B15 · Investigation: analyze and explain

Completed notes

Goals: Set out results in a table and compare them with predictions. Explain a difference with a possible cause and a test. Write a conclusion with a claim, evidence and an explanation.

Slide 1 of 7 · Put the evidence in a table

This is a **supplied** sample data set. It was not measured by us. A table puts the evidence in **one place**, with one row for each cell.

The columns are the metal, the predicted voltage, the measured voltage and the **difference**. The predicted values are calculated from the **reduction table**.

The measured values are **observations**, because they came from a voltmeter. A reader must be able to tell which numbers were seen and which were **expected**.

A good table has a **title**, units in the headings (V) and a note of the controlled conditions, such as **1.0 mol/L** solutions.

Example. A given sample set gives four metals joined to copper at 1.0 mol/L. Zinc is 1.10 V predicted and 1.07 V measured, iron 0.79 V and 0.76 V, nickel 0.60 V and 0.57 V, silver 0.46 V and 0.43 V. Organize it in a table.

1. Title: Given sample voltages of metal and copper cells at 1.0 mol/L

2. Headings: Cell | Predicted (V) | Measured (V) | Difference (V)

3. Zn/Cu | 1.10 | 1.07 | 0.03

4. Fe/Cu | 0.79 | 0.76 | 0.03

5. Ni/Cu | 0.60 | 0.57 | 0.03

6. Ag/Cu | 0.46 | 0.43 | 0.03

Try it. Another given sample set has a zinc and silver cell with 1.56 V predicted and 1.52 V measured. An iron and silver cell has 1.25 V predicted and 1.21 V measured. Organize it in a table with a title and units.

1. Title: Given sample voltages of metal and silver cells at 1.0 mol/L

2. Headings: Cell | Predicted (V) | Measured (V) | Difference (V)

3. Zn/Ag | 1.56 | 1.52 | 0.04

4. Fe/Ag | 1.25 | 1.21 | 0.04

Slide 2 of 7 · Compare prediction and observation

Difference = **predicted − measured**. For zinc, 1.10 − 1.07 = **0.03** V, and the other three cells also give 0.03 V.

Every measured voltage is **lower** than its prediction by the same 0.03 V. A constant gap means something small affects all the cells in the **same way**.

The order of the voltages also matches: zinc is highest and **silver** is lowest. So the data **support** the prediction. We say support, not prove.

It is called the percent difference, or percent error: (predicted − measured) ÷ **predicted** × 100. For zinc, 0.03 ÷ 1.10 × 100 = 2.7 %, which is **3 %** with one significant digit.

Example. Given given predicted and measured voltages: zinc 1.10 V and 1.07 V, iron 0.79 V and 0.76 V, nickel 0.60 V and 0.57 V, silver 0.46 V and 0.43 V. Find each difference and describe the pattern. Then find the percent difference for zinc.

1. Zinc: 1.10 − 1.07 = 0.03 V. Iron: 0.79 − 0.76 = 0.03 V.

2. Nickel: 0.60 − 0.57 = 0.03 V. Silver: 0.46 − 0.43 = 0.03 V.

3. Pattern: every measured voltage is 0.03 V lower, and the order Zn > Fe > Ni > Ag matches the prediction.

4. Percent difference for zinc = 0.03 ÷ 1.10 × 100 = 2.7 %, which is 3 % to one significant digit.

Try it. A given iron and silver cell has a predicted voltage of 1.25 V and a measured voltage of 1.21 V. Find the difference and the percent difference. Is the measured value higher or lower?

1. Difference = 1.25 − 1.21 = 0.04 V. The measured value is lower.

2. Percent difference = 0.04 ÷ 1.25 × 100 = 3.2 %, which is 3 % to one significant digit.

Slide 3 of 7 · Explain the difference

Possible causes of a constant gap: the salt bridge adds **resistance**, metal strips can carry a thin **oxide** coating, and the solutions may not be exactly 1.0 mol/L.

Each cause is only **possible**, because we have not tested it. Do not claim a cause that was **not tested**.

To test a cause, change **one thing** and measure again. If we sand the strips and the voltage rises toward the prediction, the oxide was part of the cause.

Temperature also affects voltage. Table values assume 1.0 mol/L solutions, **25.00 °C** and 101.325 kPa for gases. A good report records the **room temperature** and the concentration.

Example. Every given measured voltage was 0.03 V lower than the table value. Give two possible causes. Describe one test for one of them.

1. Possible cause 1: the salt bridge adds resistance, which lowers the voltage.

2. Possible cause 2: the strips have a thin oxide coating that slows the reaction.

3. Test for the oxide: sand the strips (change one thing) and measure the voltage again.

4. If the voltage rises toward the prediction, the oxide was part of the cause.

Try it. A student suspects the solutions were not exactly 1.0 mol/L. Describe a test. Say what to change, what to measure and what result would support the cause.

1. Change: remake the solutions carefully at 1.0 mol/L, and change nothing else.

2. Measure: the cell voltage again.

3. If the voltage rises toward the table value, the concentration was part of the cause.

Slide 4 of 7 · Method: how to analyze and explain results

Step 1. **Make** a table with a title, units and predicted and measured columns.

Step 2. Compare prediction and observation. Percent difference = (predicted − measured) ÷ **predicted** × 100.

Step 3. Explain a gap with one **possible** cause and say how you would test it.

Step 4. Separate the **observation** from the inference. An observation is seen or measured.

Step 5. Write a **conclusion** that answers the question, with claim, evidence and reason.

Step 6. Name a limitation and an **improvement**, such as repeating trials and averaging.

Example. Use the method on these given results. Zn: predicted 1.10 V, measured 1.07 V. Fe: 0.79 and 0.76. Ni: 0.60 and 0.57. Ag: 0.46 and 0.43.

1. Step 1: a table with columns for metal, predicted, measured and difference.

2. Step 2: Zn difference = 1.10 − 1.07 = 0.03 V. Percent difference = 0.03 ÷ 1.10 × 100 = 2.727 %, which rounds to 3 %.

3. Step 3: a possible cause is oxide on the strips. Test it by sanding the strips and measuring again.

4. Steps 4 to 6: every measured value is 0.03 V lower. The data support the table. Limitation: one trial. Improvement: repeat three trials and average.

Try it. Use the method on one given result: nickel and copper, predicted 0.60 V, measured 0.57 V. Find the difference and write a claim.

1. Difference = 0.60 − 0.57 = 0.03 V. Percent difference = 0.03 ÷ 0.60 × 100 = 5 %.

2. Claim: the result agrees with the table, because the gap is small.

3. A possible cause of the gap is salt bridge resistance. It is not tested.

Slide 5 of 7 · Identify products from observations

In the zinc and copper cell, the zinc strip loses mass, so zinc is **oxidized**: $Zn \rightarrow Zn^{2+} + 2e^-$.

The copper strip gains a **reddish-brown** coating, so copper ions are reduced: $Cu^{2+} + 2e^- \rightarrow$ **Cu**. The blue colour of the solution **fades**.

An **observation** is what we see or measure, such as a mass change, a coating or a colour. An **inference** is a conclusion drawn from observations.

Zinc ions are colourless, so Zn^{2+} is **inferred**, not seen. Together the evidence supports $Zn + Cu^{2+} \rightarrow$ **Zn^{2+} + Cu**.

Example. In a zinc and copper cell, the zinc strip gets thinner. The copper strip gets thicker with a reddish-brown coating. The blue solution fades. Name the products. Sort the statements into observations and inferences.

1. Observations: the zinc strip is thinner, the copper strip has a coating and the blue colour fades.

2. Inferences: zinc is oxidized to Zn^{2+}, and Cu^{2+} is reduced to copper metal.

3. Products: $Zn^{2+}(aq)$ and Cu(s).

4. Cell reaction: $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$. Check: charge is +2 on each side.

Try it. An iron nail is placed in blue copper(II) sulfate solution. The nail gets a reddish-brown coating and the blue colour fades. Name one observation and one inference. Write the cell reaction.

1. Observation: the nail has a reddish-brown coating, or the blue colour fades.

2. Inference: copper ions are reduced to copper metal, and iron is oxidized to Fe^{2+}.

3. Cell reaction: $Fe + Cu^{2+} \rightarrow Fe^{2+} + Cu$. Check: charge is +2 on each side.

Slide 6 of 7 · Your turn: judge the nickel and copper result

A conclusion has three parts: the **claim**, the evidence and a possible **explanation** for the gap.

Compare the voltages. Supplied: predicted 0.60 V and measured 0.57 V, a difference of **0.03** V. The nickel strip lost mass and the copper strip gained a coating, which fits a nickel **anode**.

The reaction is $Ni + Cu^{2+} \rightarrow \mathbf{Ni^{2+} + Cu}$. Salt bridge resistance or oxide on the nickel could lower the voltage, but we write this as **possible** because it was not tested.

A **limitation** is a weakness in how the data were collected. One trial does not show the variation. Repeat **three** trials and average, and clean the strips.

Example. Given a given nickel and copper result: predicted 0.60 V and measured 0.57 V. The nickel strip lost mass and the copper strip gained a coating. Write a conclusion with a claim, evidence and a possible explanation. Add one limitation and one improvement.

1. Claim: the nickel and copper cell agrees with the table.

2. Evidence: 0.57 V measured against 0.60 V predicted, a difference of 0.03 V. The nickel strip lost mass and the copper strip gained a coating.

3. Reaction: $Ni + Cu^{2+} \rightarrow Ni^{2+} + Cu$

4. Possible explanation: salt bridge resistance or oxide on the nickel lowered the voltage. This was not tested.

5. Limitation: only one trial per cell.

6. Improvement: repeat three trials and average, and clean the strips.

Try it. Given a given iron and copper result: predicted 0.79 V and measured 0.76 V. The iron strip lost mass and the copper strip gained a coating. Write a claim, the evidence, the reaction and one improvement.

1. Claim: the iron and copper cell agrees with the table.

2. Evidence: 0.76 V measured against 0.79 V predicted, a difference of 0.03 V. The iron strip lost mass and the copper strip gained a coating.

3. Reaction: $Fe + Cu^{2+} \rightarrow Fe^{2+} + Cu$

4. Improvement: repeat three trials and average, because one trial does not show the variation.

Slide 7 of 7 · Evaluate a battery design

Cells in a row add voltages. To find the battery voltage, multiply one cell by the **number of cells**. Three cells at the given 1.07 V give 3 × 1.07 = **3.21 V**.

Voltage is only one part of the evidence. We also judge mass, cost, **lifetime**, the risk of **leaks**, and safety and disposal.

Used batteries contain metals such as zinc, lead or cadmium that harm soil and water, so they are collected for **recycling**. A rechargeable cell makes less **waste**, but recycling costs energy.

A fair fuel cell presentation states the purpose, the half-reactions, the **benefits** and the **limits**. A hydrogen fuel cell gives about **1.23 V** per cell.

Example. A team builds a battery from three zinc and copper cells in a row. The given measured voltage of one cell is 1.07 V. Find the battery voltage. Name two other things to judge, and say what should happen to the used battery.

1. Battery voltage = 3 × 1.07 V = 3.21 V.

2. Other things to judge: mass, cost, how long it lasts and the risk of leaks.

3. The used battery contains metals that can harm soil and water, so it should be collected for recycling.

Try it. A battery has five cells in a row, each with a given measured voltage of 1.07 V. Find the battery voltage. Give one benefit and one issue of recycling the used battery.

1. Battery voltage = 5 × 1.07 V = 5.35 V.

2. Benefit: the metals are recovered and do not harm soil and water.

3. Issue: recycling needs energy and has a cost.

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1. Given a result for an iron and copper cell: predicted 0.79 V, measured 0.74 V. Find the difference. The order of the voltages matches the table. Does the result support the prediction?

Use Method: how to analyze and explain results. Difference = 0.79 − 0.74 = 0.05 V. The order matches, so the result supports the prediction. The gap is a little bigger than for the other cells, so look for a cause.

2. Name three things a good table of results includes.

A title, column headings with units, and the predicted values beside the measured values. It also notes what was kept the same.

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3. Every measured voltage is lower than the predicted one. Give two possible causes. Describe a test for one of them.

The salt bridge adds resistance, and the strips may have oxide coatings. Test: sand the strips, measure again and see if the voltage rises toward the prediction.

4. A copper strip is put in silver nitrate solution. It gains a grey coating and the solution turns blue. Name the observations and give one inference.

Observations: the coating on the copper and the blue colour. Inference: copper is oxidized to Cu^{2+} and silver ions are reduced to silver metal.

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5. In one trial, a measured voltage is 0.10 V lower than predicted. Give one limitation of the investigation and one improvement.

Limitation: there was only one trial, so we do not know how much the measurement changes from try to try. Improvement: repeat three trials and take the average. Also clean the strips.

6. A battery has four cells in a row. Each cell measures 1.07 V. Find the battery voltage. Name one thing to do with the used battery.

4 × 1.07 = 4.28 V. Take the used battery to be recycled. Do not put it in the garbage.

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7. Challenge: Given results for three cells. Zn / Cu: predicted 1.10 V, measured 1.04 V. Fe / Cu: predicted 0.79 V, measured 0.73 V. Zn / Fe: predicted 0.31 V, measured 0.25 V. Find the difference for each cell. Describe the pattern. Then give the most likely cause and one test for it.

Differences: 1.10 − 1.04 = 0.06 V, 0.79 − 0.73 = 0.06 V, 0.31 − 0.25 = 0.06 V. Pattern: every measured value is lower than predicted by the same amount, 0.06 V. A difference that is the same every time points to one cause that affects every cell, not to random error. The most likely cause is the voltmeter: it reads low by the same amount each time. A cause such as weak solutions would not shift three different cells by exactly the same amount. Test: measure a cell with a known voltage on the same voltmeter, changing nothing else.