Kirchhoff's Law

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Learning Outcome

I highly recommend you to finish this checklist to determine whether you've achieved the learning objectives.

- ☐ recall and apply *Kirchhoff's laws*, KCL and KVL both
- ☐ analyse the circuit using Kirchhoff's law
- ☐ use Kirchhoff's laws to derive the formulae for the combined resistance of two or more resistors *in series and in parallel*
- ☐ recognise that ammeters are connected in series within a circuit and therefore should have low resistance
- ☐ recognise that voltmeters are connected in parallel across a component, or components, and therefore should have high resistance.

Leadin

Newton's Law has governed the the classic mechanics, then we can say that Kirchhoff's Law has governed the circuits. The law is vital for understanding the electrical circuits.

Gustav Robert Kirchhoff seems a name of Russian, but actually he was a Perussia or German. Besides his great contribution in Kirchhoff's Law, he also coined the term "black-body radiation" for the spectroscopy. What a great physicist!

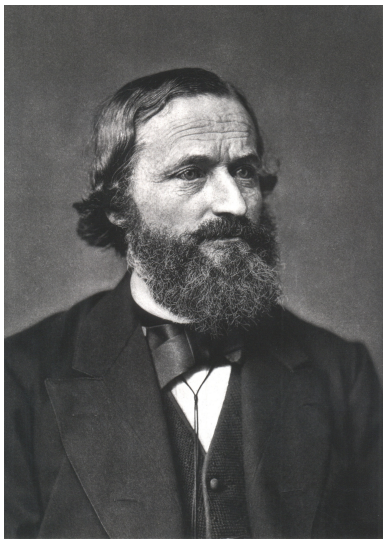

Figure 1: Kirchhoff
1824-1887
[1] Not the university KCL

Kirchhoff's First Law

The first law is about currents, thus it is also refers to KCL[1] which stands for the Kirchhoff's Current Law. Before the KCL, let's discuss the object this law is applied- JUNCTION.

Junction

A junction is a point in the circuit where currents are split or meeting, And kirchhoff's first law studies the current which flows in or out the junction, it states as the following:

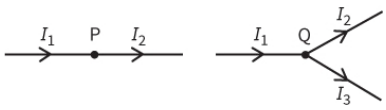

Figure 2: The second point is treated as a junction

Summary

The sum of the currents entering any junction in a circuit is equal to the sum of the currents leaving that same junction.
expressed in mathematic formula, KCL is:

$$\sum I_{\text{in}} = \sum I_{\text{out}} \qquad \sum I = 0$$

Essence of KCL

The KCL is an example of *conservation of charges*. Such conservation states that:

Summary

Charges can neither be created nor be destroyed, the net charges in a closed is always conserved.

Example

In Fig. 3 determining the current I

According to the KCL, the currents flow into that junction is $3.0+I$, the current flows out is 7.5, thus $I = 4.0\,\text{A}$.

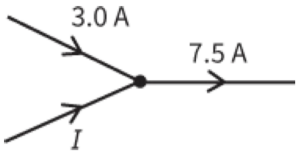

Figure 3: A junction in the circuit

Kirchhoff's Second Law

The second law is about p.d.s and e.m.f. in the circuit. The object being studied is LOOP in the circuit.

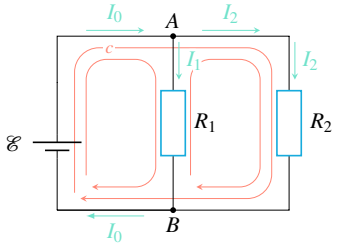

Figure 4: an example of loops in circuits

Loop

In Fig 4, three loops are present, acoording to the figure, try to explain what is loop in your own words.

Several things about the loop in circuits are listed below:

- a loop should be a closed pathway from the circuits
- a loop may or may not include an e.m.f. or battery
- if an e.m.f. or battery is included,it would be convenient to locate the starting point of loop at the negative terminal of the battery[2]
- the direction of loop can be in align with the current direction, but if they are opposite, it does not matter

[2] it is not compulsory work but would be much more reasonabless

Potential at Junctions, Voltage Drop

We already know that the voltage or potential difference exist when the currents flow through component in the circuit.

Thus, from junction A to junction B, the potential decreases[3] by $V_{\mathrm{AB}} = V_{\mathrm{A}} - V_{\mathrm{B}}$. Or this is can be denoted as ΔV, such potental can be also called voltage drop or potential difference if it follows the direction of currents. For example, in Fig 4, the loop c start from the negative terminal, the potential will increase by $\mathscr{E}$, current being I_0, then the current flows into the junction A, part of which, measures I_1, flows into the resistor R_1 to junction B, thus the potental from A to B has then **decrease** by V_{AB} which is exactly the p.d. across the resistor R_1.

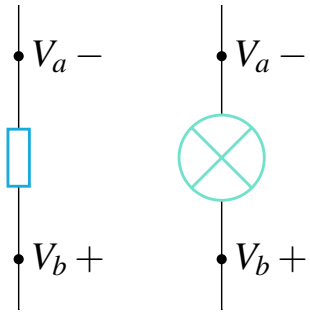

Figure 5: voltmeter actually measures the difference in two points

[3] because potential is related with energy, currents or charges flows through the componets and energy is transferred to the component, thus potential decreases

KVL

So KVL is the law that connecting the voltage drop or p.d. among all the components in the loop. It states that:

Summary

The sum of e.m.f.s around any loop in a circuit is equal to the sum of the p.d.s around the loop.
expressed in mathematic formula, KVL is:

$$\sum E = \sum V \qquad \sum \Delta V = 0$$

Essence of KVL

It seems reasonable since the KVL just states potential originating from one point finish a circuit path and back to the point the potential will remain unchanged. The Second law actually relates the energy, the charges will gain energy when it pass the battery, and then it would release energy to the components. So the two energies would be exactly same, divided by the charge itself, KVL can be deduced from it.

Application Kirchhoff's Law

The two simple laws has ruled any circuits, with KCL and KVL, we can decide the currents and p.d.s in any circuits, no matter simple or complex. The Phet Labs is completely coded under the principle of Kirchhoff's Law.

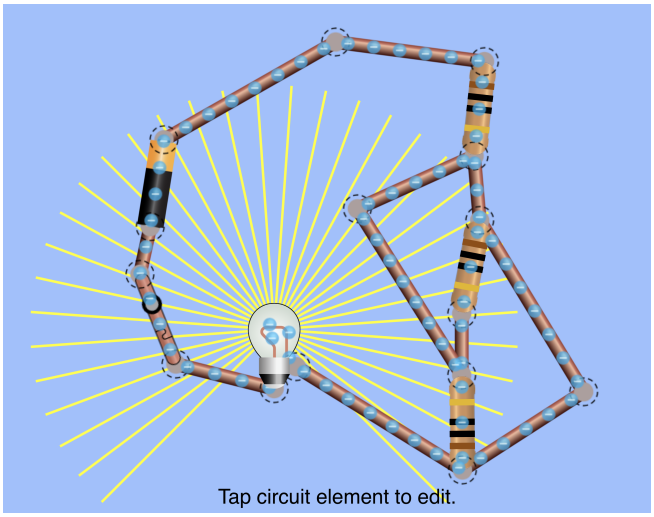

Figure 6: A simulation of circuits