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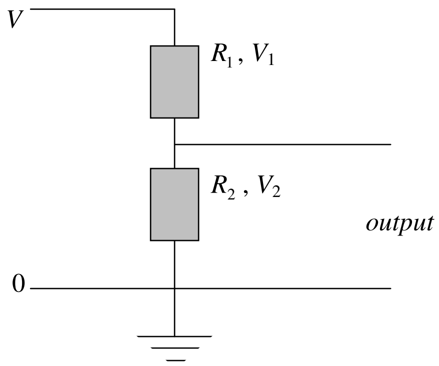
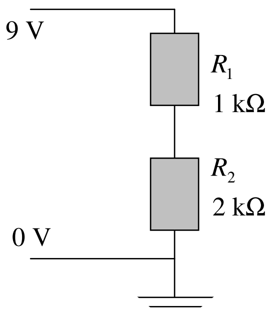
Voltage dividers

A series connection of two or more resistors forms a voltage divider. The voltage supplied to the series connection is divided into voltages in the same ratio as the resistances of the components in the unloaded voltage divider. If the voltage divider is loaded, the resistance of the load must be taken into account in calculating the voltages if it is comparable with the resistance of the voltage divider. The load resistance can be ignored if it is very much higher than the resistance of the voltage divider.



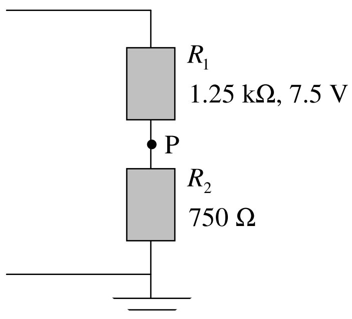
$V_1 = \frac{R_1}{R_1 + R_2} \times V$ and $V_2 = \frac{R_2}{R_1 + R_2} \times V$, where $V = V_1 + V_2$ is the supply voltage. Also, $\frac{V_1}{V_2} = \frac{R_1}{R_2}$

Example 1 A 1-kΩ and a 2-kΩ resistor are connected in series, and the potential difference between the two ends of the series is 9.0 V. Determine the voltage across each resistor.



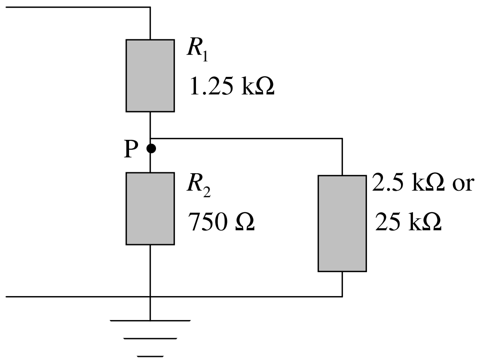
$V_1 : V_2 = R_1 : R_2$, .: $V_1 = 3.0$ V and $V_2 = 6.0$ V

Example 2 A 750-Ω and 1.25-kΩ resistors are in series, and the voltage across the latter is 7.5 V.
(a) Find the voltage across the 750-Ω resistor.
(b) Find the potential at point P.
(c) Find the supply voltage the series circuit.



(a) $\frac{V_2}{V_1} = \frac{R_2}{R_1}$, .: $V_2 = \frac{R_2}{R_1} \times V_1 = \frac{750}{1250} \times 7.5 = 4.5$ V
(b) At point P, $V = 4.5$ V
(c) Supply voltage $= 7.5 + 4.5 = 12$ V

Example 3 The circuit in example 2 is now loaded. The supply voltage remains the same.
(a) Find the potential at point P when the resistance of the load is 2.5 kΩ.
(b) Find the potential at point P when the resistance of the load is 25 kΩ.



(a) Total resistance of R_2 and the load $R = \frac{1}{\frac{1}{750} + \frac{1}{2500}} = 577\ \Omega$

Voltage across R_2 (or the load) $= \frac{577}{1250 + 577} \times 12 = 3.8$ V

Potential at point P $= 3.8$ V

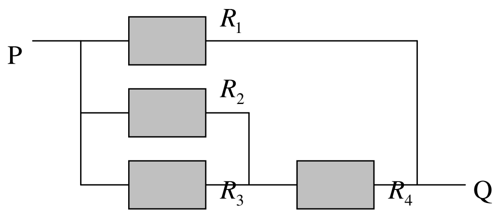
(b) Total resistance of R_2 and the load $R = \frac{1}{\frac{1}{750} + \frac{1}{25000}} = 728\,\Omega$

Voltage across R_2 (or the load) $= \frac{728}{1250 + 728} \times 12 = 4.4$ V

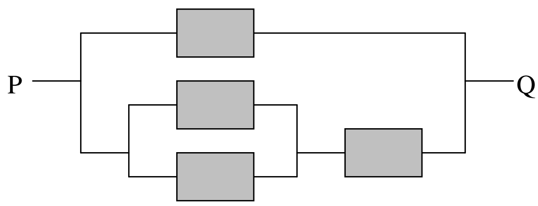
Potential at point P $= 4.4$ V, very small change

Simplifying circuits comprising parallel and series ohmic resistors and voltage dividers

Example 4 Replace the following circuit between P and Q with a single resistor. The resistors are identical 10Ω each.



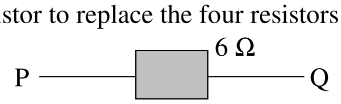
Redraw the diagram:



Effective resistance (i.e. total resistance) between P and Q:

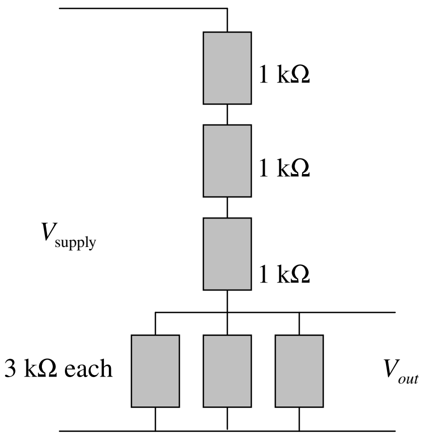
$$R_T = \frac{1}{\frac{1}{10} + \frac{1}{10 + \frac{1}{\frac{1}{10} + \frac{1}{10}}}} = 6\ \Omega$$

Use a 6-Ω resistor to replace the four resistors.

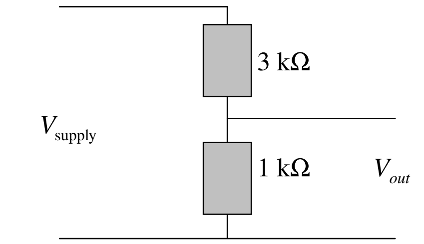


Example 5 (a) Simplify the following voltage divider to give the same output voltage V_{out}.

(b) Hence find V_{out} when $V_{supply} = 12$ V.

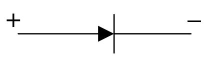


(a) Replace the three 3-kΩ resistors with a single resistor of $\frac{1}{\frac{1}{3}+\frac{1}{3}+\frac{1}{3}} = 1$ kΩ resistance, and replace the three 1-kΩ resistors with a 3-kΩ resistor. (b) $V_{out} = \frac{1}{3+1} \times 12 = 3$ V

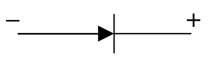


Non-ohmic conductors–diodes, thermistors and photonic transducers such as LDR, photodiodes and LED

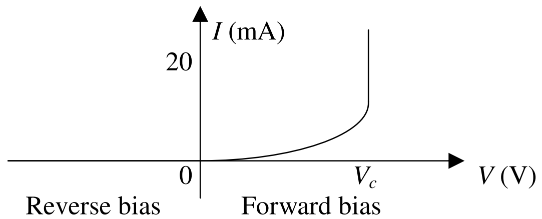
A *diode* is an electronic device that can be used to control voltage. It conducts when it is forward biased, and current drops to practically zero when it is reverse biased.



Forward bias, $R \to 0$.



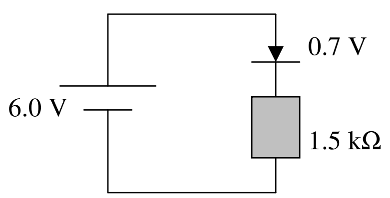
Reverse bias, $R \to \infty$.



For a germanium diode, the voltage for conduction of current $V_c \approx 0.3$ V, and for a silicon diode $V_c \approx 0.7$ V.
When a diode is in forward conductive mode, the voltage across it is fairly constant at V_c.

Example 6 A silicon diode and a 1.5-kΩ resistor is connected in series with a 6.0-V battery.
(a) Determine the voltage drop across the resistor and the current through it when the diode is in forward conductive mode.
(b) What is the voltage drop across the diode when it is reverse biased?

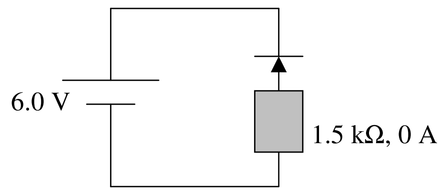
(a) In forward conductive mode:



$V_{resistor} = 6.0 - 0.7 = 5.3$ V

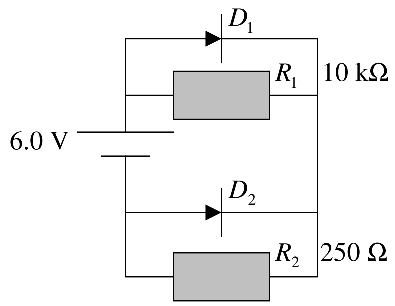
$I_{resistor} = \frac{V_{resistor}}{R} = \frac{5.3}{1.5 \times 10^3} \approx 3.5 \times 10^{-3}$ A, i.e. 3.5 mA

(b) Reversed biased:



$I_{resistor} = 0$ A, $V_{resistor} = I_{resistor} \times R = 0$ V, $V_{diode} = 6.0 - 0 = 6.0$ V

Example 7 Consider the following circuit with two silicon diodes and two ohmic resistors. Determine the voltage drop and the current through each component.



D_1 is in forward conductive mode, $V_{D1} = 0.7$ V
D_1 and R_1 are parallel, .: $V_{R1} = 0.7$ V

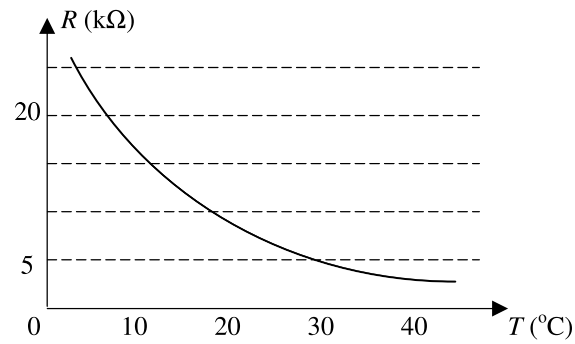
$I_{R1} = \frac{V_{R1}}{R_1} = \frac{0.7}{10 \times 10^3} = 7 \times 10^{-5}$ A ≈ 0 A

D_2 is reversed biased, .: $I_{D2} = 0$ A
The parallel connection of D_1 and R_1 is in series with the parallel connection of D_2 and R_2,

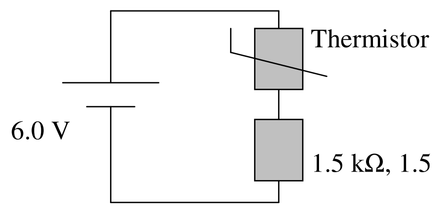
.: $V_{D2} = V_{R2} = 6.0 - 0.7 = 5.3$ V, $I_{R2} = \frac{V_{R2}}{R_2} = \frac{5.3}{250} = 0.0212$ A

$I_{D1} + I_{R1} = I_{D2} + I_{R2}$, .: $I_{D1} \approx I_{R2} \approx 21$ mA

A *thermistor* is a device whose resistance varies with temperature. The following resistance versus temperature graph shows the characteristic of a thermistor.



Example 8 A voltage divider consists of the above thermistor and a 1.5-kΩ ohmic resistor is powered by a 6.0-V battery. The voltage across the resistor is 1.5 V. Determine the temperature of the thermistor.



$V_{thermistor} = 6.0 - 1.5 = 4.5$ V

$\frac{R_{thermistor}}{R_{resistor}} = \frac{V_{thermistor}}{V_{resistor}}$, .: $R_{thermistor} = \frac{4.5}{1.5} \times 1.5 = 4.5$ kΩ

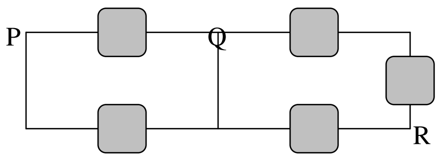
Read from graph: $T \approx 30°$ C

Exercise: Next page

Q1 A 1.5 kΩ and a 4.5 kΩ resistors form a voltage divider. The voltage of the 4.5 kΩ resistor is 9.0 V. What is the total voltage of the two resistors?

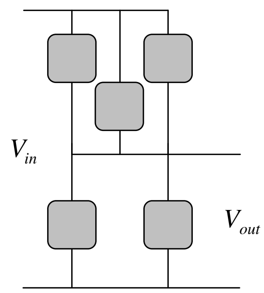
Q2 A parallel connection of two 1.0 kΩ resistors is in series with a 1.0 kΩ and a 2.0 kΩ resistor. Find the voltage of each resistor in terms of the voltage V supplied to the voltage divider.

Q3 Find the effective resistance between points P and R of the following circuit. The resistors have the same resistance of $100\,\Omega$.



Q4 Refer to Q3. Find the potential at point Q if $V_{PR} = 3$ V and the potential at point R is -0.7 V.

Q5 Simplify the following voltage divider to give the same output voltage V_{out}.
The resistors have the same resistance of $50\,\Omega$.



Q6 Refer to Q5. Would the output voltage be changed if a load of 2 kΩ is connected to the output?

Q7 Refer to the forward bias circuit in Example 6. The silicon diode is replaced with a germanium diode. Determine the voltage drop across the resistor and the current through it.

Q8 Refer to the reverse bias circuit in Example 6. The silicon diode is replaced with a germanium diode. Determine the voltage drop across the diode and the current through it.

Q9 In Example 6, the 6 V battery in the forward bias circuit is replaced by a sinusoidal voltage of 6.0 V amplitude at 50 Hz. Draw a graph showing the voltage across the resistor.

Q10 In Example 6, the 6 V battery in the reverse bias circuit is replaced by a sinusoidal voltage of 6.0 V amplitude at 50 Hz. Draw a graph showing the voltage across the resistor.

Answers: 1. 12 V 2. $V/7$, $V/7$, $2V/7$, $4V/7$ 3. 83.3 ohms 4. 0.5 V 5. Replace the 3 in parallel with a single 50/3 ohm resistor and the 2 in parallel with a single 25 ohm resistor. 6. No, because the load is very much greater than the circuit resistance. 7. 5.7 V, 3.8 mA 8. 6.0 V, 0 A