $H^+(aq)$ and $SO_4{}^{2-}(aq)$.
- **During discharge:**
  - **Reduction:** $PbO_2(s) \rightarrow PbSO_4(s)$
  - **Oxidation:** $Pb(s) \rightarrow PbSO_4(s)$
- **Balanced Half-Equations:**
  - **Reduction (Cathode):**
  - **Oxidation (Anode):**
- **Overall Reaction:**

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Exploration: Lead Oxidation Numbers During Discharge

- Consider Oxidation Numbers of Pb:

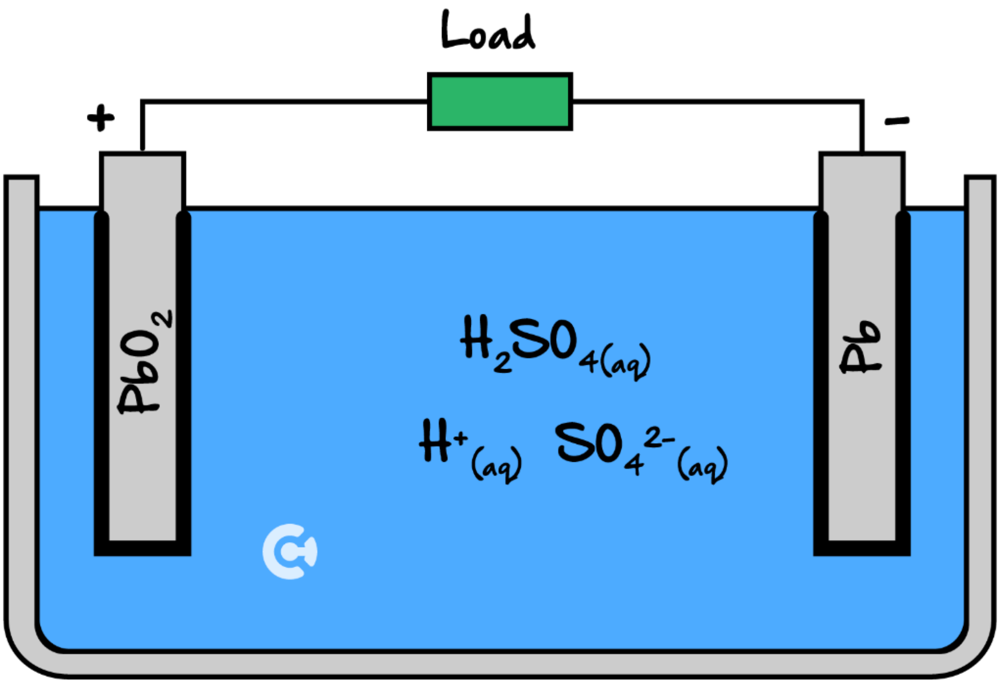
ON: ________ - $PbO_2(s)$

ON: ________ - $Pb(s)$

$PbSO_4(s)$ - ON: ________

Exploration: Operation of Lead-Acid Accumulator during Discharge

- **Half-equations:**
  - (+) **Cathode:** $PbO_2(s) + SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$
  - (−) **Anode:** $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$
- **Overall reaction:** $PbO_2(s) + Pb(s) + 2H_2SO_4(aq)) \rightarrow 2PbSO_4(s) + 2H_2O(l)$
- Anode Reaction & How Reactants Move: *(Label Below)*
- Cathode Reaction & How Reactants Move? *(Label Below)*



- **Opposite Reaction:** Now, $PbSO_4(s)$ is on the electrode, it just does the reverse!

Definition

Lead-Acid Accumulator Discharge Reactions

- **Half-equations**:
  - (+) **Cathode:** $PbO_2(s) + SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$
  - (−) **Anode:** $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$
- **Overall reaction:** $PbO_2(s) + Pb(s) + 2H_2SO_4(aq)) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

Let's figure out what happens when it recharges,
but firstly, try balancing the half-equations for the recharge!

Question 9

Write the recharge reactions **without looking at the previous question** which occur in a lead-acid accumulator. It is known that:

$PbSO_4(s)$ is oxidised into $PbO_2(s)$ and $PbSO_4(s)$ is reduced to $Pb(s)$ during recharge.

a. Write the half-equation at the cathode.

____

b. Write the half-equation at the anode.

____

c. Overall reaction.

____

____

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Question 10

The lead acid battery consists of 6 cells connected in series. It is commonly used in cars and is able to be recharged. The reactions occurring when the cell is discharging are:

- Cathode: $PbO_2(s) + H_2SO_4(aq) + 2H^+(aq) + 2e^- \rightarrow PbSO_4(aq) + 2H_2O(l)$
- Anode: $Pb(s) + H_2SO_4(aq) \rightarrow PbSO_4(aq) + 2H^+(aq) + 2e^-$

When the battery is being recharged:

A. The lead electrode is still the anode and the lead oxide electrode is still the cathode.

B. Electrons flow from the lead electrode to the lead oxide electrode.

C. The lead electrode has a negative polarity and the lead oxide electrode has a positive polarity.

D. The pH in each cell of the battery will increase.

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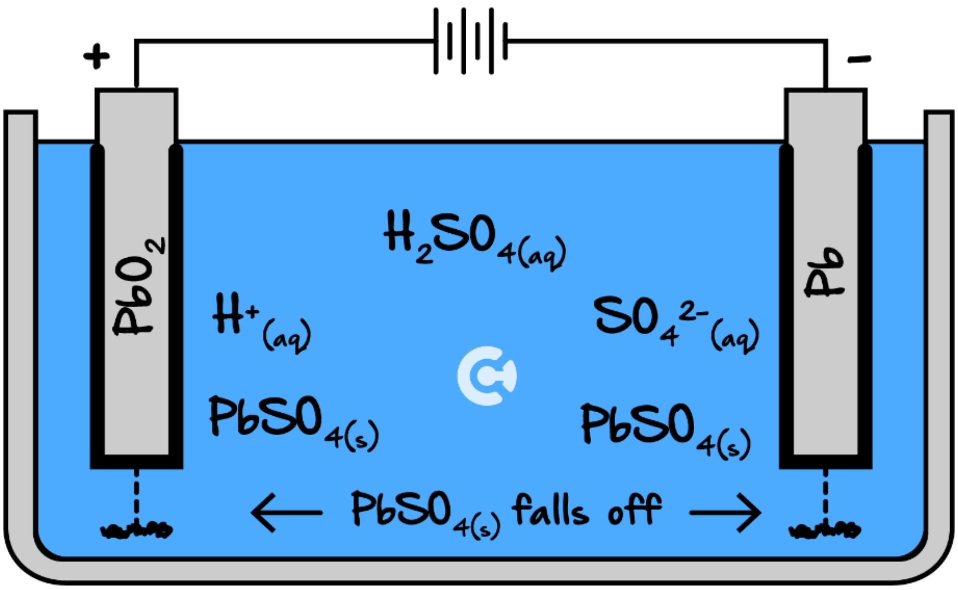
Sub-Section: Battery Life of Secondary Cells

Exploration: What affects the battery life of secondary cells?

- Imagine some of the product, $PbSO_4(s)$, has fallen off the electrodes.



- When reactants/products fall off, can they react anymore? [Yes] / [No]
- **Conclusion**: Battery life is decreased by the reactants/products falling off the electrode and losing contact.

Discussion: What can cause the products to fall off the electrodes?

- ____
- ____
- ____

NOTE: Modern secondary cells (such as phones/laptops) have a **system** in place which **stops electricity from entering a fully charged battery**. However, it is still best to not overcharge them!

Discussion: Why aren't secondary cells used everywhere? Why do we even use primary cells?

- ________________________________

- ________________________________

Requirement for Rechargeability

- **Requirements for rechargeability:**

  1. Reactants/Products must remain in contact with the electrode.
  2. Reactants/Products must not participate in side reactions.

- **This occurs by:**

  - External/Physical Stress to Battery - causes reactants/products to fall off the electrode.
  - Overheating - increases the likelihood of side reactions.
  - Overcharging the battery - does both of the above.

Primary vs Secondary Cell

Primary Cell	Secondary Cell
[rechargeable] / [non-rechargeable]	[rechargeable] / [non-rechargeable]
Can act as [galvanic] / [electrolytic] cell	Can act as [galvanic] / [electrolytic] cell
[chemical to electrical] / [electrical to chemical]	[chemical to electrical] / [electrical to chemical]
[cheap] / [expensive]	[cheap] / [expensive]

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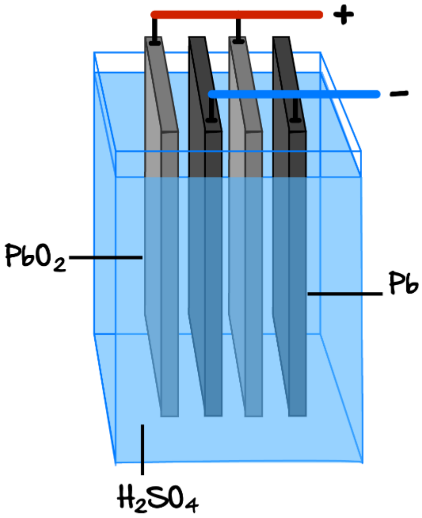
Your turn!

Question 11

The lead-acid accumulator is a secondary cell which is commonly used in cars. During discharge, the following reaction occurs:

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$$



a. Write the half-equation for the reaction occurring at the positive electrode as the cell discharges.

b. Write the half-equation for the reaction occurring at the negative electrode as the cell recharges.

c. What happens to the pH of the cell as the cell recharges?

d. Given its prevalent use in car batteries, they often experience sudden changes in velocity and as such, the battery can experience physical stress. Explain what impact this might have on the battery life of the cell.

TIP: If you're ever stuck, start off by finding the oxidation numbers of everything to figure out what is oxidised or reduced in the half-equations.

Question 12

Which of the following statements about rechargeable batteries is **incorrect**?

A. Rechargeable batteries are also called secondary cells.

B. During recharge, the polarities of the electrodes are the same as when the battery is discharging.

C. Rechargeable batteries can be used indefinitely.

D. During discharge, cations in the electrolyte move towards the anode.

Question 13 Additonal Question.

Which of the following best explains why primary cells are non-rechargeable?

A. The anode undergoes complete oxidation, leaving no active material for reversal.

B. Side reactions cause irreversible changes to electrode and electrolyte composition.

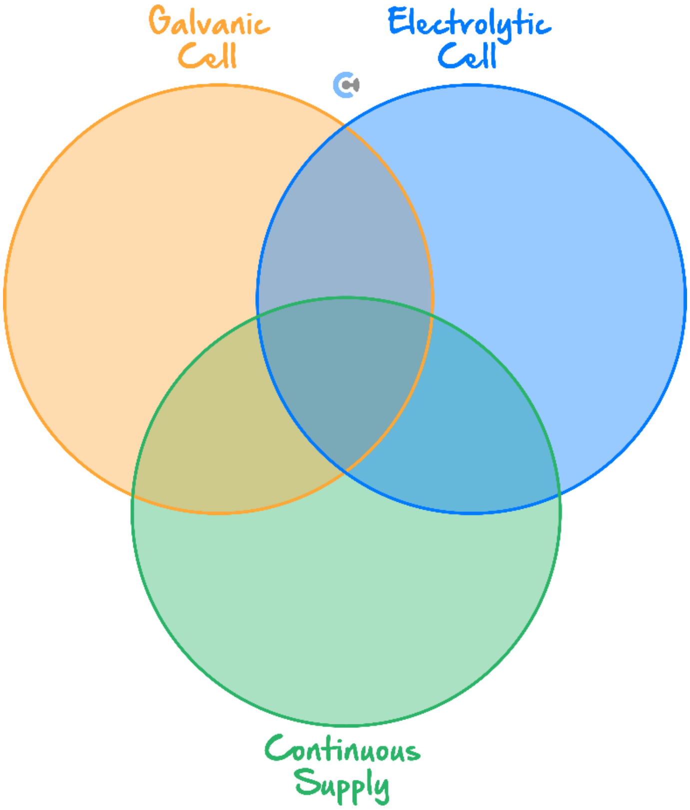
C. The cathode dissolves into the electrolyte, preventing electron flow.

D. The internal resistance of the cell becomes infinite after discharge.

Section B: Redox Flow Battery

Context

- Redox flow batteries are essentially a **combination** of fuel cells and secondary cells.



- **Redox Flow Battery**: **Rechargeable cell** with a **continuous supply** of reactants!
- The most common type of redox flow battery which is covered is the **Vanadium Redox Flow Battery**.

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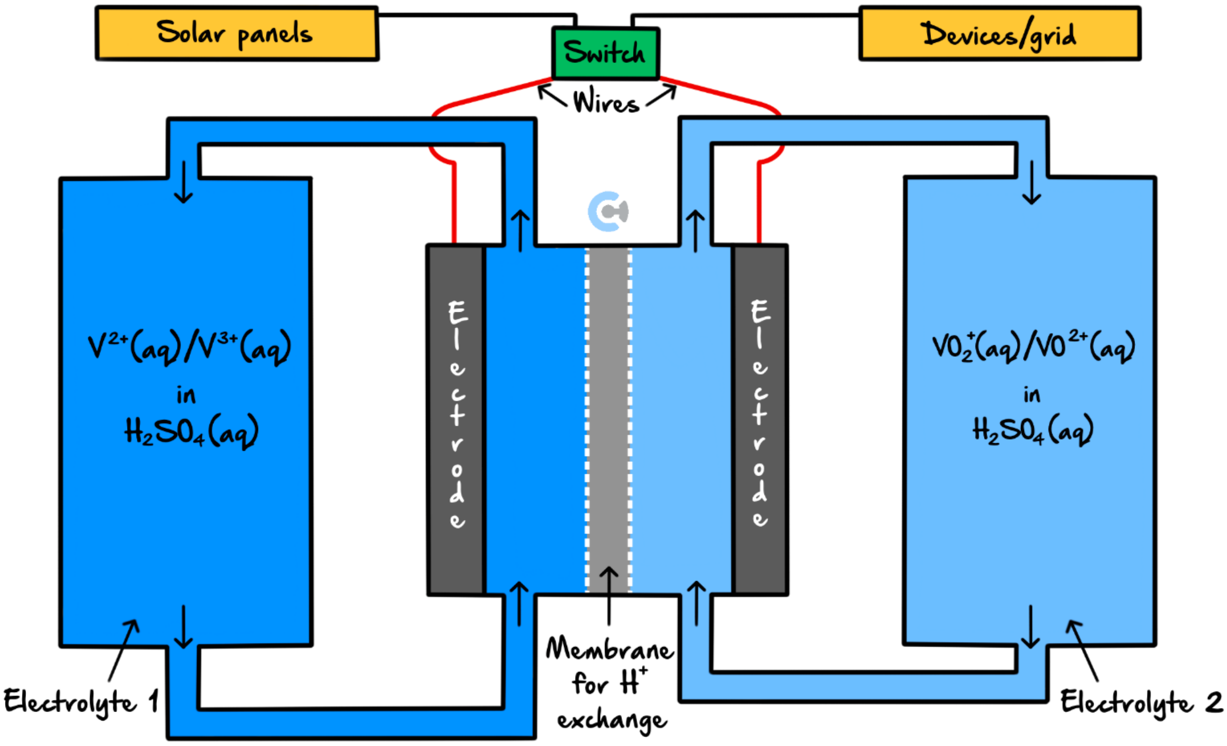
Definition

Vanadium Redox Flow Battery

- Consists of power cells in which the two electrolytes are separated by a proton exchange membrane.



- Half-Equations:

$$VO_2^+(aq) + 2H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + H_2O(l) \qquad E^\circ = +1.004\ V$$

$$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq) \qquad E^\circ = -0.255\ V$$

  - Half-equations are both given as reversible reduction half-equations like Data Book.
  - Four Oxidation States of Vanadium: $VO_2^+(aq)$, $VO^{2+}(aq)$, $V^{3+}(aq)$, $V^{2+}(aq)$.

- **Method of finding reaction**: Find the strongest oxidant and strongest reductant.

NOTE: It is like a secondary cell, but with continuous supply!

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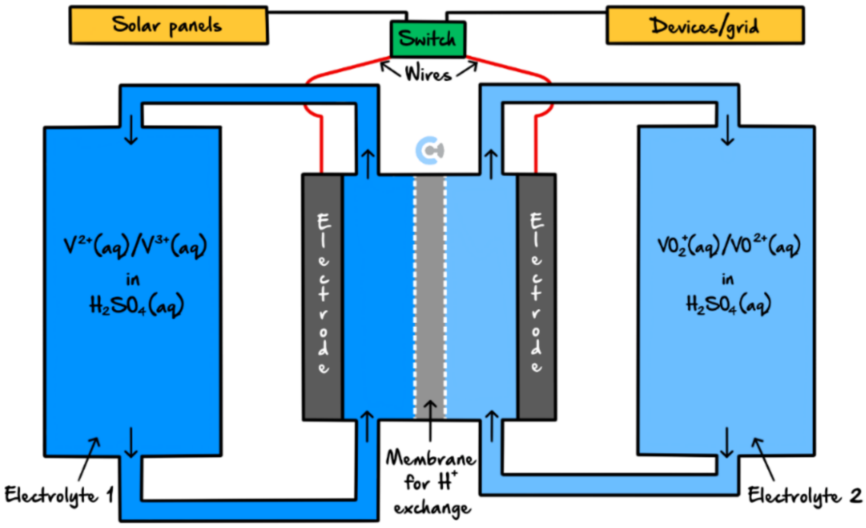
Let's look at a question together!

Question 14 Walkthrough.

An increasingly popular battery for storing energy from solar panels is the vanadium redox battery. The battery takes advantage of the four oxidation states of vanadium that are stable in aqueous acidic solutions.

A schematic diagram of a vanadium redox battery is shown below.



The two relevant half-equations for the vanadium redox battery are:

$$VO_2^+(aq) + 2H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + H_2O(l) \qquad E° = +1.00\ V$$

$$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq) \qquad E° = -0.26\ V$$

a. The overall reaction that occurs when the battery is discharging is: (1 mark)

A. $VO_2^+(aq) + 2H^+(aq) + V^{2+}(aq) \rightarrow VO^{2+}(aq) + V^{3+}(aq) + H_2O(l)$

B. $VO^{2+}(aq) + H_2O(l) + V^{3+}(aq) \rightarrow VO_2^+(aq) + V^{2+}(aq) + 2H^+(aq)$

C. $VO^{2+}(aq) + V^{2+}(aq) + 2H^+(aq) \rightarrow 2V^{3+}(aq) + H_2O(l)$

D. $VO_2^+(aq) + V^{3+}(aq) \rightarrow 2VO^{2+}(aq)$

b. Write the half-equation which occurs at the positive electrode during recharge.

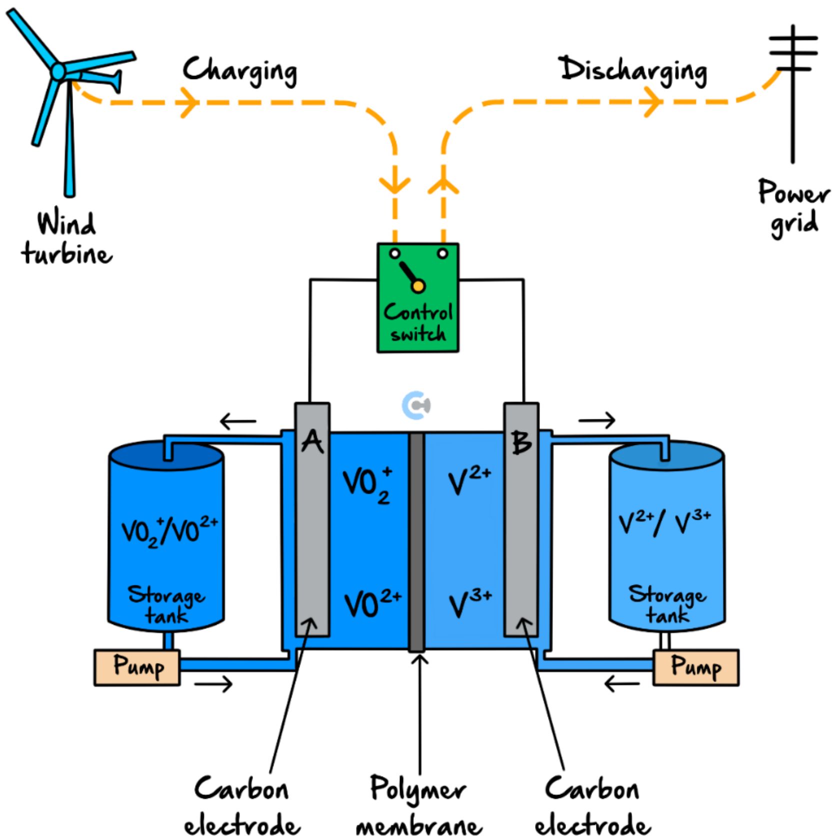
___

Your turn!

Question 15

A vanadium redox battery is used to store electrical energy generated at a wind farm in Tasmania. The battery supplies electricity to the power grid as required through a control switch.

The diagram below shows the structure of a cell in a vanadium redox battery. The reactants are dissolved in an acidic solution, stored in large tanks and pumped through the cell. The cell is recharged using electricity generated by the wind turbines. A polymer membrane allows the movement of particular ions.



The two relevant half-equations for the vanadium redox battery are:

$$VO_2^{+}(aq) + 2H^{+}(aq) + e^{-} \rightleftharpoons VO^{2+}(aq) + H_2O(l) \qquad E^\circ = +1.004\ V$$

$$V^{3+}(aq) + e^{-} \rightleftharpoons V^{2+}(aq) \qquad E^\circ = -0.255\ V$$

a. State the polarity of each electrode as the battery is discharged.

Electrode A: ________________________________.

Electrode B: ________________________________.

b. Write a balanced overall equation for the reaction that occurs when the cell is being **recharged**.

____

____

c. As the cell is **recharging**, circle the vanadium-containing ion that would have the highest concentration at the negative electrode when the cell is **fully charged**.

VO_2^{+} VO^{2+} V^{3+} V^{2+}

d. Compare the vanadium redox cell to a fuel cell by describing one major way in which they differ.

____

____

____

____

e. Write a balanced overall equation to show why iron would be an unsuitable material to use as electrode *B* in the vanadium redox cell.

____

____

____

NOTE: When a substance is 'fully charged', there's either the maximum amount of the substance as a reactant before discharge, or the maximum amount of the substance produced as a product at the end of recharging!

Space for Personal Notes

Section C: Connected Cells

Sub-Section: Galvanic vs Electrolytic Cells

Cells can be connected together!

Context

- Let's first cover how to identify whether a cell is galvanic or electrolytic.

Differences between Galvanic and Electrolytic Cells

	Galvanic Cells	Electrolytic Cells
Terminology Cues	Look for "Galvanic" or "Spontaneous" in question.	Look for "Electrolytic" or "Non-spontaneous" in question.
External Circuit	Attached to [load] / [power source]	Attached to [load] / [power source]

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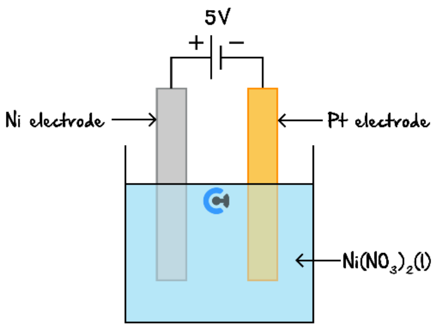
Let's look at a question together!

Question 16 Walkthrough.

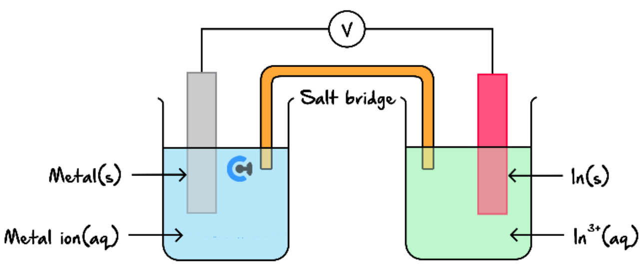
Identify whether each of the following is galvanic or electrolytic.

a.



[galvanic] / [electrolytic]

b.

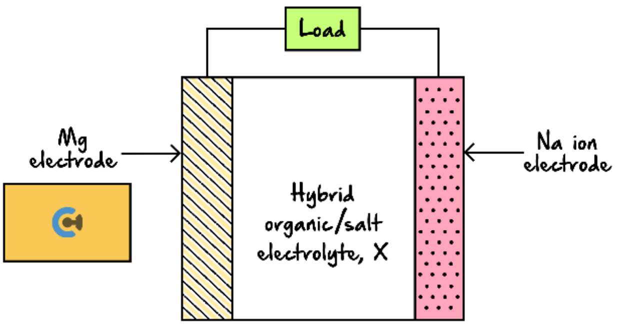


[galvanic] / [electrolytic]

Question 17

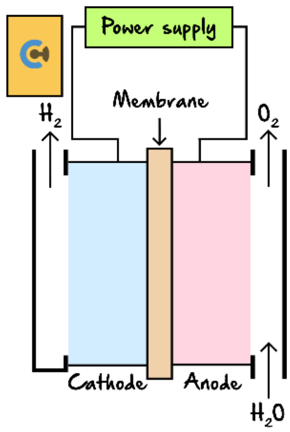
Identify whether each of the following is galvanic or electrolytic.

a.



[galvanic] / [electrolytic]

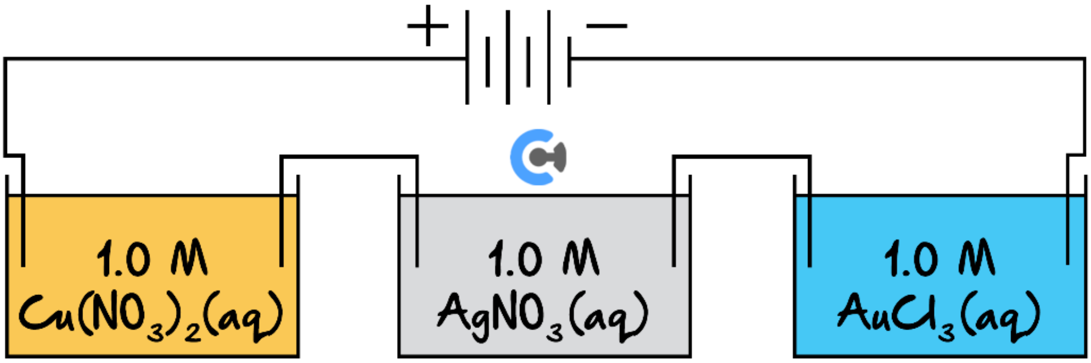
b.



[galvanic] / [electrolytic]

<u>Context</u>

- However, sometimes VCAA gives cells that are connected.



- **Alternative Name:** ____.

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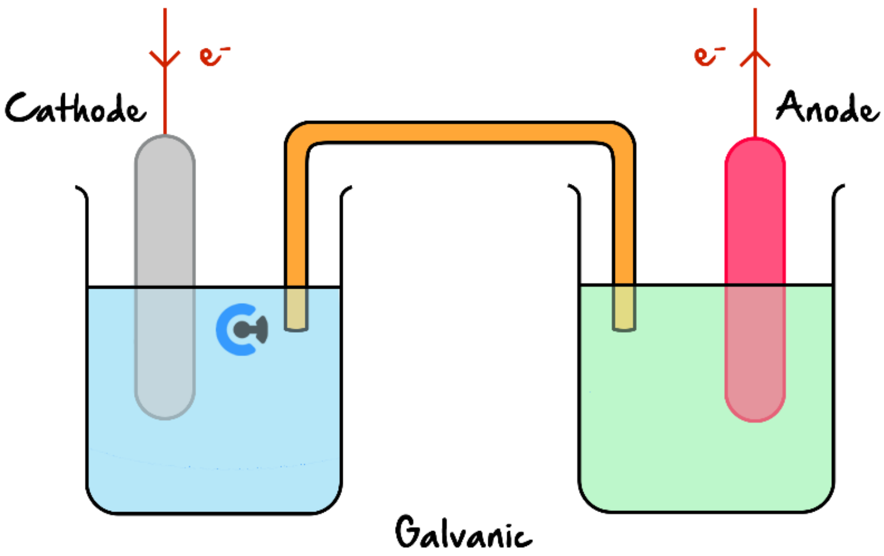
Sub-Section: Galvanic Connected Cells

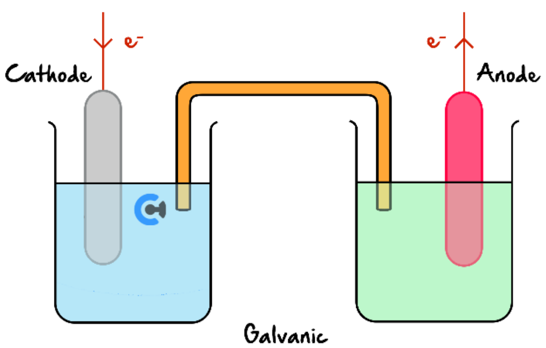
There are multiple types of connected cells – the first is when galvanic cells are connected.

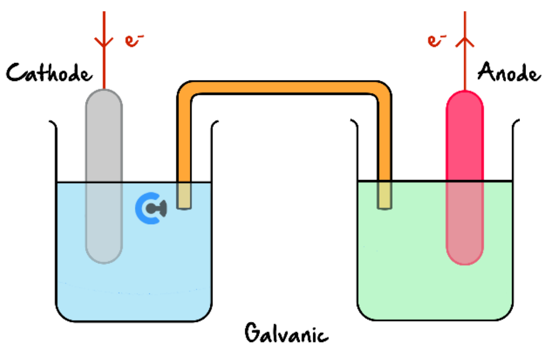
Exploration: Connected Galvanic Cells

- Consider a single galvanic cell.

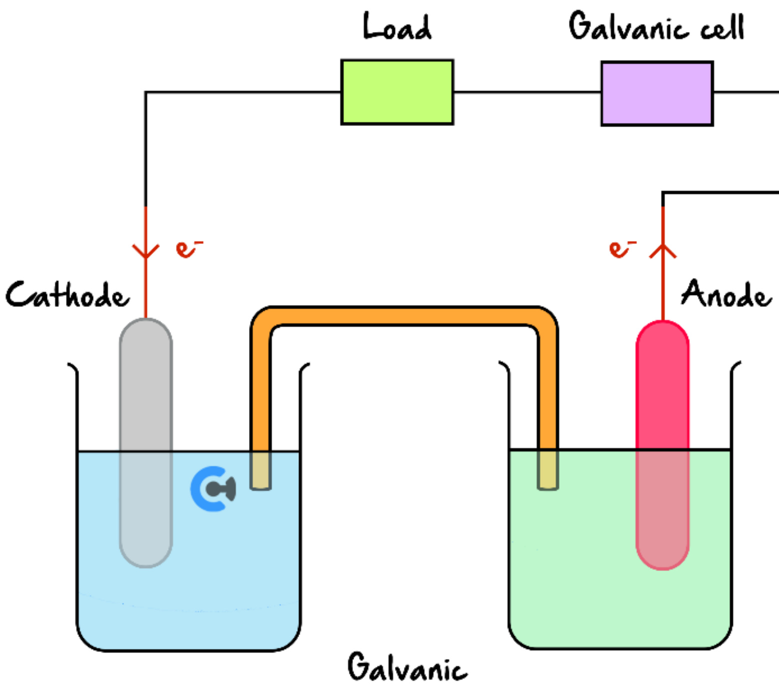


- **What if we link them together?**





- **Another Visualisation:**



- **Conclusion**: In connected galvanic cells, there is still a load that uses electrical energy.

- **Connected Galvanic Cell Alternative Name**: ________________________.

- **Scenario**: Each galvanic cell involving $Cu^{2+}(aq)/Cu(s)$ & $Zn^{2+}(aq)/Zn(s)$ produces $EMF = +1.10\ V$.

- **Total $\mathbf{EMF}$ produced in connected galvanic cell:** ________________.

TIP: Galvanic cells and connected galvanic cells both produce electrical energy and thus, there is a load that uses that energy.

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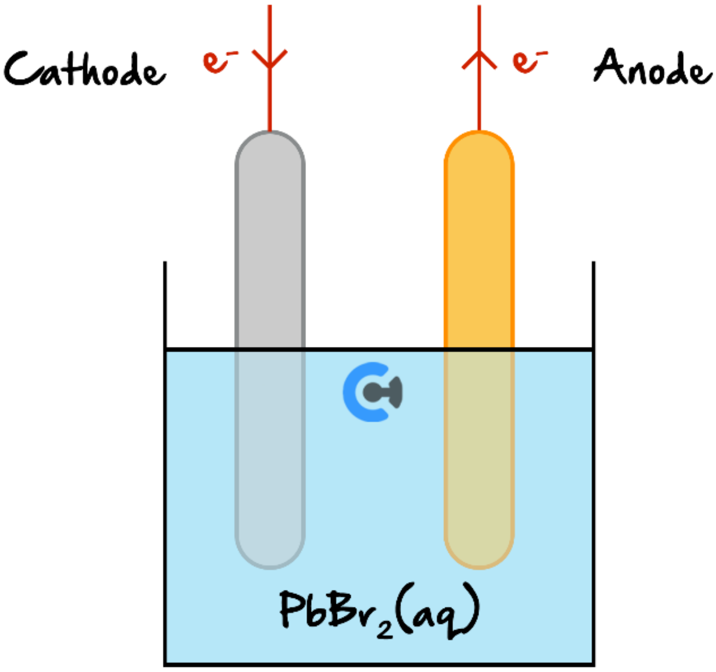
Sub-Section: Electrolytic Connected Cells

Exploration: Connected Electrolytic Cells

- Consider an electrolytic cell with lead bromide solution ($PbBr_2(aq)$) and inert electrodes.



- **Half-Equations:**
  - **Reduction:** $Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$
  - **Oxidation:** $2Br^-(aq) \rightarrow Br_2(l) + 2e^-$
- **Energy:** [inputted] / [produced]

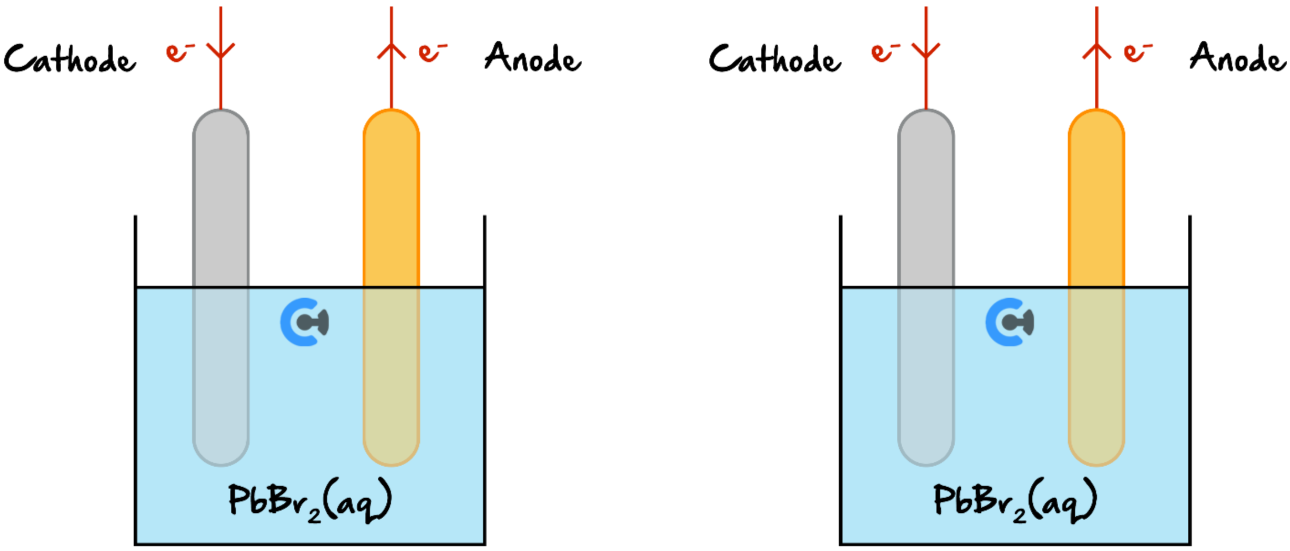
$$EMF = (-0.13) - (+1.09) = -1.22\ V$$

- **Voltage Required for Cell to Operate:** ________________.

REMINDER: During electrolysis, a voltage greater than the difference in voltage is required for a reaction to occur, as a positive EMF must be obtained before a reaction can proceed.

Exploration: Connected Electrolytic Cells Continued

- Consider two electrolytic cells connected.



- **Context**: Each electrolytic cell requires $> 1.22\ V$.
- **EMF Required for Connected Cell**: __________________.

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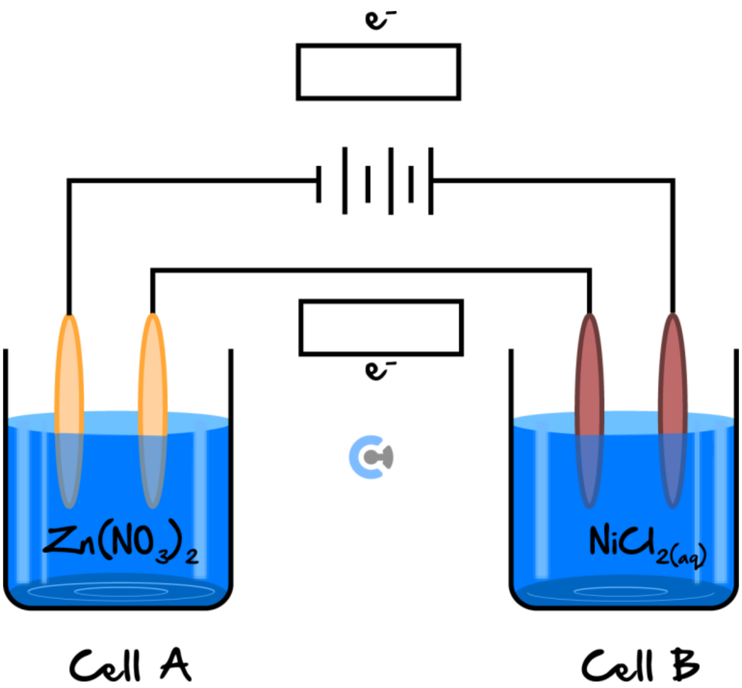
Let's have a look at a question together!

Question 18 Walkthrough.

Two cells, cell *A* and cell *B* are connected in series to a power source, with zinc nitrate electrolyte in cell *A*, and nickel chloride electrolyte in cell *B* as depicted below. Inert electrodes are used.



a. Label the direction of electron flow in the diagram above.

b. Write the balanced half-equations which occur in cell *A*.

Reduction: ____

Oxidation: ____

c. Write the balanced half-equations which occur in cell *B*.

Reduction: ____

Oxidation: ____

Space for Personal Notes

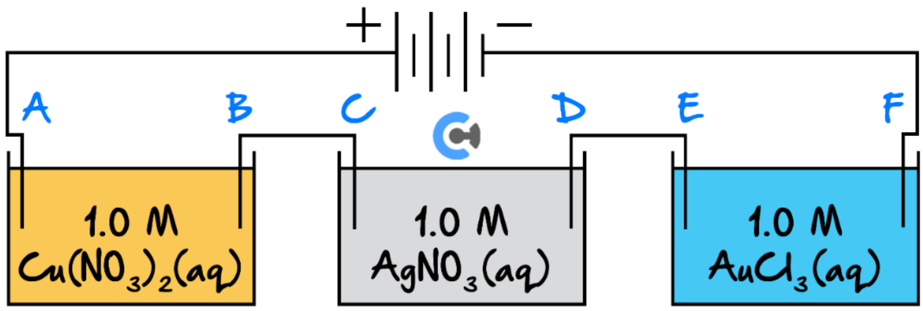
TIPS:

- First, **find the direction of electron flow!**
- In connected cells, **treat each cell as separate** – yes, they are connected, but the equations which occur in each cell do not change!

Your turn!

Question 19

A student sets up a circuit for electroplating copper, silver and gold in their separate cells as shown in the diagram below. The cells are connected in series.



a. In the right-most cell, state whether electrodes E and F are cathodes or anodes.

Electrode *E*	**Electrode *F***

b. Write the half-equation which occurs at:

i. Electrode A.

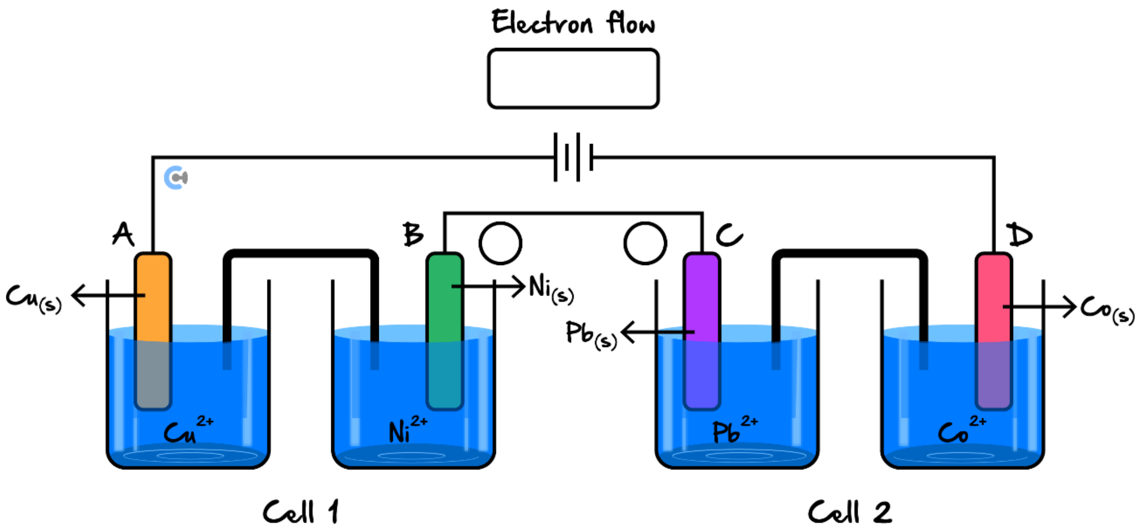
____

ii. Electrode B.

____

Question 20

A connected cell is set up below.



a. Label the direction of electron flow in the box provided, and label the polarities of electrodes *B* and *C* in the circles provided.

b. Identify whether electrode *D* is the cathode or anode.

____

c. Write the half-equation for the reaction which occurs at electrode *A*.

____

d. Write the half-equation for the reaction which occurs at electrode *B*.

____

e. What is the overall voltage required for the cell to operate both cell 1 and cell 2?

____

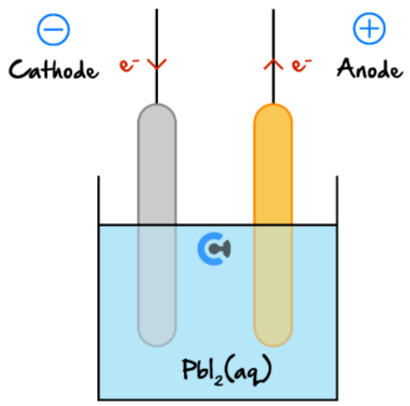
NOTE: As this is an electrolytic cell, a non-spontaneous reaction occurs!

ALSO NOTE: We'll cover how this works when we look at the next type of cell in depth!

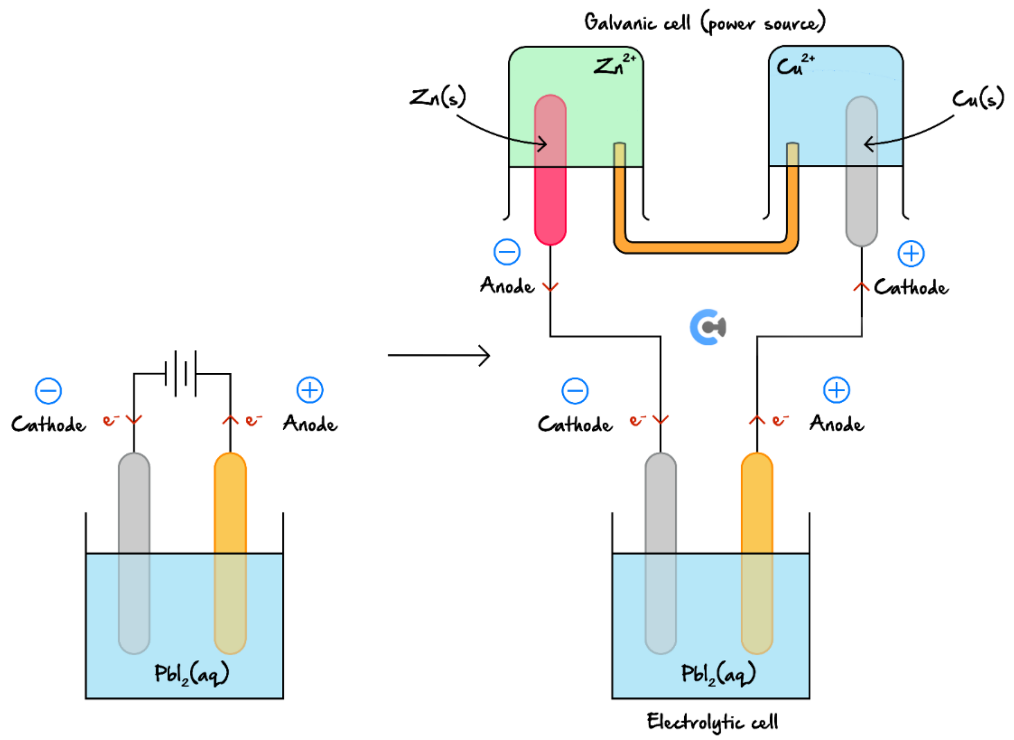
Sub-Section: Galvanic - Electrolytic Connected Cells

Exploration: Galvanic - Electrolytic Connected Cell

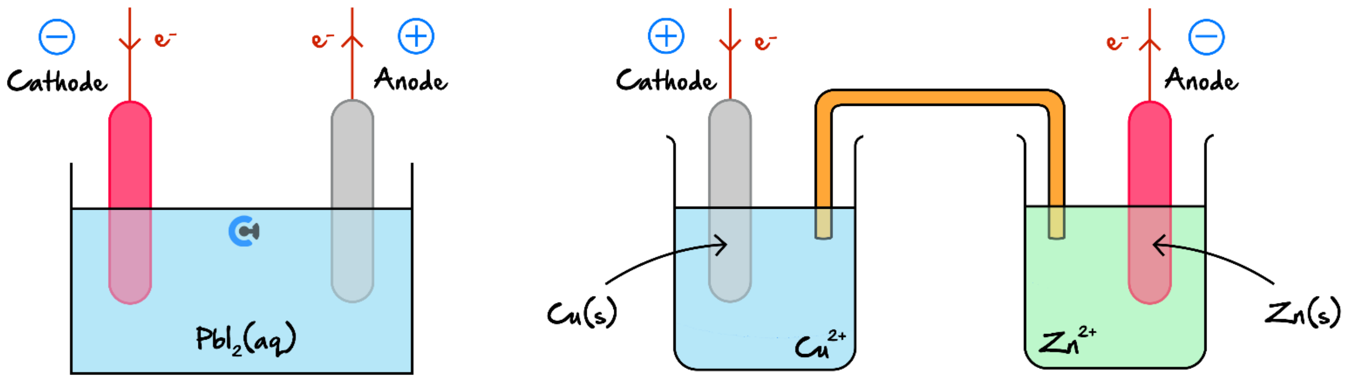
- Electrolytic Cells need a power source.



- What type of cell is a power source?[galvanic] / [electrolytic] cell
- **Conclusion**: To power an electrolytic cell, a [galvanic] / [electrolytic] cell is used.
- Instead of using an external power source, **connect** the **electrolytic cell** to a **galvanic cell**.

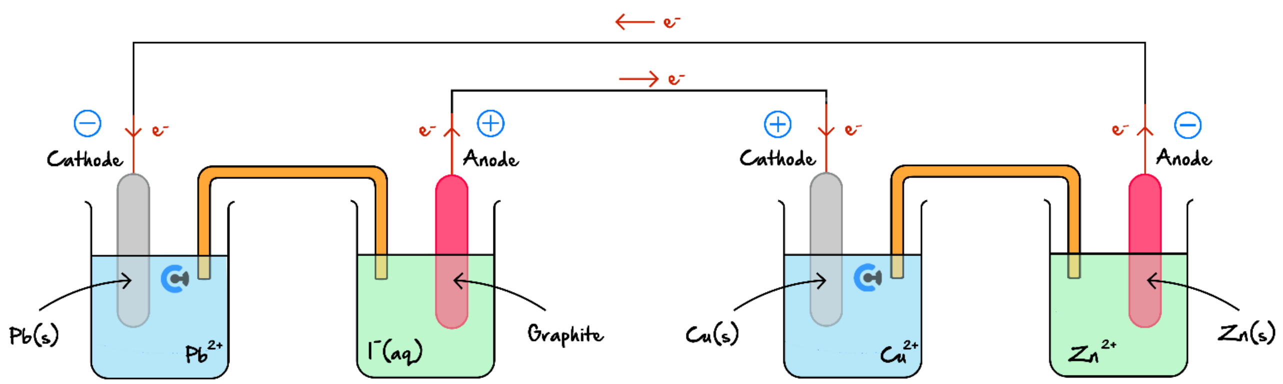


- Galvanic-Electrolytic Cell Redrawn.



- The galvanic cell (right) **produces** energy for the electrolytic cell (left) which **uses** energy.
- The galvanic cell ________________ the electrolytic cell!
- Galvanic Cell Produces $1.1\ V$, Electrolytic Cell Needs $> 0.67\ V$.
- Will the connected cell operate? [Yes] / [No]

- Sometimes, instead of drawing the electrolytic cell, it is also drawn with a salt-bridge.



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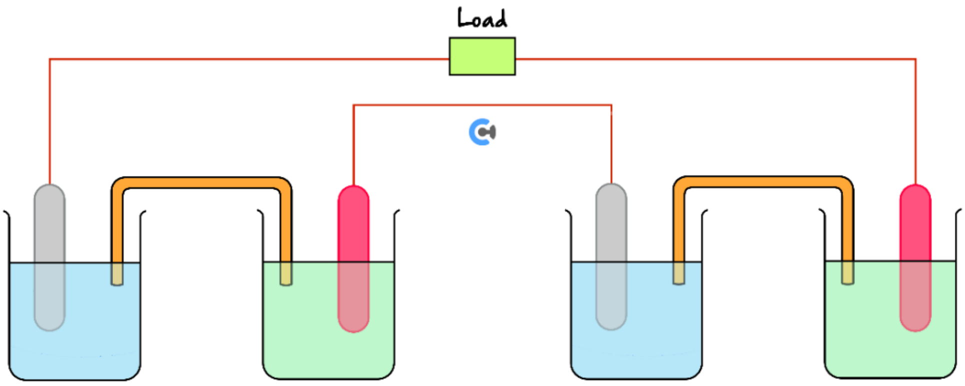
How do we distinguish between them?

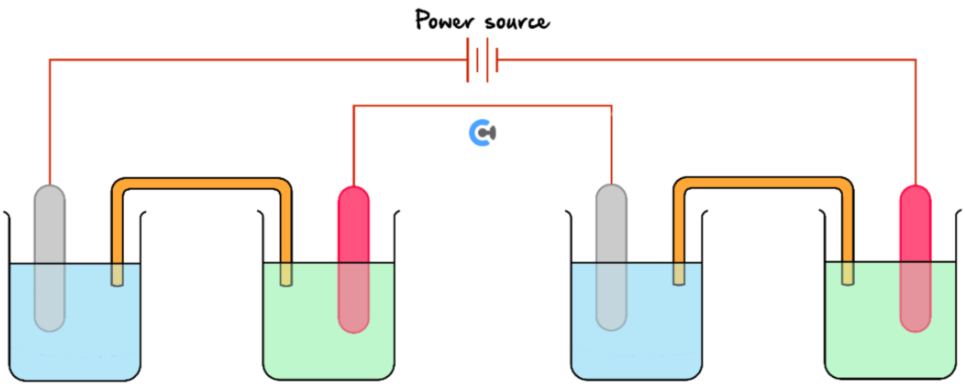
Definition

Types of Connected Cells

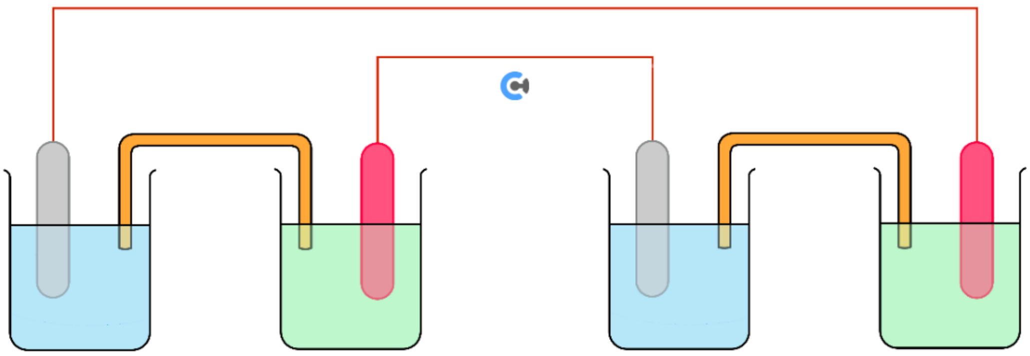
- **Connected Galvanic Cells** – Connected to load.



- **Connected Electrolytic Cells** – Connected to power source.



- **Galvanic-Electrolytic Cells** – No power source/load necessary, but may have one.



Now, let's try questions together!

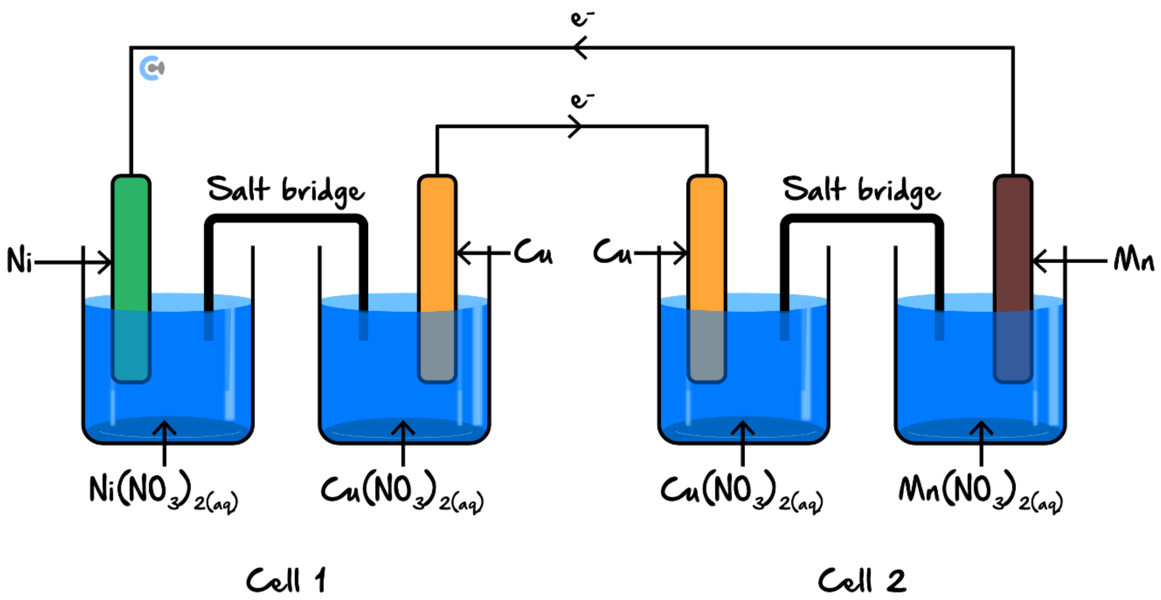
TIP: Figure out if each half-cell is spontaneous or non-spontaneous first!

Question 21 Walkthrough.

Inspired from VCAA NHT Chemistry ¾ Exam 2022
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2022/NHT/2022ChemistryNHT-w.pdf

The diagram below shows two electrochemical cells connected together under standard conditions.

The colour of the copper(II) nitrate, $Cu(NO_3)_2(aq)$, the solution in each cell is blue at the beginning of the experiment.



Which one of the following is correct?

A. Electrical energy is converted to chemical energy in Cell 2.

B. Copper is produced at the negative electrode in Cell 2.

C. The mass of metal deposited at the cathode is identical in each cell.

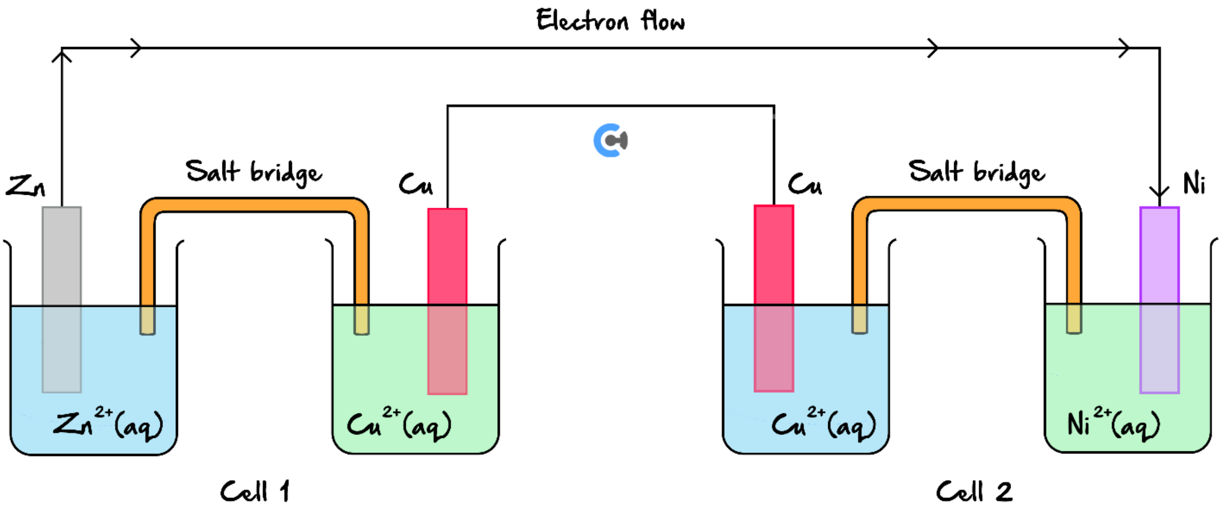
D. The colour of the $Cu(NO_3)_2$ solution deepens in Cell 1.

Your turn!

Question 22

Inspired from VCAA Chemistry ¾ Exam 2021
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2021/2021chem-w.pdf

The following diagram shows two connected electrochemical cells.



Which of the following gives the energy transformations that occur in Cell 1 and Cell 2?

	Cell 1	Cell 2
A.	Chemical → electrical	Chemical → electrical
B.	Electrical → chemical	Chemical → electrical
C.	Chemical → electrical	Electrical → chemical
D.	Electrical → chemical	Electrical → chemical

Space for Personal Notes

Contour Check

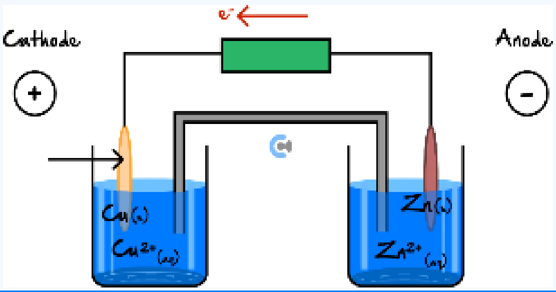
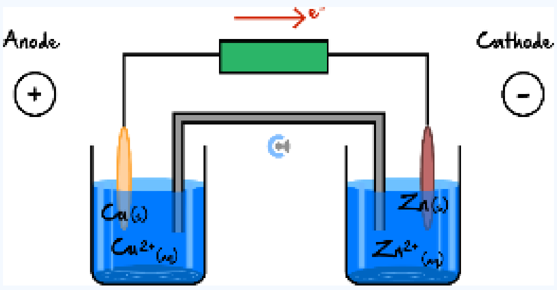
Learning Objective: [2.3.1] - Write Discharge & Recharge Reactions in Secondary Cells

Study Design

"The common design features general operating principles of rechargeable (secondary) cells, with reference to discharging as a galvanic cell and recharging as an electrolytic cell, including the conditions required for the cell reactions to be reversed and the electrode polarities in each mode. (Details of specific cells not required)"

Key Takeaways

Primary Cells	Secondary Cells
[rechargeable] / [non-rechargeable]	[rechargeable] / [non-rechargeable]

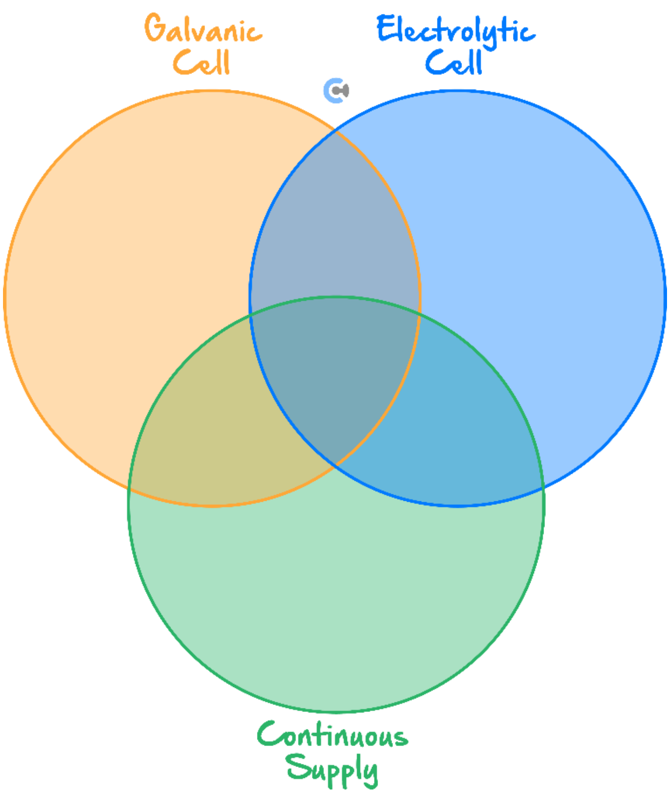
Discharge (Galvanic)	Recharge (Electrolytic)
	
Electron flow: [left] / [right]	Electron flow: [left] / [right]
⊕: ⊖:	⊖: ⊕:

Left Electrode Polarity: [+] / [–]	Left Electrode Polarity: [+] / [–]
Left Electrode Type: [cathode] / [anode]	Left Electrode Type: [cathode] / [anode]

- **During discharge/recharge:**
  - Polarities [stays same] / [swap]
  - Type of electrode (cathode/anode) [stays same] / [swap]

Learning Objective: [2.3.2] - Identify Factors which Affect Rechargeability & Compare Similarities/Differences between Secondary Cells and Other Cells

Key Takeaways



Primary Cell	Secondary Cell
[rechargeable] / [non-rechargeable]	[rechargeable] / [non-rechargeable]
Can act as [galvanic] / [electrolytic] cell	Can act as [galvanic] / [electrolytic] cell
[chemical to electrical] / [electrical to chemical]	[chemical to electrical] / [electrical to chemical]
[cheap] / [expensive]	[cheap] / [expensive]

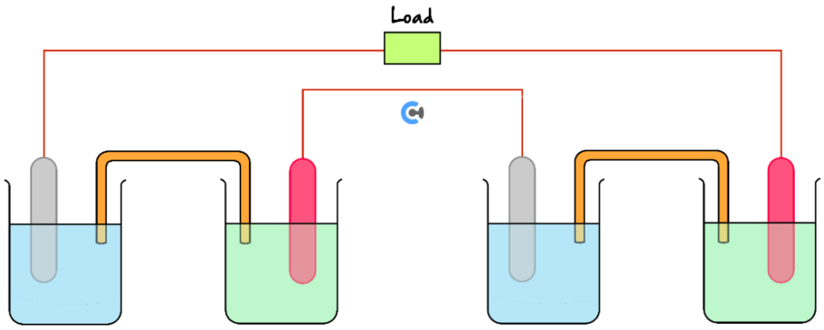
- Reasons for Rechargeability:
  - ____.
  - ____.
- Reasons for decreased battery life:
  - ____.
  - ____.

Space for Personal Notes

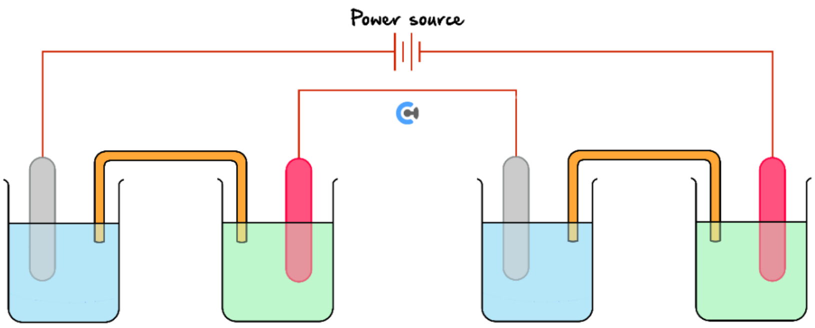
Learning Objective: [2.3.3] - Find Reactions Occurring in Connected Cells

Key Takeaways

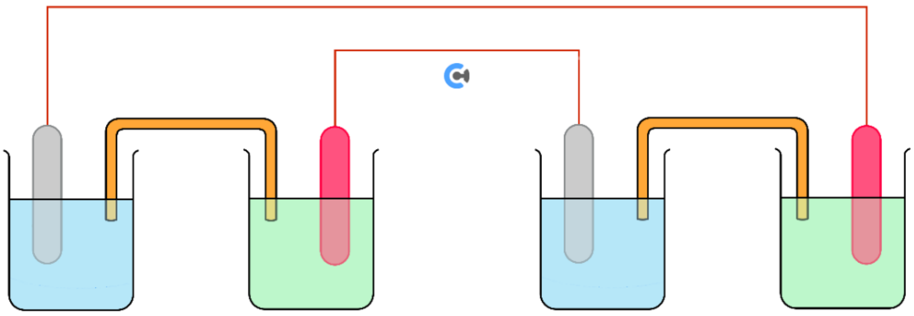
- Connected ______________________ Cells:



- Connected ______________________ Cells:



- Connected ______________________ Cells:



- TIPS:
  - First find: ______________________.
  - Treat each cell as: ________________.

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