Kirchhoff’s Rules

**Unit:** Electricity & Magnetism

**NGSS Standards:** N/A

**MA Curriculum Frameworks (2006):** 5.3


**Knowledge & Understanding:**
- Understand Kirchhoff’s junction rule and Kirchhoff’s loop rule.

**Skills:**
- Use Kirchhoff’s rules to determine voltage, current, and resistance in complex circuits.

**Language Objectives:**
- Accurately describe how to measure voltage, current, and resistance in an electric circuit, using appropriate academic language.

**Notes:**

In 1845, the German physicist Gustav Kirchhoff came up with two simple rules that describe the behavior of current in complex circuits. Those rules are:

**Kirchhoff’s junction rule:** the total current coming into any junction must equal the total current coming out of the junction.

The junction rule is based on the concept that electric charge cannot be created or destroyed. Current is simply the flow of electric charge, so any charges that come into a junction must also come out of it.

**Kirchhoff’s loop rule:** the sum of the voltages around any closed loop must add up to zero.

The loop rule is based on the concept that voltage is the difference in electric potential between one location in the circuit and another. If you come back to the same point in the circuit, the difference in electric potential between where you started and where you ended (the same place) must be zero. Therefore, any increases and decreases in voltage around the loop must cancel.

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**Junction Rule Example:**

As an example of the junction rule, consider the following circuit:

The junction rule tells us that the current flowing into junction J1 must equal the current flowing out. If we assume current $I_1$ flows into the junction, and currents $I_2$ and $I_3$ flow out of it, then $I_1 = I_2 + I_3$.

We know that the voltage across both resistors is 12 V. From Ohm’s Law we can determine that the current through the 3 Ω resistor is $I_2 = 4\,\text{A}$, and the current through the 4 Ω resistor is $I_3 = 3\,\text{A}$. The junction rule tells us that the total current must therefore be $I_1 = I_2 + I_3 = 4\,\text{A} + 3\,\text{A} = 7\,\text{A}$.

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**Loop Rule Example:**

For the loop rule, consider the following circuit:

![Circuit Diagram](image)

If we start at point A and move counterclockwise around the loop (in the direction of the arrow), the voltage should be zero when we get back to point A.

For this example, we are moving around the circuit in the same direction that the current flows, because that makes the most intuitive sense. However, it wouldn’t matter if we moved clockwise instead—just as with vector quantities, we choose a positive direction and assign each quantity to a positive or negative number accordingly, and the math tells us what is actually happening.

Starting from point A, we first move through the 6 V battery. We are moving from the negative pole to the positive pole of the battery, so the voltage increases by +6 V. When we move through the second battery, the voltage increases by +3 V.

Next, we move through the 15 Ω resistor. When we move through a resistor in the positive direction (of current flow), the voltage drops, so we assign the resistor a voltage of −15 I (based on \( V = IR \), where \( I \) is the current through the resistor). Similarly, the voltage across the 10 Ω resistor is −10 I. Applying the loop rule gives:

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6 + 3 + (-15I) + (-10I) = 0
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\[
9 - 25I = 0
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\[
9 = 25I
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\[
I = \frac{9}{25} = 0.36 \text{ A}
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