FACTFILE:
GCE TECHNOLOGY & DESIGN

1.14 CALCULATIONS

Rewarding Learning

Electronic Components

Learning Outcomes

Students should be able to:

- use knowledge and understanding of formulae, and given information to complete calculations for:
  - V = I × R and W = V × I;
  - power ratings of resistors in circuits;
  - Rt = R1 + R2 + ... + Rn;
  - Rt = R1 × R2/ (R1 + R2);
  - $V_{out} = V_{in} \times R2/ (R1 + R2)$;
  - time constant = C × R [see Fact File 1.15];
  - Light emitting diode (LED) including maximum current, forward voltage, series resistance and power dissipation for series resistance;
  - current flow through output devices [see Fact File 1.17];
  - time period T =I/f [see Fact File 1.14 and 1.17];
  - time period, T=1.1CxR of output of monostable circuits using 555 timer [see Fact File 1.14 and 1.17];
  - frequency, f=1.44/(R1+2R2)C of output of astable circuits using 555 timer, to include mark/space ratio [see Fact File 1.14 and 1.17]; and
  - transistor to include calculation of base resistor, hfe, Ic(max)and Vbe [see Fact File 1.14 and 1.17].

Students need to know the relevant formulas as we will not provide these in the assessment.

Calculation for Ohm's Law

If current flows through a resistor, the potential at one end must be greater than the potential at the other end - i.e. a potential difference exists across it. The size of the current through a resistor is related to the size of the pd across it by Ohm's Law:

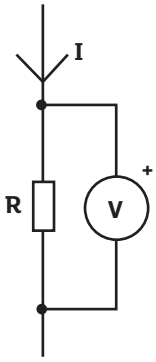
The current through a conductor is directly proportional to the pd across it provided the temperature remains constant.

$I \propto V$ or

V=IR

LEARN THIS!

R is called the resistance of the conductor and is measured in ohms (Ω)



The direction of conventional current is always from the higher potential (voltage) to the lower potential. Note that not all materials obey Ohm's Law.

Worked Examples

1 A resistor is connected across a 9 V battery and a current of 5 mA flows through it. Find the value of the resistor.

Solution

R = V/I = 9/ 0.005 = 1800 Ω

2 What voltage will cause a current of 0.5 mA to flow through a 10 kΩ resistor?

Solution

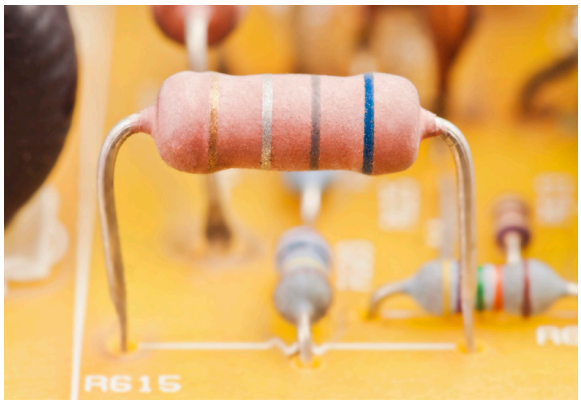
V = I x R = 0.0005 x 10000 = 5 V

3 A 6V battery causes a current of 3μA to flow through a resistor. What is the value of the resistor?

Solution

R = V/I = 6/ 0.000003 = 2 MΩ

Calculation for Power Rating of Resistors in Circuits



Electrical energy is converted to heat when current flows through a resistor. Usually the effect is not important, but if the resistance is low (or the voltage across the resistor high) a large current may pass making the resistor become warm to the touch. The resistor must be able to withstand the heating effect and so resistors with appropriate power ratings must be chosen. The maximum rate at which the electrical energy may be converted to heat in the resistor is the power rating and is measured in Watts. It may be shown that the power produced in a resistor is proportional to the current through it and the pd between its ends.

$P = VI$ or $P = I^2R$ or $P = V^2/R$

LEARN THIS!

For the majority of resistors used in circuits, a power rating of 0.25W would be suitable. However it is wise to perform a simple calculation to check if a resistor with a higher power rating would be required. It is possible to obtain resistors with power ratings from 0.1 W to 100 W.

Worked Example

A buzzer is considered to be an inductive load and draws a current of 450 mA when operational. Calculate the power dissipated by the buzzer when the voltage across it is 6 V.

Solution

P = VI Substituting: P = 6 x 0.45 = 2.7 W

Calculation for Resistors in Series

When resistors are connected in series, the electric current has to pass through all of the resistors and so the total resistance is the sum of the individual resistances:

$Rt = R1 + R2 + \ldots + Rn$

LEARN THIS!

Calculation for Resistors in Parallel

When components are connected in parallel:

- the ends of components connected to the same point are at the same potential. It follows that the same potential exists across components in parallel.
- the total current through the components is the sum of the individual currents.

The equivalent resistance of two resistors in parallel can therefore be calculated using:

$$I = \frac{V}{Rt} = \frac{V}{R1} + \frac{V}{R2}$$

$$\therefore \quad \frac{1}{Rt} = \frac{1}{R1} + \frac{1}{R2}$$

$$\therefore \boldsymbol{Rt = \frac{R1 \times R2}{(R1 + R2)}}$$

LEARN THIS!

Worked Examples

1 Find the single resistor that could replace the parallel combination of a 12 kΩ resistor and an 18 kΩ resistor?

Solution

Rt = (12 k x 18 k) / (12 k + 18 k) = 7.2 kΩ

2 Two resistors each of value 10 kΩ are connected in parallel. What is their combined resistance?

Solution

Rt = (10 k x 10 k) / (10 k + 10 k) = 5 kΩ

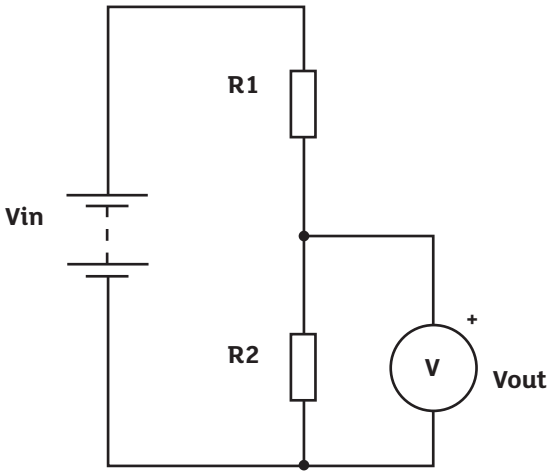
3 Find the single resistor to replace the combination of a 22 kΩ resistor and a 39 kΩ resistor (a) in series and (b) in parallel.

Solution

(a) Rt = R1 + R2 = 22 k + 39 k = 61 kΩ
(b) Rt = (22 k x 39 k) / (22 k + 39 k) = 14.06 kΩ

Calculation for Potential Dividers

If two components are connected across a power supply or battery, the supply voltage is divided between the two components, according to their resistances. This is called a potential divider or voltage divider circuit.



For a voltage divider circuit:

- The voltages divide in the same ratio as the resistances
- The sum of the voltages equals the supply voltage
- The same current flows in each resistor

The current through R2 is given by Vout / R2
The current through R1 and R2 is given by Vin / (R1 + R2)

Since these are equal, we can say that
Vout / R2 = Vin / (R1 + R2)

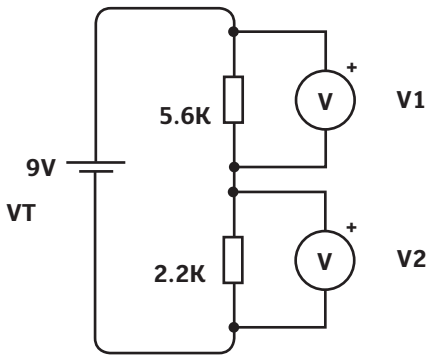
or

$$\boldsymbol{Vout = \frac{Vin \times R2}{(R1+R2)}}$$

LEARN THIS!

Worked Example

(a) Calculate the value of the voltage V2.
(b) Calculate the value of the voltage V1.



Solutions

(a) Use the equation: $V2 = \frac{Vt \times R2}{R1 + R2}$

Substitute values: $V_2 = \frac{2.2k \times 9}{5.6k + 2.2k}$

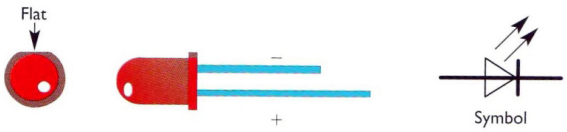
Calculate answer: $V_2 = \frac{19.8k}{7.8k} = 2.54V$

(b) Use the equation: $V_1 = V_T - V_2$

Substitute values: $V_1 = 9 - 2.54$

Calculate answer: $V_1 = 6.46\ V$

Calculation for Light Emitting Diodes (LEDs)



A light emitting diode (LED) produces a single colour of light when connected to the correct supply voltage the correct way round. LEDs are available in a variety of colours (e.g. red, yellow, amber, green and blue), sizes (e.g. standard is 5 mm, jumbo is 10 mm) and shapes (round, rectangular, square, triangular etc.). The 'shoulder' of the LED has a flat side. This should be connected closest to the negative of the battery. The operating voltage of an LED depends on the colour of light produced and is typically around 2 V. LEDs will work with higher voltages if a protective resistor of the correct value is connected in series with the LED. LEDs may be used in seven segment displays to display numbers and some letters. A number of LEDs may be operated from the same supply with the appropriate protective resistor. The value of the protective resistor depends on the number of LEDs used, and on the battery voltage.

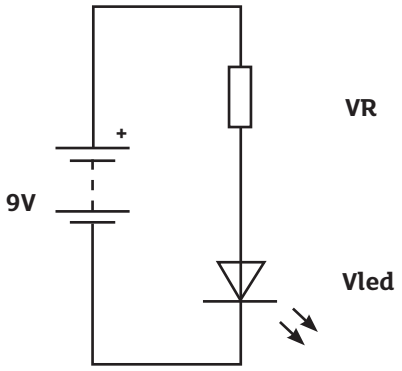
Worked Example

1 Calculate the protective resistor for an LED with a forward voltage rating of 2 V and a maximum current of 10 mA supplied by a 9 V battery

Solution

Since the LED and resistor are connected in series, we can say that:

- the same current flows in each (0.01 A)
- the voltage across the LED plus the voltage across the resistor equals the supply voltage, 9 V



Hence the voltage across the resistor equals the supply voltage minus the voltage across the LED. In order to calculate the resistor value, the following equation is used:

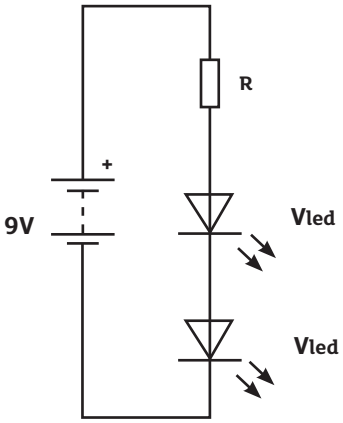
$$\text{Value of resistor R} = \frac{\text{Voltage across resistor}}{\text{Current}}$$

$$= \frac{\text{Supply Voltage} - \text{Voltage across LED}}{\text{Current}}$$

Substituting, we obtain $R = \frac{9-2}{0.01} = \frac{7}{0.01} = 700\Omega$

If we consult the table of E12 series values, the nearest preferred value = 680 Ω. However since this is less than the calculated value, there is a possibility that the resistor will offer less protection and so the LED could be damaged. Instead we should select the next highest value in the E12 series, 820 Ω.

2 Calculate the protective resistor for two identical LEDs connected in series if they each have a forward voltage rating of 2.3 V and a maximum current of 12 mA supplied by a 9 V battery.



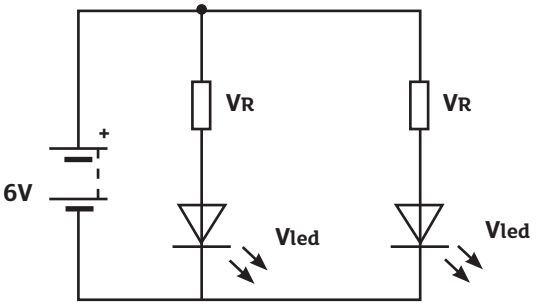
$$\text{Value of resistor R} = \frac{\text{Voltage across resistor}}{\text{Current}}$$

$$= \frac{\text{Supply Voltage} - \text{Voltage across LED}}{\text{Current}}$$

Substituting, we obtain $R = \frac{9-4.6}{0.012} = \frac{4.4}{0.012} = 367\Omega$

If we consult the table of E12 series values, the next highest value in the E12 series is 390 Ω

3 Calculate the protective resistors for two identical LEDs connected in parallel, each with their own protective resistor as shown in the diagram. They each have a forward voltage rating of 2.1 V and a maximum current of 9 mA supplied by a 9V battery.



Solution

These LEDs may be treated separately since they each have their own protective resistor.

$$\text{Value of resistor R} = \frac{\text{Voltage across resistor}}{\text{Current}}$$

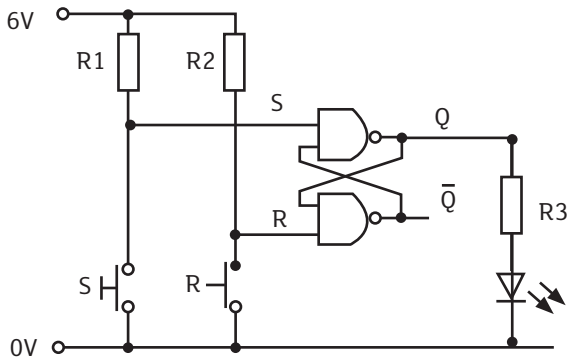
$$= \frac{\text{Supply Voltage} - \text{Voltage across LED}}{\text{Current}}$$

Substituting, we obtain $R = \frac{6-2.1}{0.009} = \frac{3.9}{0.009} = 433\Omega$ each

If we consult the table of E12 series values, the next highest value in the E12 series is 470 Ω.

Revision Questions

1 The LED in the figure below is designed to work at a forward voltage of 1.8 volts and a current of 15 mA.



(i) Calculate the value of resistor R3 in the figure above required to allow the LED to function safely. Assume that the output voltage corresponding to a logic high is 6 volts.

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(ii) Choose a value for the resistor from the E12 preferred value series as shown below.
10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82

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(iii) Calculate the power dissipated by your preferred value resistor and then select the most appropriate rating from the range available. Resistors are available in 0.25, 0.5 and 0.75 Watt ratings.

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Revision Questions

2 Calculate the power dissipated in mW by the resistor R3 in the figure below if the LEDs shown are each designed to operate at a forward voltage of 1.8 V and a current of 10 mA. Then select a resistor with the most appropriate rating from the following:
0.125W, 0.25W, 0.5W and 1W.

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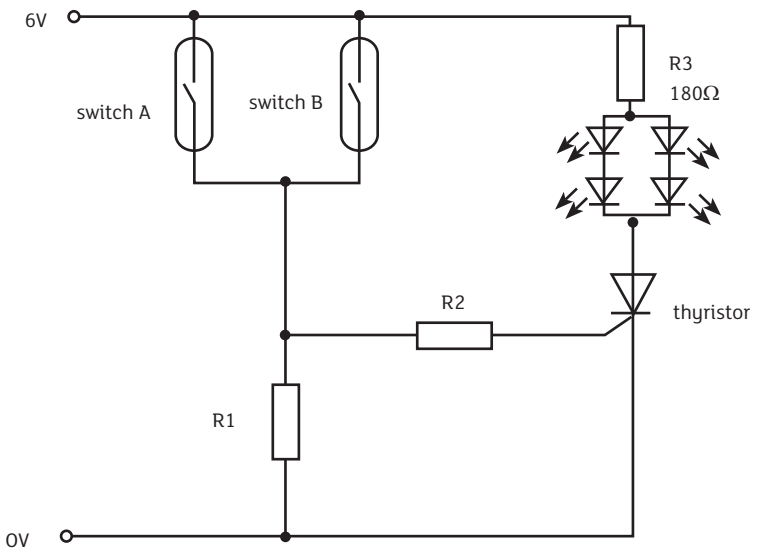

Revision Questions

3 Calculate the maximum current in a 12 volt 50 Watt bulb when operating at 12 volts.

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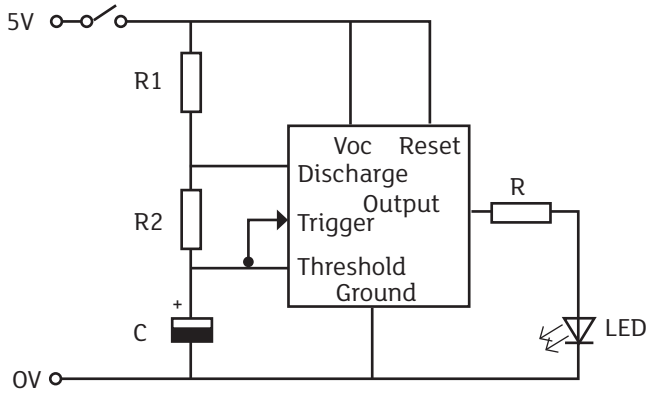
4 An LED is to be connected to the 555 timer along with a protective resistor (R) as shown in the figure below. The LED is designed to work at a forward voltage of 1.8 volts and a current of 15mA.



(i) Calculate the value of R required to allow the LED to function safely. (Assume the output voltage from the 555 timer is 5V).

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(ii) Choose a practical value for R from the E12 preferred value series 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82, and justify your choice.

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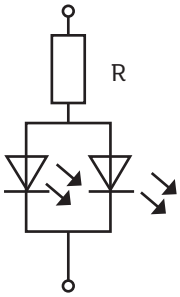
Revision Questions

5 The Q output from a logic circuit is connected to two LEDs via a protective resistor R as shown in the figure below.



(i) The resistor R shown in the figure above is required to limit the current in each LED to 5 mA where the forward voltage of each LED is 2.2 volts. Calculate the following:

- The required value for the resistor R.
- The power dissipated by the resistor R.

(Assume that the voltage at Q is 5 V when high)

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(ii) The resistor R in the figure above is to be selected from the E12 series of resistors shown below. 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82. Choose a suitable value for resistor R from the E12 series and explain your choice of value.

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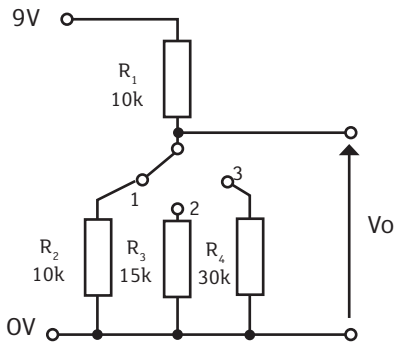
Revision Questions

6 A voltage divider circuit which consists of a power supply, a rotary switch and four fixed resistors is shown below.



(i) State the purpose of the rotary switch in the voltage divider circuit shown above.

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(ii) Calculate the voltage for Vo in the figure above when the rotary switch is moved to position 3.

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Credits

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