2: Resistor Circuits

Kirchoff's Voltage Law

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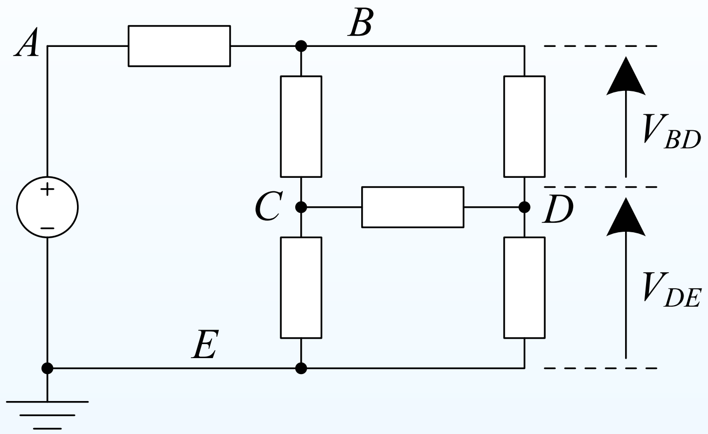

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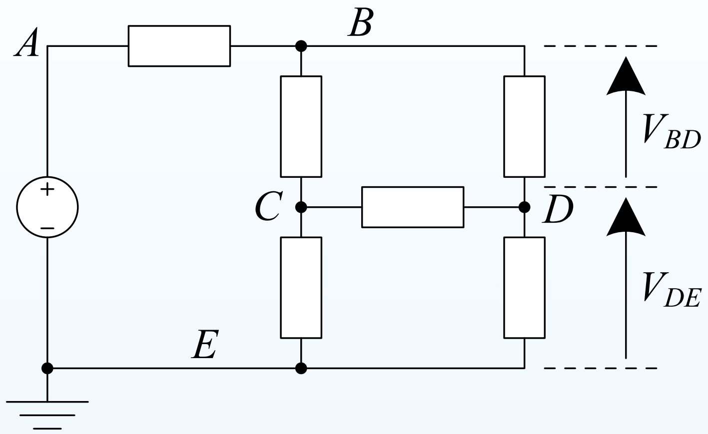

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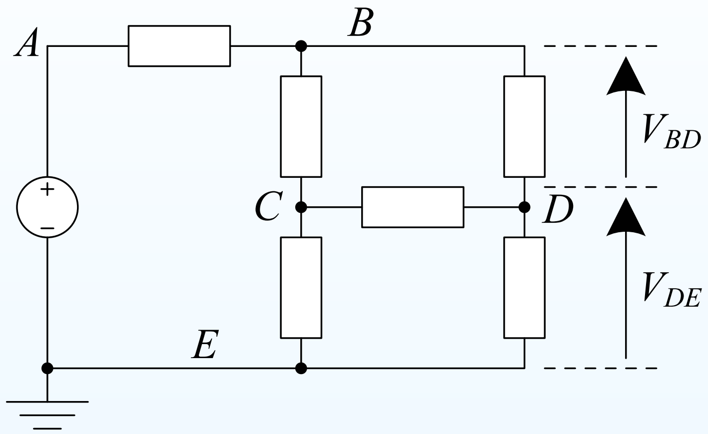

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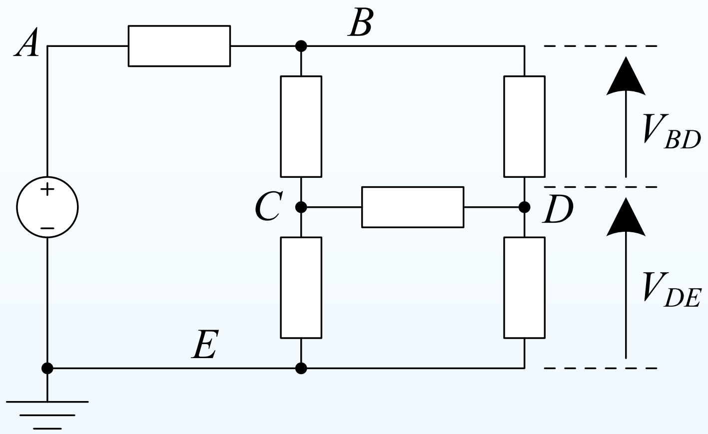

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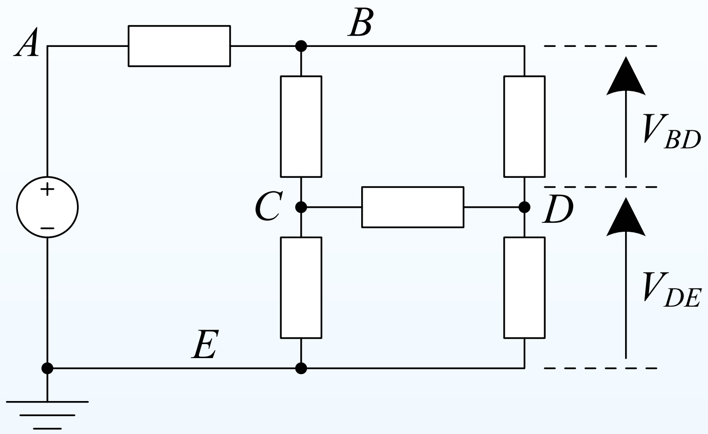

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Equivalent formulation:

$V_{XY} = V_{XE} - V_{YE} = V_X - V_Y$ for any nodes X and Y.

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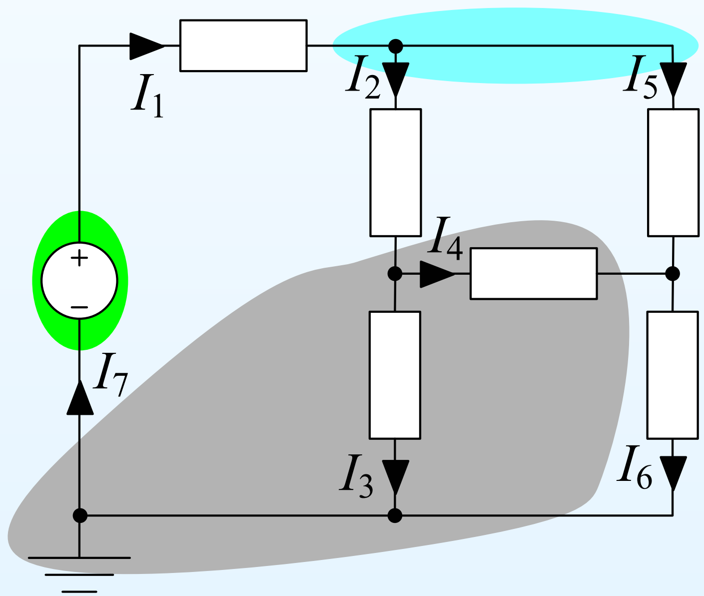

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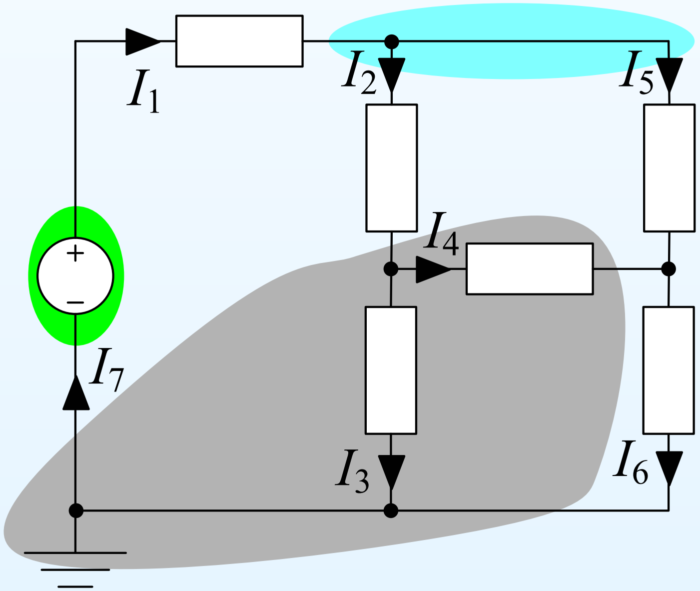

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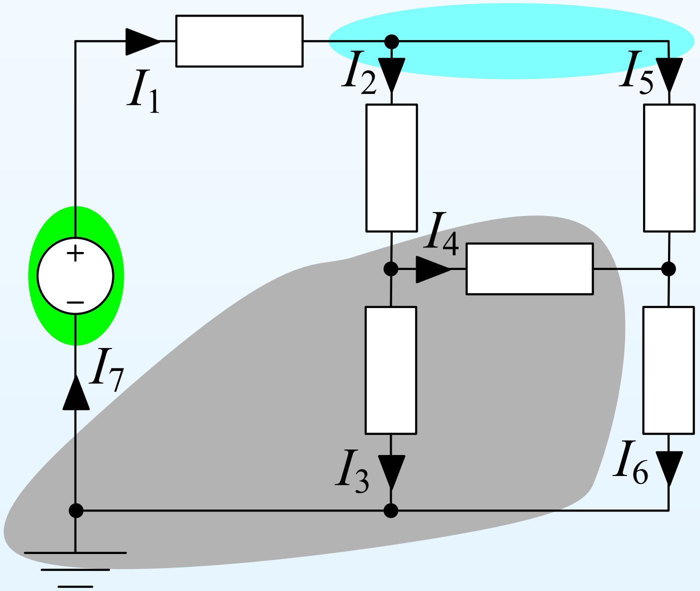

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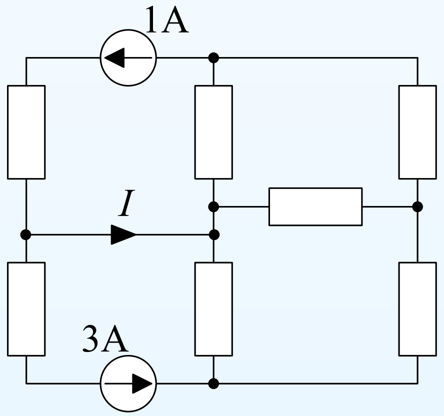

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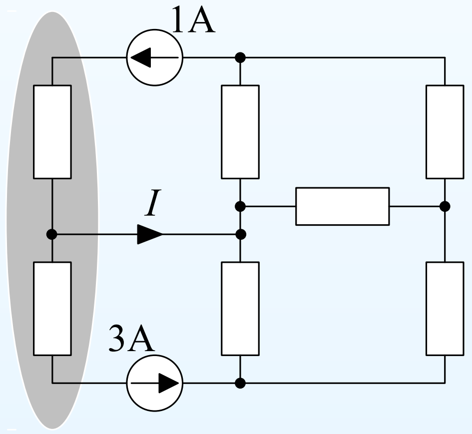

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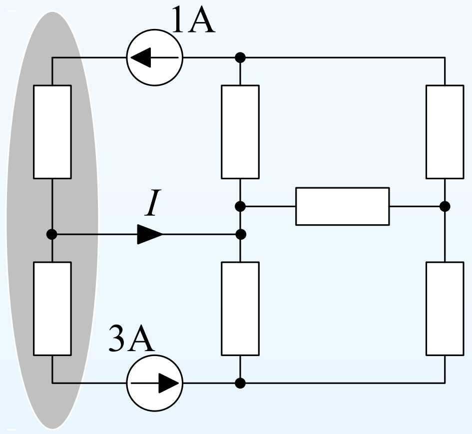

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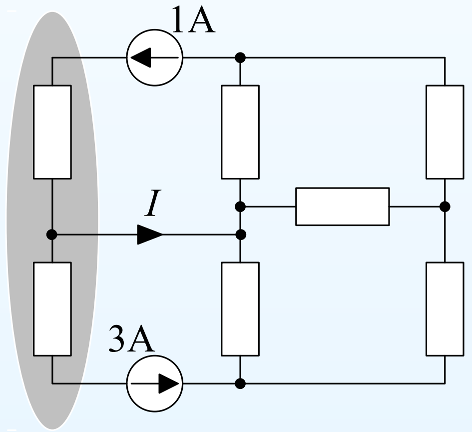

Note that here I ends up negative which means we chose the wrong arrow direction to label the circuit. This does not matter. You can choose the directions arbitrarily and let the algebra take care of reality.

Series and Parallel

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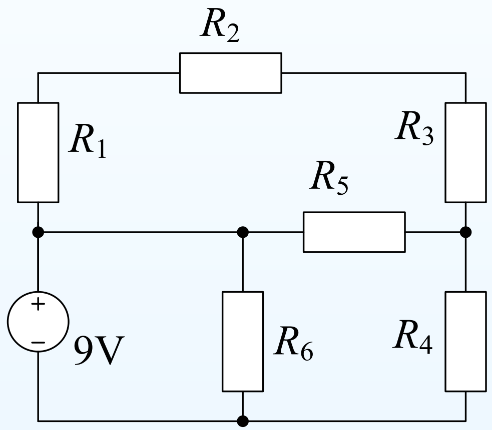

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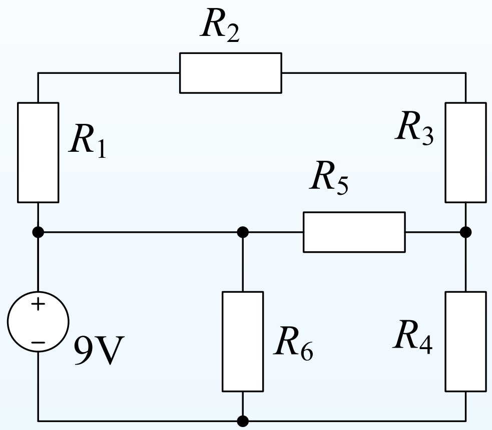

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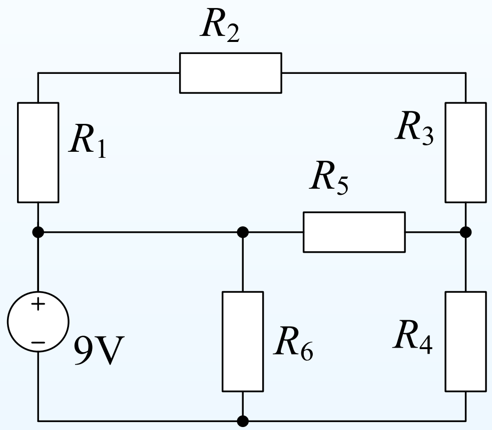

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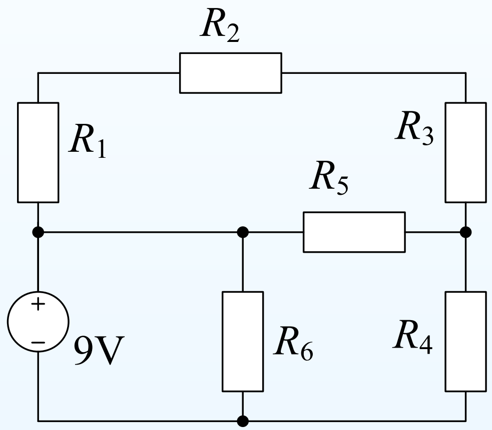

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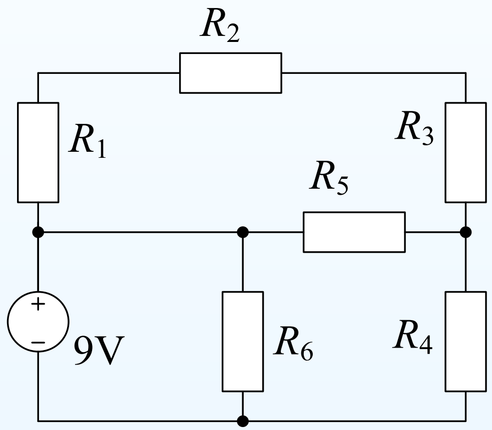

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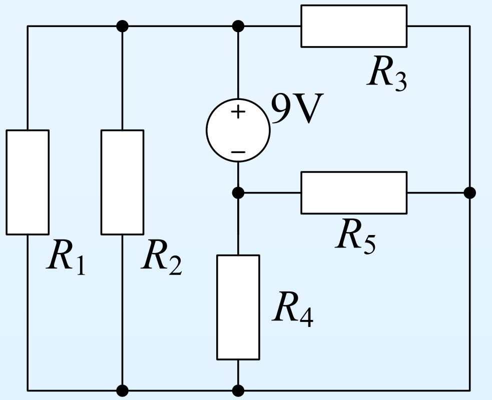

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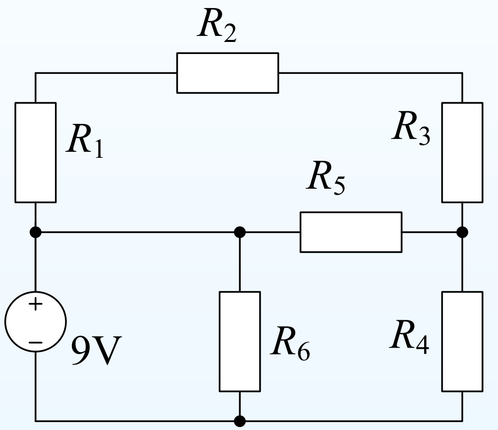

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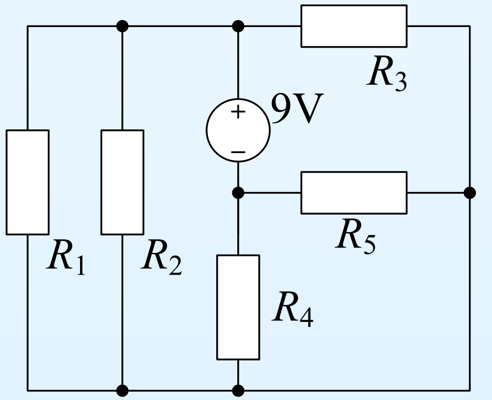
R_1, R_2, R_3 are in parallel and the same voltage is across each resistor (even though R_3 is not close to the others).



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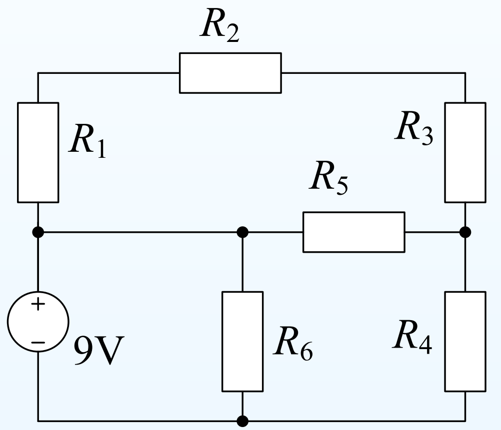

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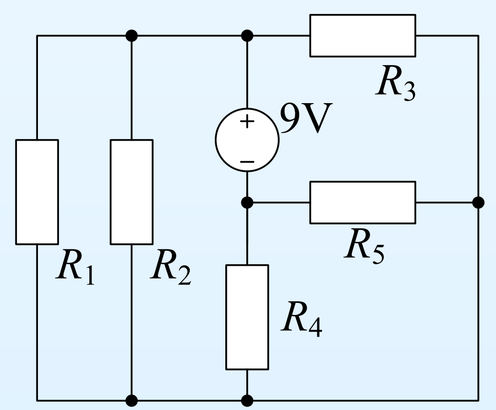

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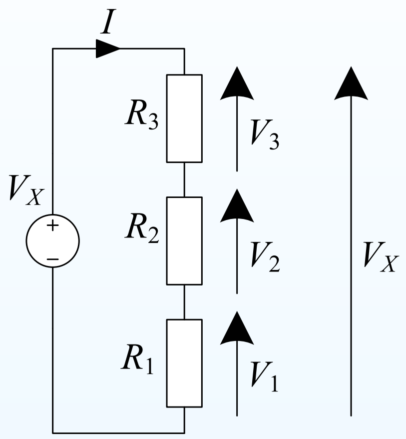
$$V_X = V_1 + V_2 + V_3$$



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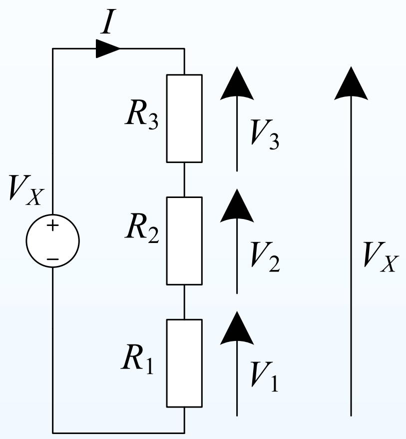

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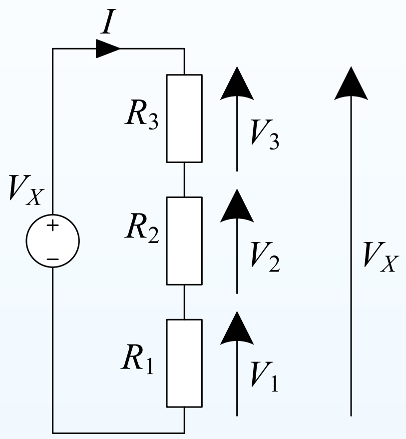

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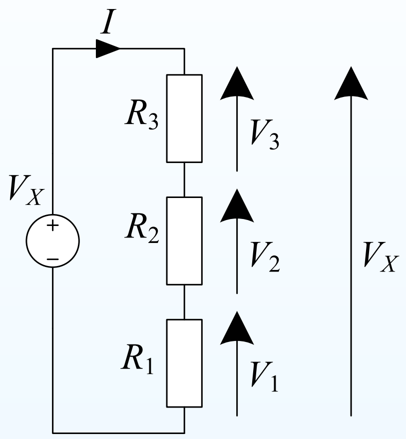

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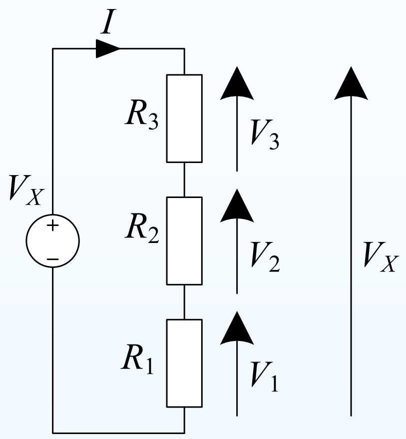

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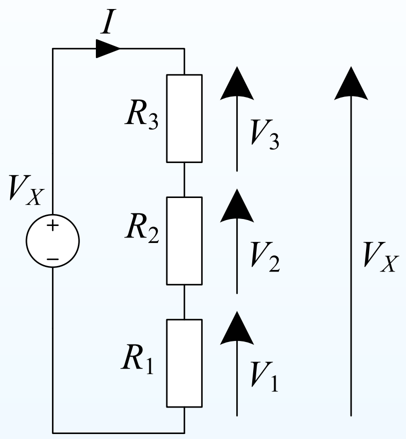
where $R_T = R_1 + R_2 + R_3$ is the total resistance of the chain.



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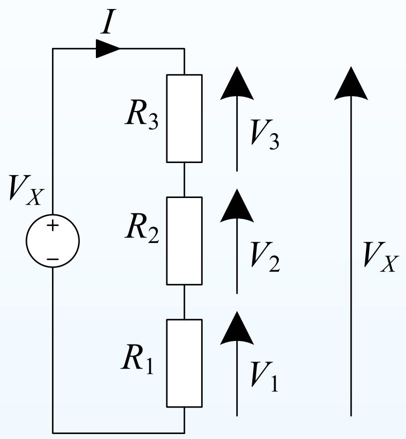

V_X is divided into $V_1 : V_2 : V_3$ in the proportions $R_1 : R_2 : R_3$.

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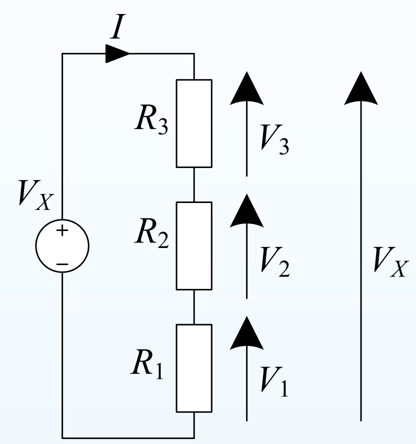

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Approximate Voltage Divider:

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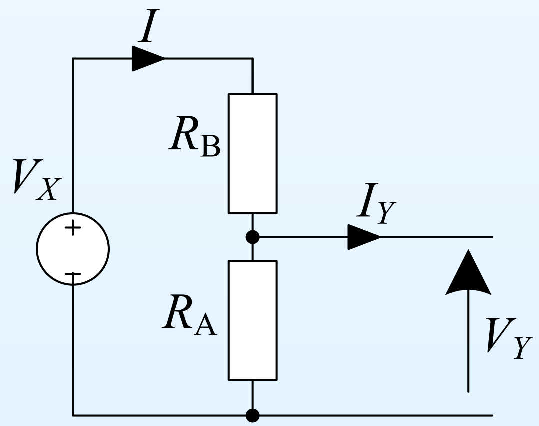

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$$\begin{aligned} V_X &= V_1 + V_2 + V_3 \\ &= IR_1 + IR_2 + IR_3 \\ &= I(R_1 + R_2 + R_3) \end{aligned}$$

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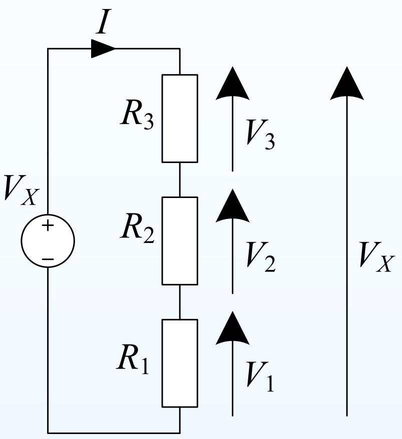

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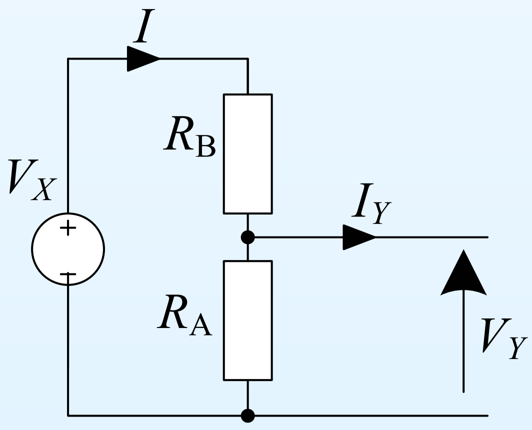
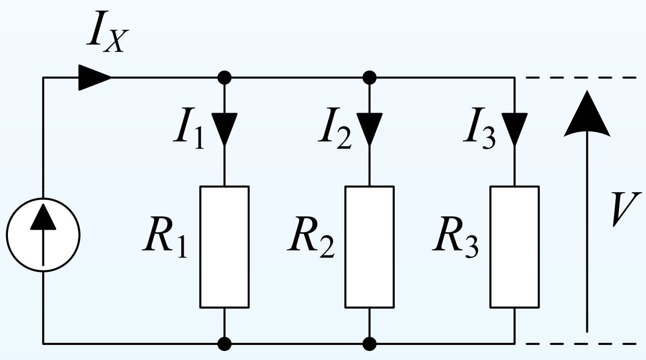


Parallel Resistors: Current Divider

Parallel resistors all share the same V.



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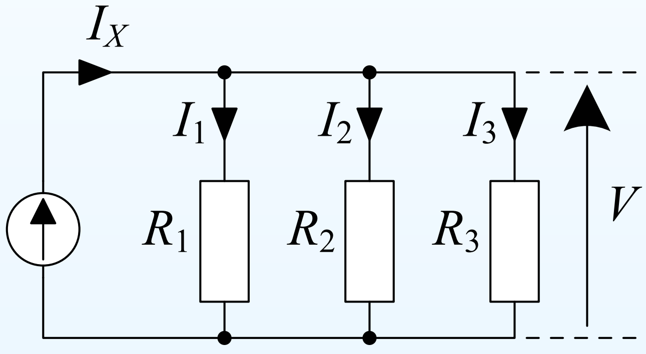

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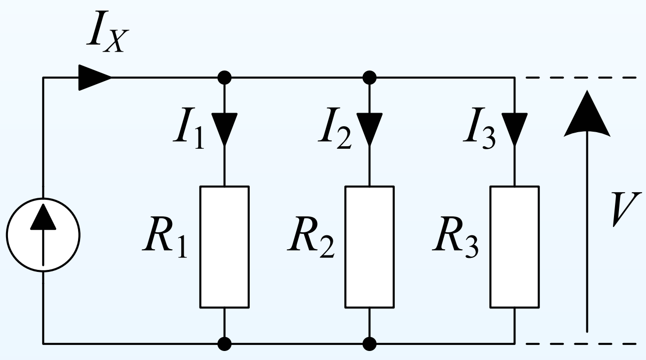

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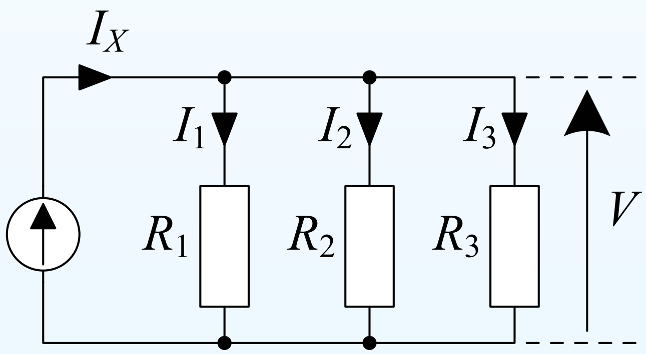

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where $G_P = G_1 + G_2 + G_3$ is the total conductance of the parallel resistors.

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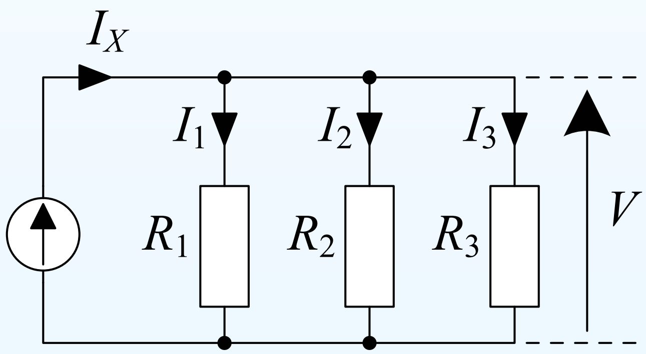


$\frac{I_1}{I_X} = \frac{VG_1}{V(G_1+G_2+G_3)} = \frac{G_1}{G_1+G_2+G_3} = \frac{G_1}{G_P}$

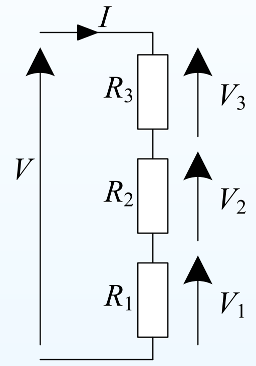
where $G_P = G_1 + G_2 + G_3$ is the total conductance of the parallel resistors.

I_X is divided into $I_1 : I_2 : I_3$ in the proportions $G_1 : G_2 : G_3$.

Equivalent Resistance: Series

We know that $V = V_1 + V_2 + V_3 = I(R_1 + R_2 + R_3) = IR_T$

So we can replace the three resistors by a single *equivalent resistor* of value R_T without affecting the relationship between V and I.



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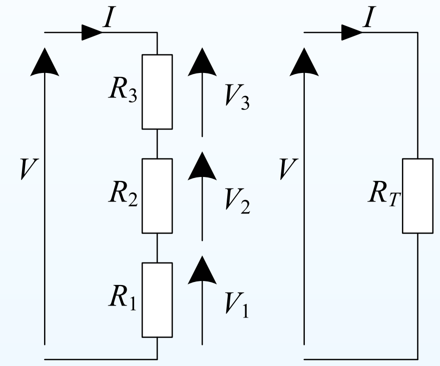

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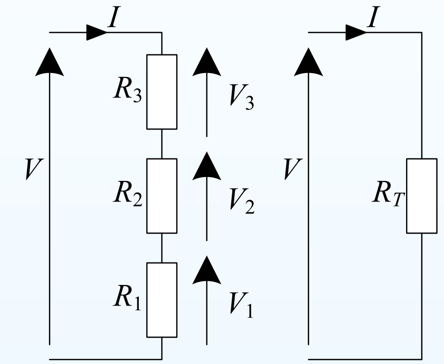

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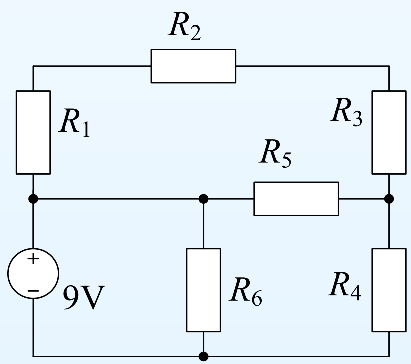

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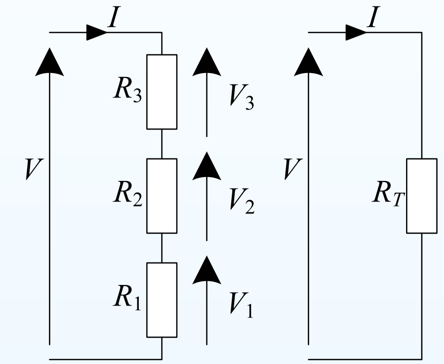

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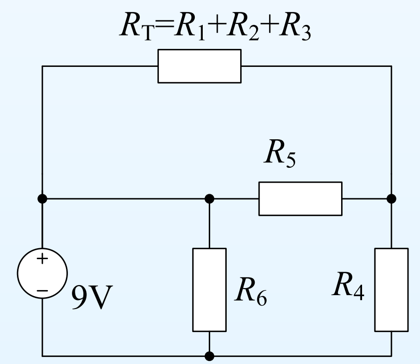
However the individual voltages V_1, V_2 and V_3 are no longer accessible.



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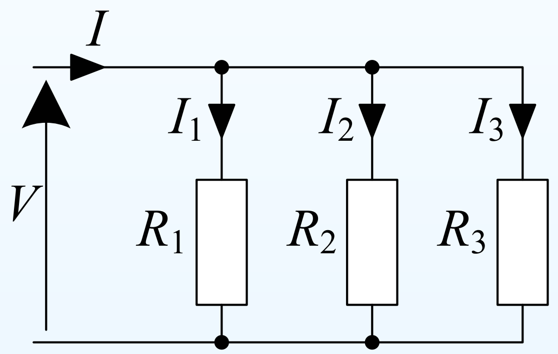

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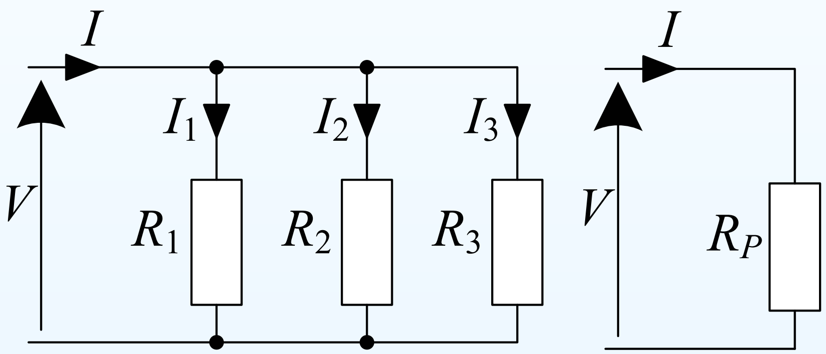

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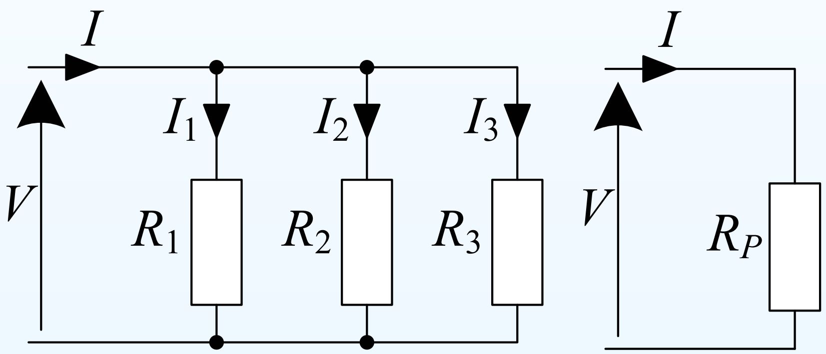

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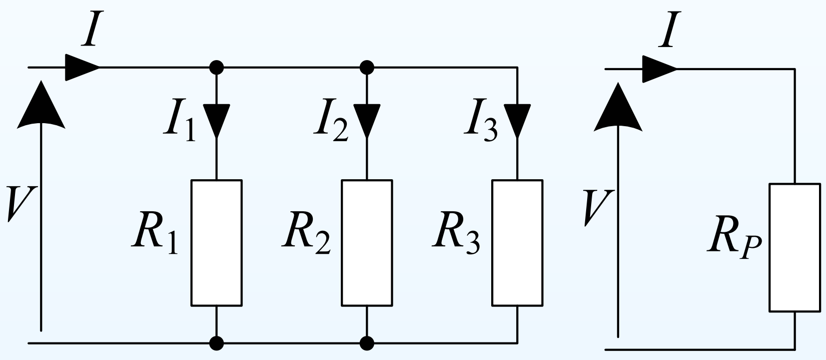
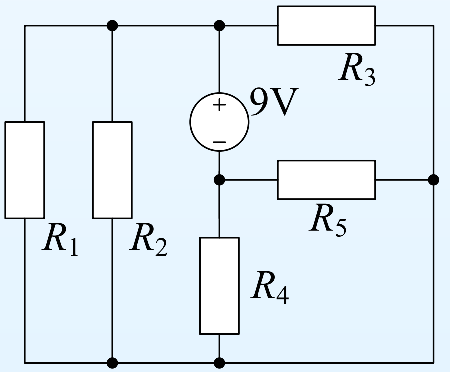


Replacing parallel resistors by their equivalent resistor will not affect any of the voltages or currents in the rest of the circuit.



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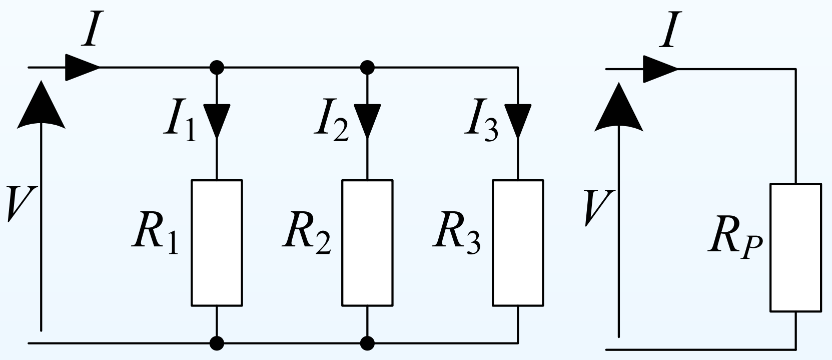

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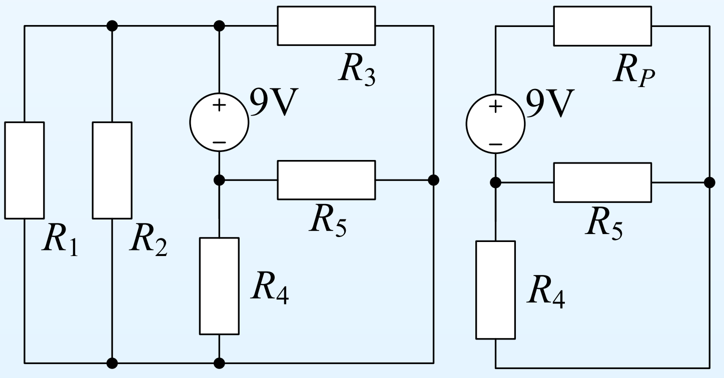

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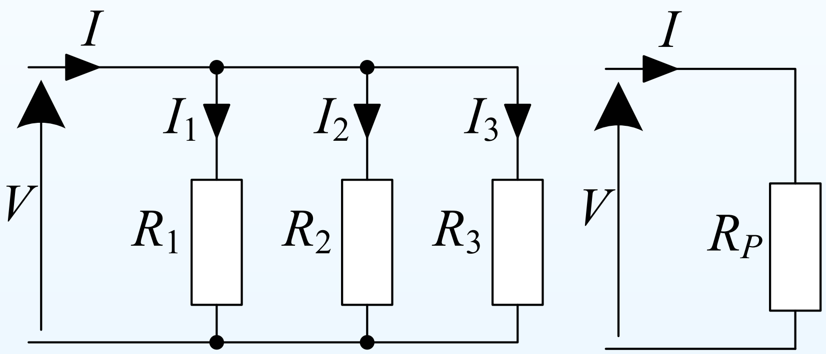

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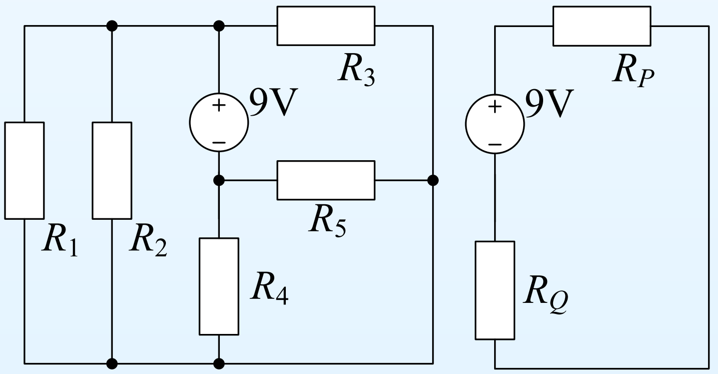
R_4 and R_5 are also in parallel.



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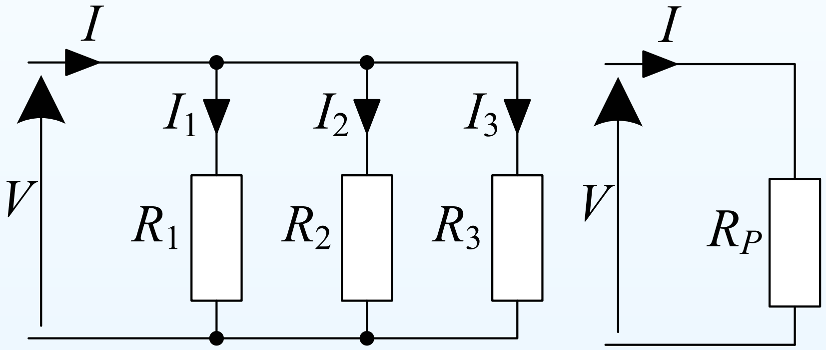

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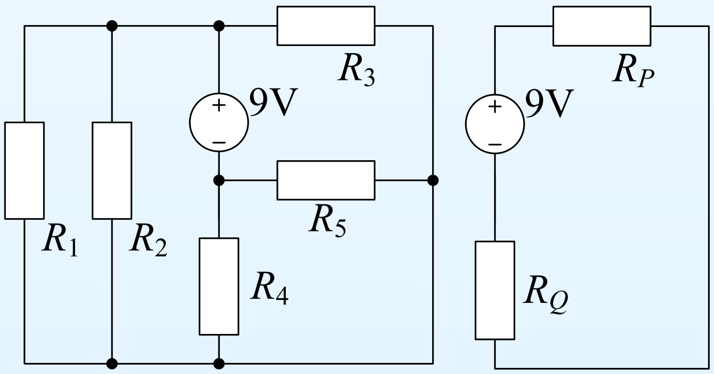

Much simpler - although none of the original currents $I_1, \cdots, I_5$ are now accessible. The three node voltages are identical.

Equivalent Resistance: Parallel Formulae

For parallel resistors $G_P = G_1 + G_2 + G_3$

or equivalently $R_P = R_1 || R_2 || R_3 = \frac{1}{1/R_1 + 1/R_2 + 1/R_3}$.

These formulae work for any number of resistors.

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- If one resistor is a multiple of the other

Suppose $R_2 = kR_1$, then

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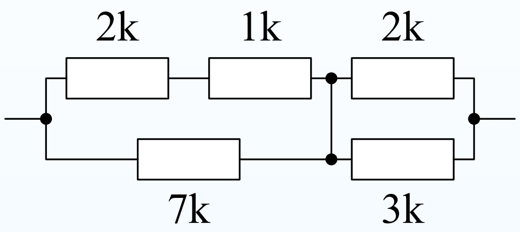
Important: The equivalent resistance of parallel resistors is always less than any of them.

Simplifying Resistor Networks

Many resistor circuits can be simplified by alternately combining series and parallel resistors.



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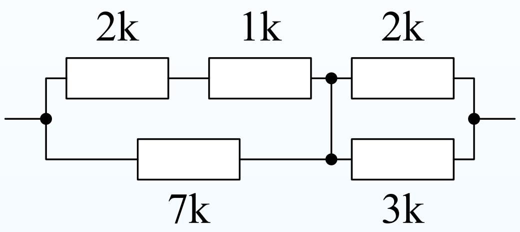
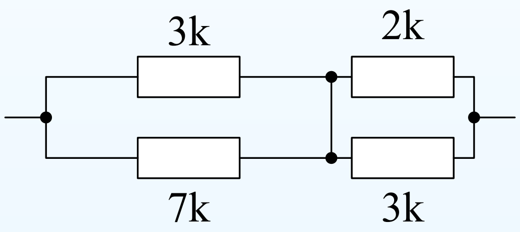


Series: $2\,\mathrm{k} + 1\,\mathrm{k} = 3\,\mathrm{k}$



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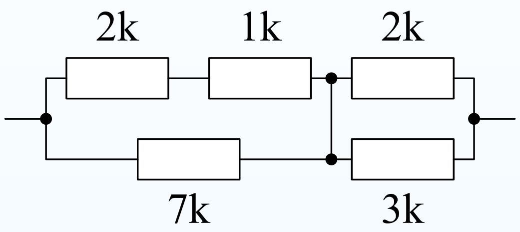

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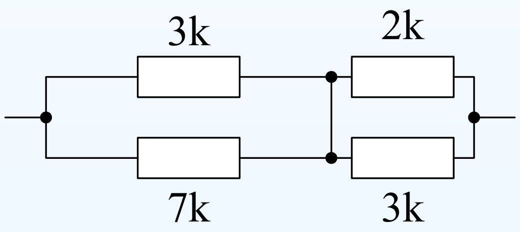

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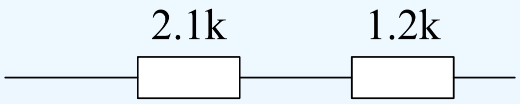

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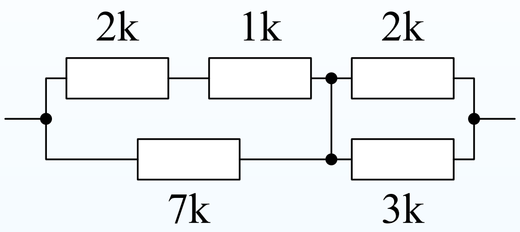

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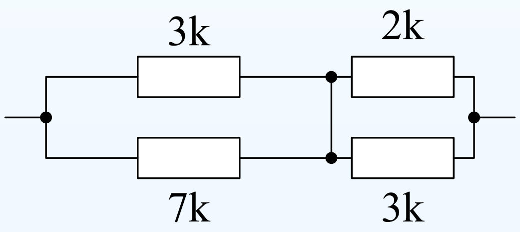

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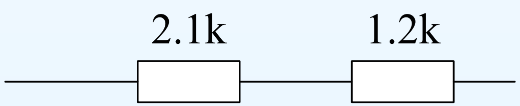

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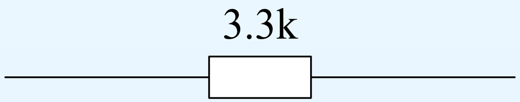

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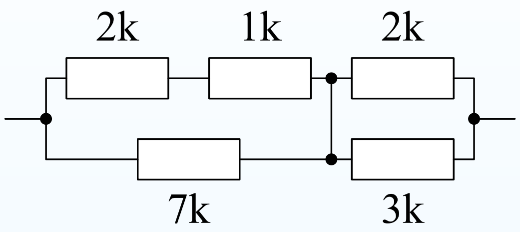

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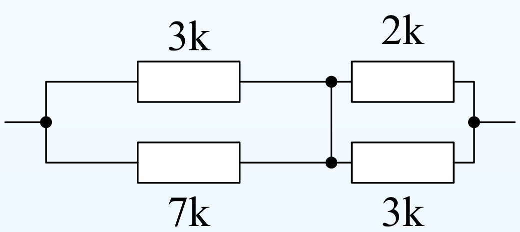

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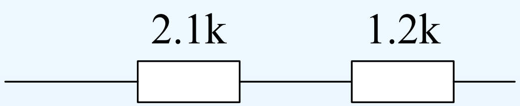

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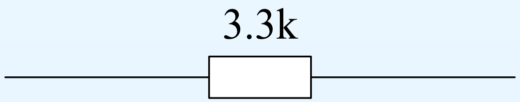
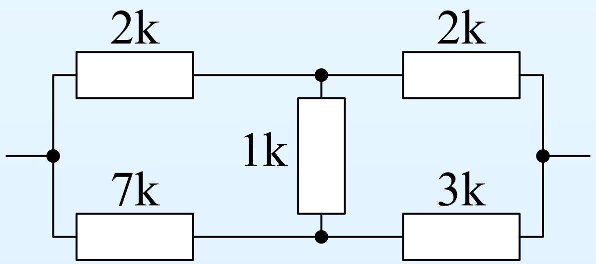


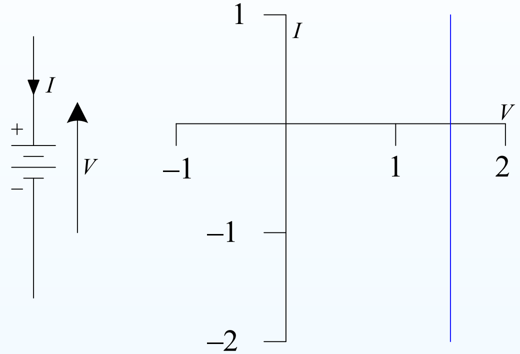
Sadly this method does not always work: there are no series or parallel resistors here.



Non-ideal Voltage Source

An ideal battery has a characteristic that is vertical: battery voltage does not vary with current.

Normally a battery is supplying energy so V and I have opposite signs, so $I \leq 0$.



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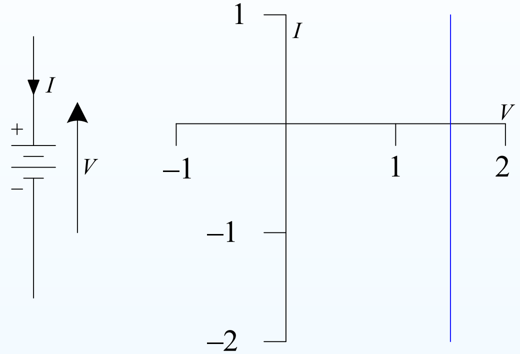
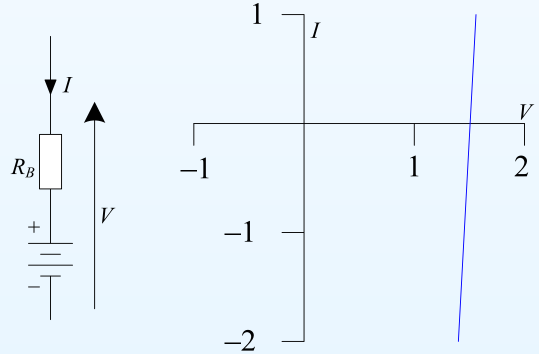


An real battery has a characteristic that has a slight positive slope: battery voltage decreases as the (negative) current increases.

Model this by including a small resistor in series. $V = V_B + IR_B$.



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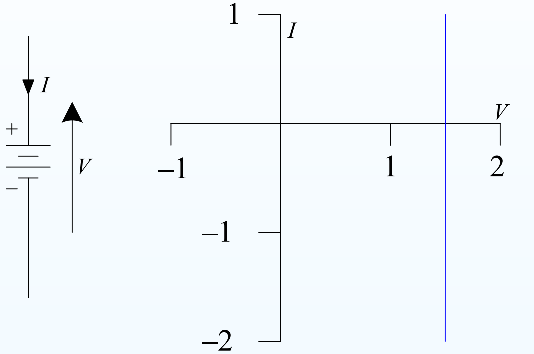

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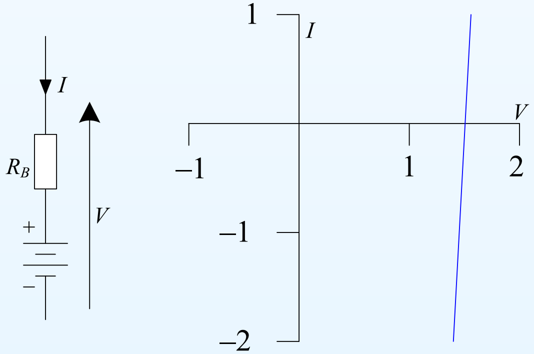

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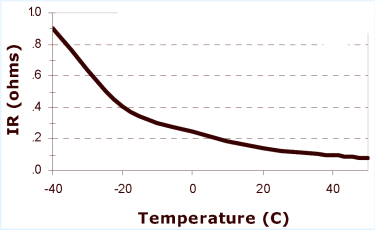
The equivalent resistance for a battery increases at low temperatures.



Summary

- Kichoff's Voltage and Current Laws
- Series and Parallel components
- Voltage and Current Dividers
- Simplifying Resistor Networks
- Battery Internal Resistance

For further details see Irwin & Nelms Chapter 2.