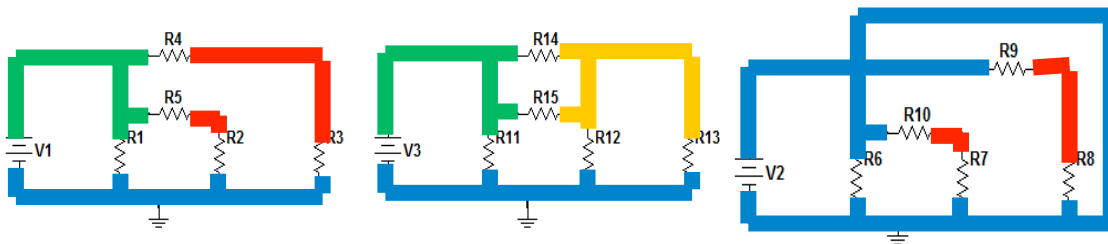




- How to identify electric **nodes**, and if they are ordinary or extraordinary.
- How to identify which combinations of resistors are in **series** or **parallel**?
- How to determine which resistors can be eliminated because they are in parallel with a **short circuit**.

- 1) **Identify all electrical components in your circuit:** Electrical components include voltage and current sources, resistors, capacitors, inductors, diodes, op amps, transistors, etc. A wire or junction of wires is NOT a component.
- 2) **Identify nodes:** A node is any region/combination of wires that connects electric components. Start at one electrical component, and "color in" every wire & junction that connects it to other components. A node has the same voltage everywhere on that node. (If you have a short circuit, you may find that many different parts of your circuit are all joined as one large node.)

Examples:



- 3) **Identify if the nodes are ordinary (red) or extraordinary (blue,yellow,green,etc.):**
If a node connects only TWO elements, it is ordinary. These nodes are red in the examples above. If a node connects more than two elements, it is extraordinary. These nodes are blue, yellow, or green in the examples above.
- 4) **Identify which components are in series.** If two components are connected by an ordinary (red) node, they are in series. **If several components are connected in a line, with only ordinary nodes between them, they are all in series. One convenient way to indicate two (or more) resistors are in series is to put a plus between them:** $R2+R5$, $R3+R4$, $R7+R10$, and $R8+R9$ for example. The order in which you list series resistors doesn't matter. ($R2+R5$ is the same as $R5+R2$). Resistors in series have the same current passing through them.
- 5) **Identify which components are in parallel.** If two (or more) components are in parallel, they share one color on one end and they share one color on the other end. **One convenient way to indicate two resistors are in parallel is to put a || between them:** $R14||R15$, $R12||R13$, $V1||R1$, $V3||R11$, $V2||R6$ for example. The order in which you list parallel resistors doesn't matter. ($R14||R15$ is the same as $R15||R14$). Resistors in parallel have the same voltage across them.
- 6) **Identify combinations of components that are in series and/or parallel:** Combinations of resistors can also be said to be in series or parallel. First, identify the individual components that are in series or parallel (steps 4, 5). Then, treat each of those series/parallel combinations as if they were individual resistors, and consider their combinations with other resistors. This is a little hard to explain, so let's look at the examples above:

Circuit 1: $R_2 + R_5$, $R_3 + R_4$, $R_1 \parallel (R_2 + R_5) \parallel (R_3 + R_4)$

In "Engineering Speak", we say: "R1 is in parallel with the series combinations of R2 and R5, and R3 and R4." By putting (parentheses) around components, we can indicate if they are series groupings, and then parallel, or the other way round. This matters. In the absence of parentheses, the parallel operators act before the plus signs, just as multiplies act before the plus signs in a calculator expression. In the parlance of computer science, "the parallel operator binds more tightly than the plus operator."

Circuit 2: $R_{14} \parallel R_{15}$, $R_{12} \parallel R_{13}$, $(R_{14} \parallel R_{15}) + (R_{12} \parallel R_{13})$, $R_{11} \parallel ((R_{14} \parallel R_{15}) + (R_{12} \parallel R_{13}))$

"R11 is in parallel with the series combination of R14 and R15 in parallel and R12 and R13 in parallel." (Ok, at about this point, you better draw the circuit diagram for the person you are talking with... the spoken description gets confusing quickly.)

- 7) How to handle short circuits:** Short circuits (we often just call these 'shorts'), such as the one shown in Circuit 3 in blue, are any wire or other conductor that connects two or more circuit elements. Any wire is technically a short circuit, but *usually* when we talk about a short circuit, we are talking about a wire/conductor that is in parallel with other elements of the circuit and "shorts them out."
- Identify nodes in the circuit as in step 1. The short circuit MAY connect many parts of the circuit, such as the voltage source and ground in this example. Just 'color in' (in this case, in blue) the wires/conductors until you reach all of the circuit elements they are attached to.
 - Identify components and combinations of components that are in series and parallel, as in steps 5, 6.
 - Identify components or combinations of components that are shorted out. If the same color of node connects both ends of a component or block, that component or combination of components is shorted out. In this case, the short circuit may be treated as a component in parallel with the other combinations, particularly in "Engineer Speak." For example:

Circuit 3: $R_7 + R_{10}$, $R_8 + R_9$, $R_6 \parallel (R_7 + R_{10}) \parallel (R_8 + R_9) \parallel \text{short circuit}$

- Any component or combination of components in parallel with a short circuit is "shorted out." Since wires are assumed to have zero resistance in circuit models, a component or combination of components that is shorted out has no voltage drop across it. The consequences of a component being shorted out depend on the type of component:
 - Voltage source:** A shorted out (ideal) voltage source is an invalid circuit. It cannot obey Kirchhoff's voltage law. It cannot be used as a circuit model. In real life, a voltage source like a battery or power supply always has some internal resistance in series with the voltage source.
 - Current source:** A shorted out (ideal) current source is a valid circuit. The current from the current source simply flows in a circle from the source, through the short, and back into the source.
 - Resistance:** A shorted out resistance carries zero current. All current will flow through the short circuit. The resistance may be removed from the circuit without affecting the solution of the remainder of the circuit.