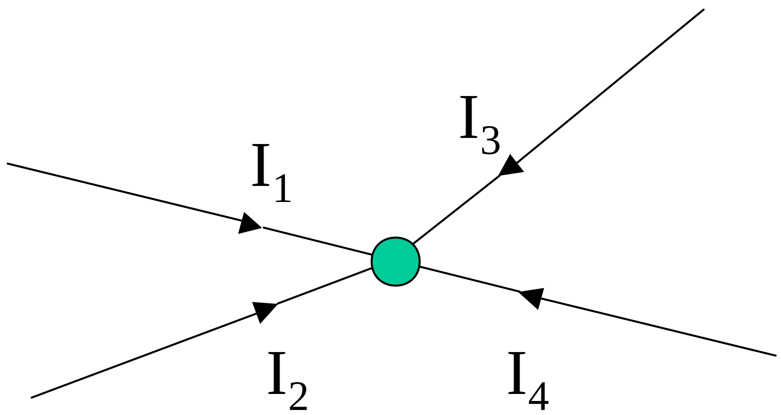
Kirchoff's Current Law

- If you have water flowing into and out of a junction of several pipes, water flowing into the junction must equal water flowing out.
- The same applies to electric currents.



.

- That is, $I_1+I_2+I_3+I_4=0$.

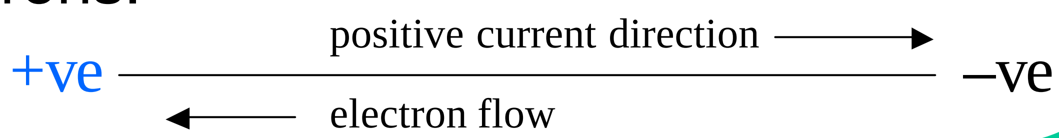
Kirchoff’s Current Law

- Note that for this formula to work, some of the currents in the diagram must have negative values.
- If a current does have a negative value, all this means is that the current is in the direction opposite to the arrow as drawn.
- Put simply, Kirchoff’s current law states that the sum of the currents into a node (junction) must be equal to zero. That is.

$$\sum_{n=1}^{N} I_n = 0$$

Conventional Current

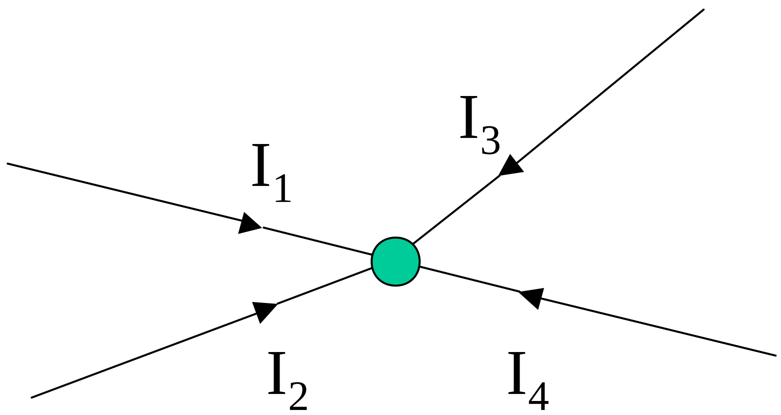
- A flow of current in a wire is a flow of negatively charged electrons. That is, from the negative terminal to the positive in an electric circuit.
- In EE we always use *conventional current* which is the direction of flow of positively charged particles.
- For this reason, the direction of conventional current flow is the direction opposite to the electron flow. That is, it is from the positive terminal to the negative.
- The convention was established well before the discovery of electrons.



Worked Example

- Q: If I_1=900mA, I_2=-600mA, and I_3=-600mA, what is I_4?

- A: I_4=300mA



Voltage

- Now what makes the current flow?
  - In the case of water in pipes, it would be the water pressure.
  - In the case of electric current, it is the *voltage (V),* sometimes referred to as the *electromotive force (emf).*
  - In the water model, an increase in water pressure leads to increased flow rate. The actual flow rate is determined by the pressure and the resistance of the pipes to the flow due to friction etc. Large pipes have low resistance, whereas small pipes have high resistance.
  - In electric circuits, the current I increases linearly with applied voltage V as expressed by ohm’s law.

Ohm’s Law

$$V = IR \text{ or, equivalently, } I = \frac{V}{R}$$

where R is the resistance of the circuit expressed in Ohms (Ω)

The electric current is moved by a force, and that force is the applied voltage. Ohm’s law simply says that the current (rate of flow) is proportional to the force

Resistance and Resistors

- A resistor is a physical component used in electrical circuits to provide resistance. (cf large/small diameter pipes for water model)
- Typical values of resistance used in electronic circuits range from, say, 1Ω to $10M\Omega$
- Typically only certain resistance values are available as single components
- For example, in the E12 sequence for 5% tolerance resistors, only the following values are available:
  10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82
  in each decade. For example, 270 Ω, 1.2k Ω, and $39k\Omega$ resistors are easily found in the labs.

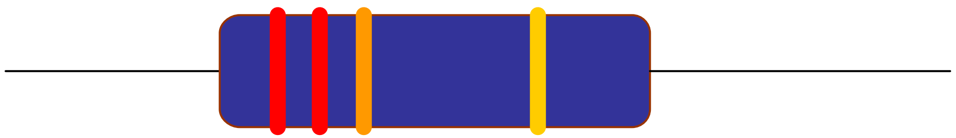
Resistor Values

- Sometimes the resistance of a resistor is written numerically on the component.
- More commonly, it is marked using the resistor colour code which you should commit to memory to help you in lab work
- The 3 band resistor colour code uses two colour bands for the value (E12) and one band for the multiplier (power of 10).
- Another band, which is spaced apart from the value bands, indicates the component tolerance.
- For example, a 5% tolerance (gold band) resistor is guaranteed to be within 5% of the nominal value.

Resistor Colour Code

Band Colour	Significant Digit	Mutiplier	Tolerance
Black	0	1	-
Brown	1	10	1%
Red	2	100	2%
Orange	3	1k	3%
Yellow	4	10k	4%
Green	5	100k	-
Blue	6	1M	-
Violet	7	10M	-
Gray	8	-	-
White	9	-	-
Gold	-	0.1	5%
Silver	-	0.01	10%
No Band	-	-	20%

Example

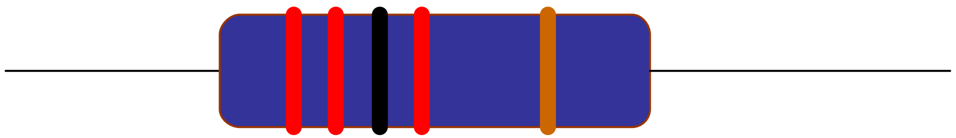


22kW, 5% component tolerance

4 Band Colour Code

- Some resistors (1% tolerance) use 3 bands to describe the value, one for the multiplier
- These use the E24 series values as follows:
  10, 11, 12, 13, 15, 16, 18, 20, 22, 24, 27, 30,
  33, 36, 39, 43, 47, 51, 56, 62, 68, 75, 82, 91
- These are read in exactly the same way.
- Note the change in the colour of the multiplier band!

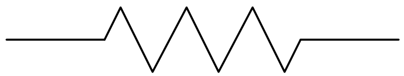
Example



22kW, 1% component tolerance

Schematic Symbol for Resistor

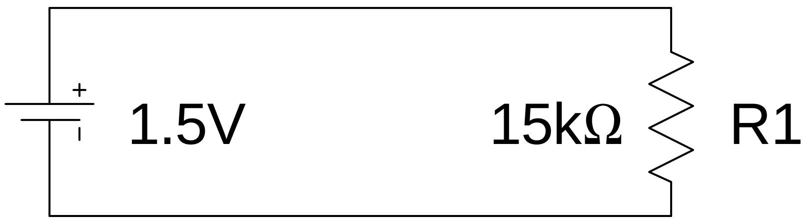
- In a schematic diagram we use the following symbol for the resistor.



- We generally label the resistor with its value and give it a name, such as R_1, to distinguish it from any other resistors in the circuit.

Example

What is the current?



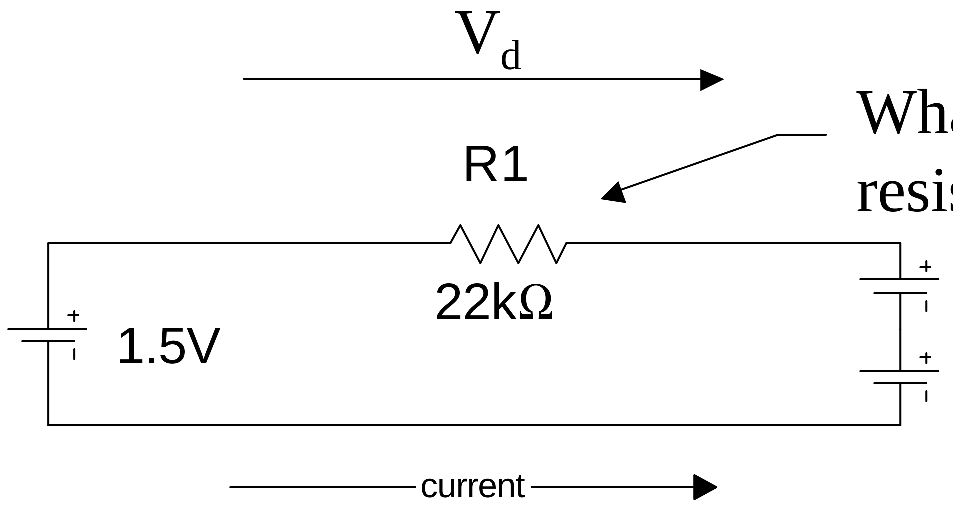
$I=V/R=1.5/15=0.1mA$

Note: mA, kΩ, and V can be used in Ohm’s Law instead of A, Ω, and V

Potential Difference

- If we had two water taps at the same pressure and connected them together with a hose, no water would flow.
- However, if the taps had different pressures, water would flow at a rate determined by the pressure difference and the resistance of the hose.
- Similarly, if a resistor is connected between two batteries the current flow will depend upon the potential (voltage) difference between the two ends of the resistor.

Potential Difference Example



What happens if this resistor is removed?

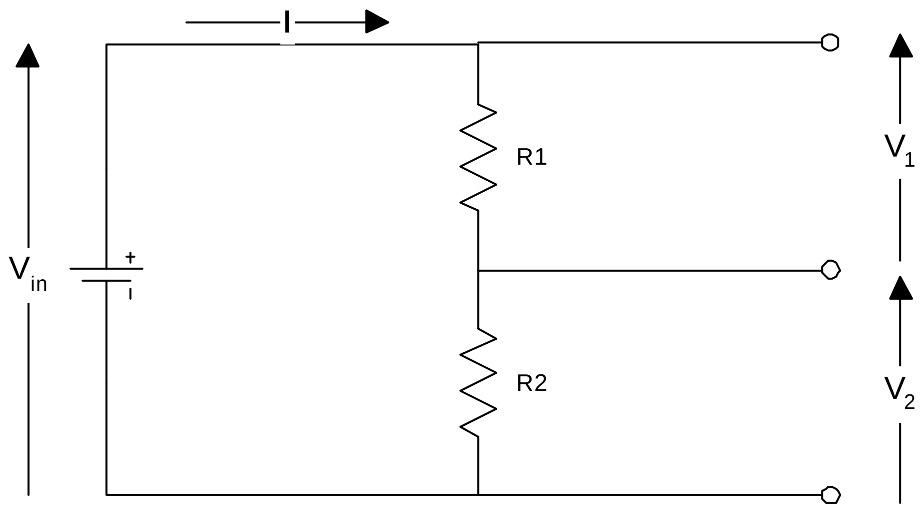
The circuit gets HOT!

What is the current?

Potential difference, V_d = 3-1.5=1.5V

Current =V_d/R=1.5/22=0.068mA=68μA

Resistors in Series



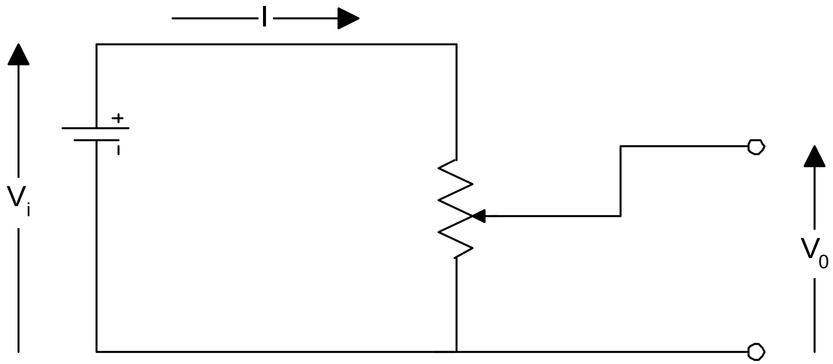
$$V_{in} = IR_1 + IR_2 = I(R_1 + R_2) = IR_{Total}$$

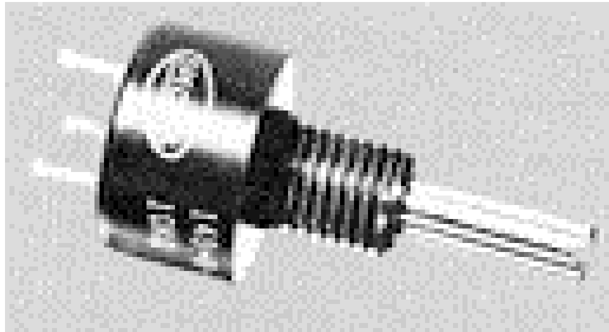
The total resistance of resistors in series is the *sum* of the resistance values

$$\frac{V_1}{V_2} = \frac{IR_1}{IR_2} = \frac{R_1}{R_2}$$

The voltages across the resistors divide in proportion to the resistances.
Such a circuit is called a *voltage divider*.

Potentiometer



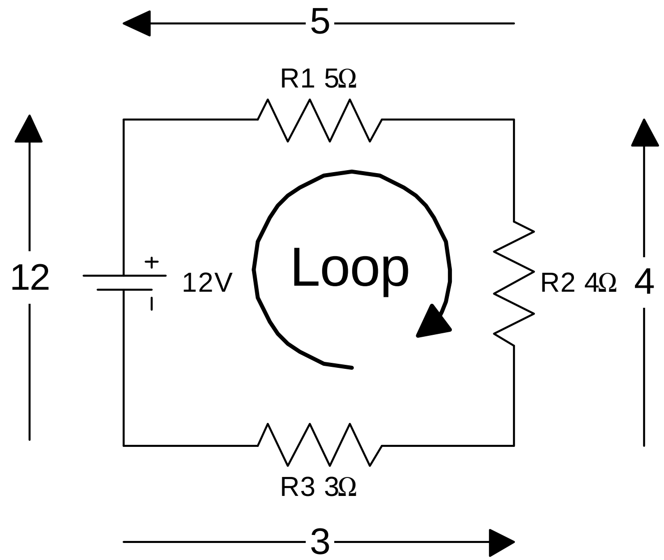


Simple extension of the voltage divider concept. Output voltage varies between 0 and V_i as the shaft of the potentiometer is rotated

Application – volume control on a stereo amplifier.

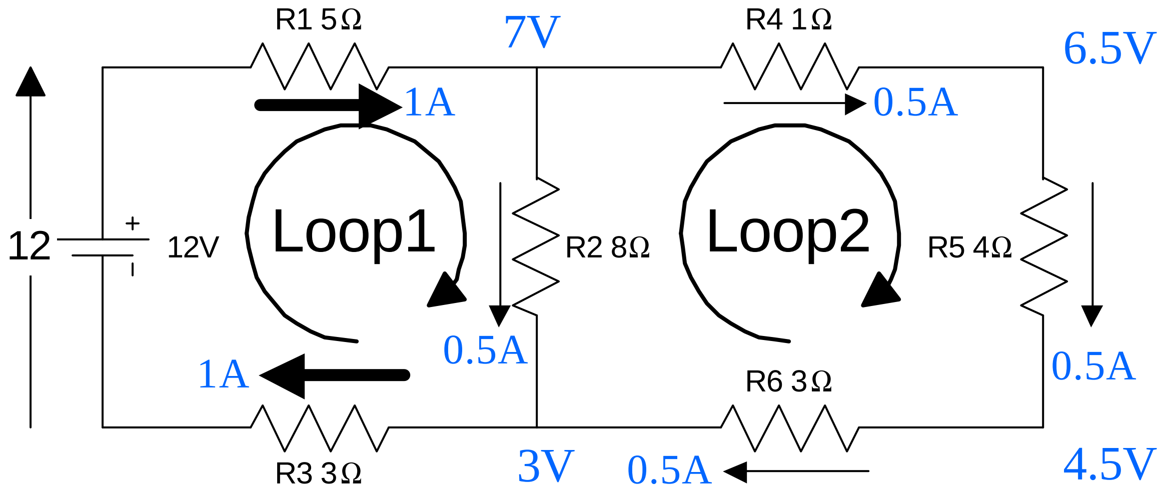
Kirchoff's Voltage Law

- The sum of the voltages around a closed loop of an electric circuit must equal zero.



Current is 1A

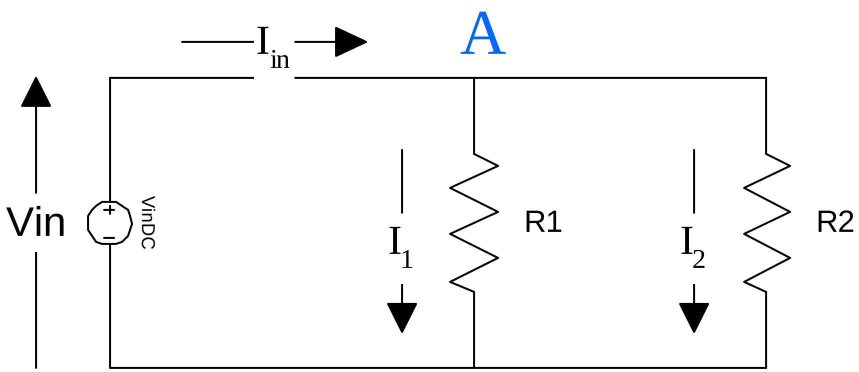
Harder Example



R4, R5, and R6 sum to 1+4+3=8 Ohms.
By putting this resistance in parallel with R2, we get 8||8=4 Ohms.
Thus current in Loop1 is 1A, current in Loop2 is 0.5A.
Use Ohm's Law to solve.

Note that Kirchoff's Voltage law applies to the outer loop as well

Resistors in Parallel



Using Kirchoff's current law at node A.

$$I_{in} = I_1 + I_2 = \frac{V_{in}}{R_1} + \frac{V_{in}}{R_2} = V_{in}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$\frac{1}{R_{total}} = \frac{I_{in}}{V_{in}} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

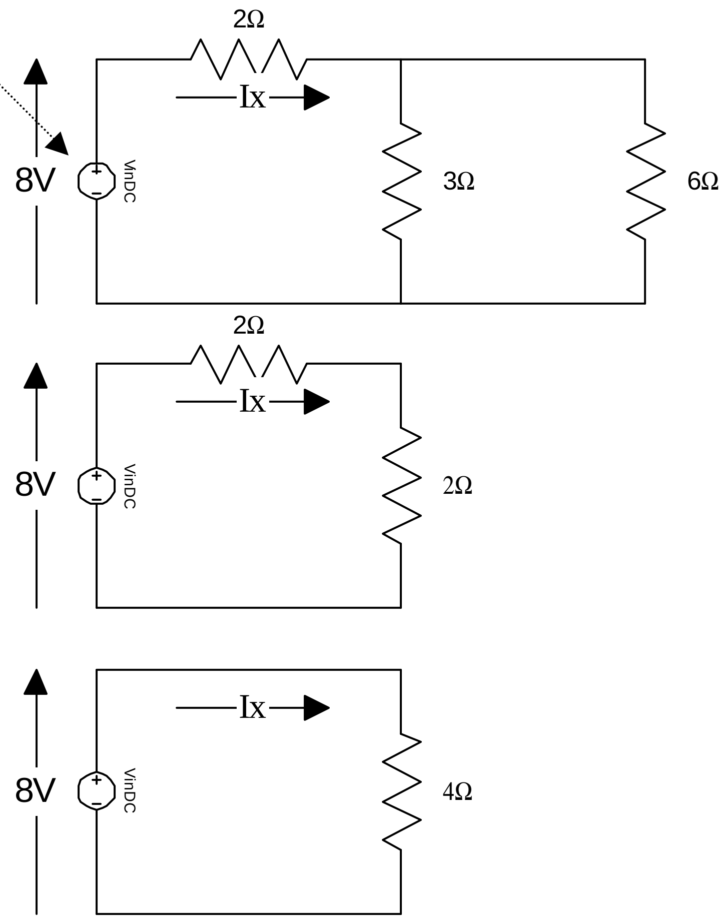
$$R_{total} = \frac{R_1 R_2}{R_1 + R_2}$$

In general, for N resistors in parallel

$$\frac{1}{R_{total}} = \sum_{i=1}^{N} \frac{1}{R_i}$$

Simplification Example 1

Constant Voltage Source

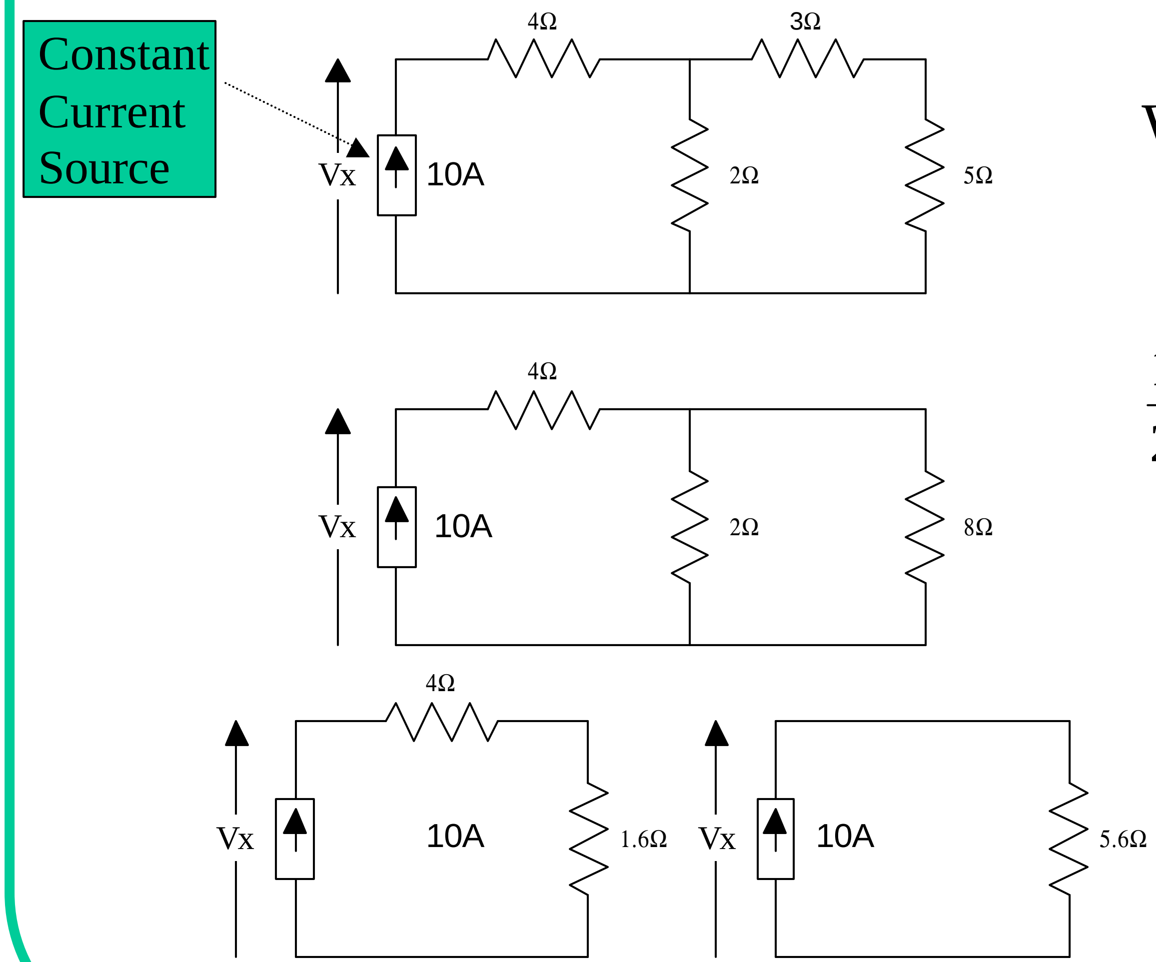


What is the current, I_x?

$$\frac{1}{2} = \frac{1}{6} + \frac{1}{3} \quad \therefore R_{total} = 2$$

Effective load resistance is 4Ω. Current is 2A.

Simplification Example 2



What is the voltage, V_x?

$$\frac{1}{2}+\frac{1}{8}=\frac{5}{8} \qquad \therefore R_{total}=\frac{8}{5}=1.6$$

Effective load resistance is 5.6Ω

Voltage, V_x, is IR=10 x 5.6 = 56V