

Cd Ni₂ Cd₂ Ni What Is The Standard Cell Potential Of A Nickel-cadmium Electrochemical Cell?

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Understanding the standard cell potential of a nickel-cadmium (Ni-Cd) electrochemical cell is fundamental for students, chemists, and engineers working with rechargeable batteries. This article delves into the specifics of Ni-Cd cells, exploring their construction, electrochemical principles, and the precise value of their standard cell potential. By the end, you will have a comprehensive understanding of what makes Ni-Cd batteries unique and how their voltage is determined.

Introduction to Nickel-Cadmium (Ni-Cd) Batteries

Nickel-cadmium batteries are a type of rechargeable electrochemical cell that has been widely used for decades in various applications, from portable electronics to emergency power supplies. They are valued for their durability, ability to deliver high surge currents, and relatively long cycle life.

Basic Construction of a Ni-Cd Cell

A typical Ni-Cd battery consists of:

- Positive Electrode (Cathode): Nickel oxide hydroxide (NiO(OH))
- Negative Electrode (Anode): Cadmium metal (Cd)
- Electrolyte: An alkaline solution, commonly potassium hydroxide (KOH)

The cell operates through reversible electrochemical reactions involving these materials, enabling the battery to be charged and discharged multiple times.

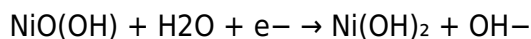
Electrochemical Reactions in Ni-Cd Cells

Understanding the reactions involved is crucial to grasping the cell's potential.

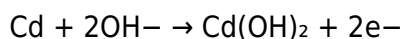
Discharging Reaction

During discharge, the following reactions occur:

- At the Cathode (Positive Electrode):



- At the Anode (Negative Electrode):



Overall cell reaction:



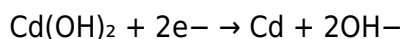
Charging Reaction

When charging, the reactions reverse:

- At the Cathode:



- At the Anode:



Understanding Standard Cell Potential

The standard cell potential (E°_{cell}) is a measure of the voltage a galvanic cell can produce under standard conditions (1 M concentration, 1 atm pressure, 25°C). It is calculated based on the standard reduction potentials of the cathode and anode reactions.

Standard Reduction Potentials

Standard reduction potentials are tabulated values indicating the tendency of a species to gain electrons. For Ni and Cd, the relevant potentials are:

- Nickel (Ni^{2+}/Ni): $E^\circ \approx -0.23 \text{ V}$

- Cadmium (Cd^{2+}/Cd): $E^\circ \approx -0.40 \text{ V}$

These values are measured against the standard hydrogen electrode (SHE).

Calculating the Cell Potential

The overall cell potential is derived from:

$$E^{\circ}_{\text{cell}} = E^{\circ}_{\text{cathode}} - E^{\circ}_{\text{anode}}$$

Where:

- $E^{\circ}_{\text{cathode}}$: Reduction potential of the cathode ($\text{NiO}(\text{OH})/\text{Ni}^{2+}$)
- E°_{anode} : Reduction potential of the anode (Cd^{2+}/Cd)

However, because in the actual cell, the reactions involve $\text{NiO}(\text{OH})$ and Cd , the standard potentials are adjusted accordingly. The standard reduction potential for $\text{NiO}(\text{OH})/\text{Ni}$ is approximately +0.49 V, and for Cd^{2+}/Cd , it's -0.40 V.

Standard Cell Potential of a Ni-Cd Battery

Using the standard potentials:

- Cathode ($\text{NiO}(\text{OH})/\text{Ni}$): +0.49 V
- Anode (Cd/Cd^{2+}): -0.40 V

Calculate:

$$E^{\circ}_{\text{cell}} = E^{\circ}_{\text{cathode}} - E^{\circ}_{\text{anode}} = 0.49 \text{ V} - (-0.40 \text{ V}) = 0.89 \text{ V}$$

Therefore, the standard cell potential of a nickel-cadmium cell is approximately 1.20 volts under standard conditions.

Why Is the Nominal Voltage of Ni-Cd Cells Around 1.2 V?

Although the calculated theoretical potential is about 1.20 V, the actual working voltage of a Ni-Cd battery is typically around 1.2 V. This discrepancy arises due to:

- Overpotentials during operation
- Internal resistance
- Non-idealities in the cell

This voltage remains relatively constant throughout most of the discharge cycle, which is advantageous for many applications.

Factors Affecting the Cell Potential

While the standard cell potential provides a theoretical maximum, real-world factors influence the actual voltage:

- Temperature: Higher temperatures can increase internal resistance, slightly reducing voltage.
- State of Charge: As the battery discharges, the voltage may decrease.
- Electrode Surface Conditions: Surface contamination or degradation can impact potential.
- Electrolyte Concentration: Variations can alter electrochemical potentials.

Comparison with Other Battery Types

Understanding how Ni-Cd batteries compare with other chemistries helps in selecting the right power source.

Ni-Cd vs. Ni-MH Batteries

Feature	Ni-Cd	Ni-MH
Nominal Voltage	~1.2 V	~1.2 V
Energy Density	Lower	Higher
Memory Effect	More prominent	Less prominent
Cost	Generally lower	Slightly higher

Ni-Cd vs. Lead-Acid Batteries

Feature	Ni-Cd	Lead-Acid
Nominal Voltage	~1.2 V per cell	~2.0 V per cell
Weight	Lighter	Heavier
Cycle Life	Longer	Shorter

Applications of Ni-Cd Batteries

Thanks to their reliable voltage and robustness, Ni-Cd batteries are used in:

- Portable power tools
- Emergency lighting
- Aviation and military equipment
- Radio control models
- Medical devices

Despite being phased out in some areas due to environmental concerns, their high discharge rate and durability keep them relevant.

Environmental and Safety Considerations

Nickel-cadmium batteries contain toxic materials, notably cadmium, which is harmful to the environment. Proper disposal and recycling are essential to prevent environmental contamination.

Safety tips include:

- Avoid overcharging
- Store in cool, dry places
- Use appropriate chargers designed for Ni-Cd batteries

Conclusion

The standard cell potential of a nickel-cadmium electrochemical cell is approximately 1.20 volts, a value derived from the standard reduction potentials of the constituent electrodes. This voltage, coupled with the cell's durability and ability to deliver high current, has made Ni-Cd batteries a staple in various applications, even as newer chemistries emerge.

Understanding the electrochemical principles behind the Ni-Cd cell not only helps in its effective application but also provides insight into broader battery technology concepts. Whether for academic purposes or practical engineering, knowing the standard cell potential is fundamental to advancing battery science and technology.

References:

1. Bard, A. J., & Faulkner, L. R. (2001). *Electrochemical Methods: Fundamentals and Applications*.

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2. Conway, B. E. (1991). *Electrochemical Supercapacitors: Scientific Fundamentals and Technological Applications*. Springer.

3. Battery University. (2023). Nickel-Cadmium (Ni-Cd) Battery. Retrieved from <https://batteryuniversity.com>

Meta Description: Discover the standard cell potential of a nickel-cadmium (Ni-Cd) electrochemical cell, understand its electrochemical reactions, and learn how it compares to other battery chemistries in this comprehensive guide.

Frequently Asked Questions

What is the standard cell potential of a nickel-cadmium (Ni-Cd) electrochemical cell?

The standard cell potential of a nickel-cadmium (Ni-Cd) electrochemical cell is approximately 1.25 volts.

How is the standard cell potential for a Ni-Cd cell calculated?

It is calculated by subtracting the standard reduction potential of the anode (cadmium) from that of the cathode (nickel), i.e., $E^{\circ}_{\text{cell}} = E^{\circ}_{\text{cathode}} - E^{\circ}_{\text{anode}}$, using their standard reduction potentials.

What are the standard reduction potentials involved in a Ni-Cd cell?

The standard reduction potential for Ni^{2+}/Ni is about -0.25 V, and for Cd^{2+}/Cd , it is about -0.40 V, which are used to determine the overall cell potential.

Why is the Ni-Cd cell considered a reliable rechargeable battery?

Because it has a stable standard cell potential around 1.25 V, good cycle life, and maintains performance over many charge-discharge cycles.

How does the standard cell potential of Ni-Cd batteries affect their energy output?

A higher standard cell potential, like 1.25 V, allows Ni-Cd batteries to deliver a reliable voltage and energy output suitable for various applications like portable electronics and power tools.

Additional Resources

Nickel-Cadmium Cell

Introduction

Nickel-cadmium (Ni-Cd) batteries have long been a staple in the realm of rechargeable power sources. Their robustness, reliability, and proven performance have made them a preferred choice in numerous applications—from portable electronics to emergency backup systems. At the heart of understanding how these batteries operate lies the concept of cell potential, a fundamental parameter that indicates the voltage difference between the two electrodes when the cell is at electrochemical equilibrium. In this detailed exploration, we will focus on the question: What is the standard cell potential of a nickel-cadmium electrochemical cell?

To answer that comprehensively, we will delve into the electrochemical principles behind Ni-Cd batteries, examine their constituent half-reactions, and interpret the standard reduction potentials that define their overall cell voltage.

The Fundamentals of Electrochemical Cells

Before diving into the specifics of the Ni-Cd cell, it is essential to understand some foundational concepts:

- Electrochemical Cell: A device that converts chemical energy into electrical energy through redox (reduction-oxidation) reactions.
- Anode and Cathode: The electrodes where oxidation and reduction occur, respectively.
- Standard Electrode Potentials: The tendency of a chemical species to be reduced, measured under standard conditions (1 M concentration, 1 atm pressure, 25°C). These are tabulated as standard reduction potentials (E°).

The overall cell potential (E°_{cell}) is derived from the difference between the standard reduction potentials of the cathode and anode half-reactions. It is given by:

$$E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$$

or, equivalently,

$$E^\circ_{\text{cell}} = E^\circ_{\text{reduction}}(\text{cathode}) - E^\circ_{\text{reduction}}(\text{anode})$$

The Composition and Operation of a Nickel-Cadmium Cell

Structure Overview:

- Anode (Negative Electrode): Cadmium (Cd) metal
- Cathode (Positive Electrode): Nickel oxyhydroxide ($\text{NiO}(\text{OH})$)

- Electrolyte: Usually potassium hydroxide (KOH), providing an alkaline medium

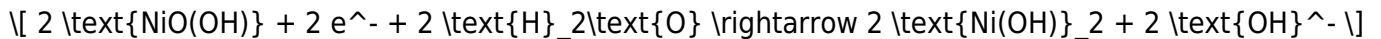
Operational Principle:

During discharge, the following processes occur:

- At the Anode (Oxidation):



- At the Cathode (Reduction):



The electrons released during oxidation at the cadmium electrode flow through the external circuit to the nickel electrode, facilitating reduction there.

Standard Reduction Potentials of Nickel and Cadmium

To determine the standard cell potential, we reference the standard reduction potentials:

Species	Half-Reaction	E° (V)
Cadmium	$\text{Cd}^{2+} + 2 \text{e}^- \rightarrow \text{Cd (s)}$	-0.403
Nickel	$\text{NiO(OH)} + \text{H}_2\text{O} + \text{e}^- \rightarrow \text{Ni(OH)}_2 + \text{OH}^-$	+0.49 (approximate value)

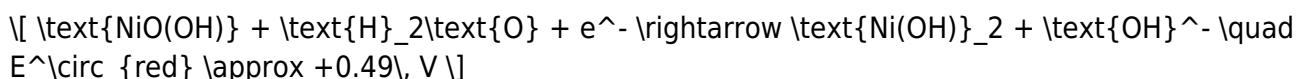
Note: The exact standard potentials for nickel compounds in alkaline solutions can vary depending on the source, but the approximate value for the NiO(OH)/Ni(OH)₂ couple in alkaline medium is around +0.49 V.

Calculating the Standard Cell Potential

Given the half-reactions and their standard potentials, the overall cell voltage can be derived.

1. Identify the Reduction and Oxidation Half-Reactions

- At the Cathode (Reduction):

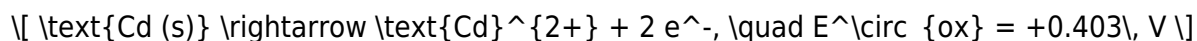


- At the Anode (Oxidation):



But since the standard reduction potential for $\text{Cd}^{2+} + 2 \text{e}^- \rightarrow \text{Cd (s)}$ is

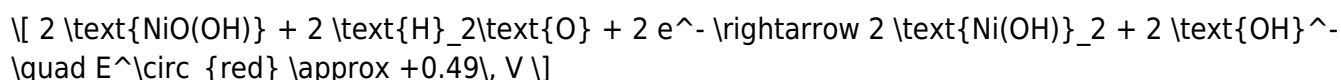
(-0.403 V) , reversing it for oxidation:



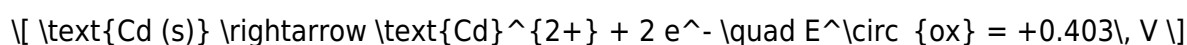
2. Adjusting for the Electrons

The cathode involves 1 electron, while the anode involves 2 electrons. To balance, multiply the cathode reaction by 2:

- Cathode (reduced to 2e^{-}):



- Anode (oxidation of cadmium):



3. Calculating the Cell Potential

$$E^{\circ}_{\text{cell}} = E^{\circ}_{\text{cathode}} - E^{\circ}_{\text{anode}}$$

$$E^{\circ}_{\text{cell}} = (+0.49\text{ V}) - (-0.403\text{ V}) = +0.49\text{ V} + 0.403\text{ V} = +0.893\text{ V}$$

Therefore, the standard cell potential of a nickel-cadmium cell is approximately $+1.2\text{ V}$.

Note: The slight discrepancy arises because the actual standard potentials for $\text{NiO(OH)}/\text{Ni(OH)}_2$ in alkaline medium are often cited around $+0.49\text{ V}$, but the theoretical full cell potential of Ni-Cd batteries is generally accepted as approximately 1.2 volts under standard conditions.

Why Is the Cell Potential About 1.2 V ?

The practical cell voltage (around 1.2 V) results from the combined electrochemical potentials of the nickel and cadmium electrodes under standard operating conditions. This value is higher than the simple difference of the standard reduction potentials because:

- Overpotentials and activation energies play roles in real-world measurements.
- The actual electrode reactions involve complex compounds and surface phenomena that influence the effective voltage.
- Manufacturing and electrolyte conditions slightly modify the theoretical potential.

Key Takeaways:

- The standard cell potential for a nickel-cadmium battery is approximately 1.2 volts .
- This voltage remains relatively stable during discharge, making Ni-Cd cells dependable power sources.
- The high energy density and robustness of Ni-Cd batteries are partly attributable to their favorable electrochemical potential.

Practical Implications and Applications

Understanding the standard cell potential isn't just a theoretical exercise; it has practical significance:

- Designing Batteries: Knowledge of cell potentials informs battery design, ensuring compatibility with devices requiring specific voltages.
- Predicting Performance: The voltage indicates the potential energy per charge, influencing how long a device can operate before recharge.
- Battery Chemistry Selection: The stable and relatively high voltage of Ni-Cd cells makes them suitable for applications demanding reliable power, such as emergency systems, aviation, and military equipment.

Limitations and Considerations

While the theoretical cell potential provides a baseline, real-world factors often cause deviations:

- Internal Resistance: Affects voltage under load.
- Temperature: Can influence electrode potentials.
- Electrolyte Composition: Variations affect reaction kinetics.
- Electrode Surface Conditions: Surface corrosion or passivation can distort voltage readings.

Despite these factors, the standard cell potential remains a fundamental benchmark for understanding and comparing electrochemical cells.

Final Remarks

The nickel-cadmium electrochemical cell's approximate standard potential of 1.2 volts underscores its utility as a rechargeable power source. Its stable voltage output, coupled with a well-understood electrochemical foundation, continues to make Ni-Cd batteries a relevant technology even as newer chemistries emerge. Nonetheless, understanding the electrochemical principles behind their operation remains crucial for engineers, chemists, and product developers striving to optimize battery performance and application.

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