CfE Electronics — B McMULLEN

Electronic Systems

Electronics is the study of the use of electrical devices in a system. A system is a collection of items connected together to perform a particular task.

No matter how simple or complicated an electronic system is, it consists of three parts:

1) Input — Picks up the input signals correctly.

2) Process — Understand and process the signal produced

3) Output — Output a signal that makes sense.

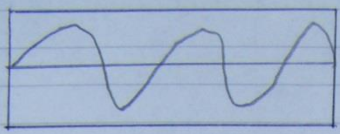
Two types of electrical signals.

The two types of electrical signal are ANALOGUE and DIGITAL.

Analogue signals can have any value between zero and a maximum.

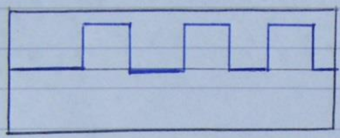
Digital signals have only two values ie ON(1) and Off(0). Sometimes the terms HIGH and LOW are used instead.

Analogue Signals



This shows an analogue signal as it is continuously varying from positive to negative.

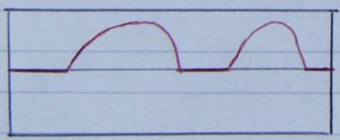
Digital Signals



This shows a digital signal with a HIGH(1) or a LOW(0).

EX

Q Is the waveform below analogue or digital?



A Analogue signal.

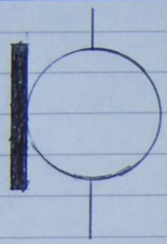
Although this waveform may at first glance look digital however the waveform has variation, so it must analogue.

* Digital waveforms must either be LOGIC 1 (HIGH) or LOGIC 0 (LOW) with no variation in between. *

Input Devices

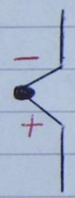
An input device changes some form of energy into electrical energy.

a) Microphone



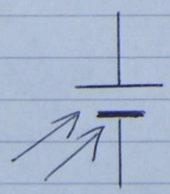
Sound energy
↓
electrical energy.

b) Thermocouple (Used to measure high temperatures)



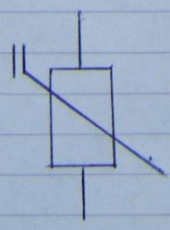
Heat energy
↓
electrical energy.

c) Solar Cell



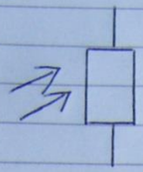
Light energy
↓
electrical energy.

d) Thermistor



Heat energy
↓
electrical energy.

e) Light dependant Resistor (LDR)



Light Energy
↓
Electrical Energy

What is a thermistor?
This is a resistor whose resistance will vary with temperature.

TURD

* Temperature Up Resistance Down *
and vice-versa!!

(LDR) What is a light dependant resistor?
This is a resistor whose resistance will vary with Light Irradiance. (Brightness)

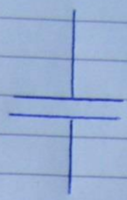
LIURD

* Light Irradiance Up Resistance Down *
and vice-versa.

Light Irradiance Down Resistance Up.

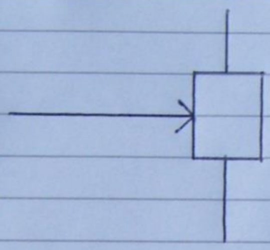
f) Capacitor

Capacitors are used in time delay circuits



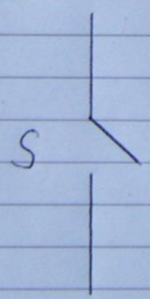
Capacitors store electrical charge and electrical energy.

g) Potentiometer (Voltage Divider)



A potentiometer uses a variable resistor to control voltage.

h) Switch



This is a digital input device which can change voltage levels in a circuit.

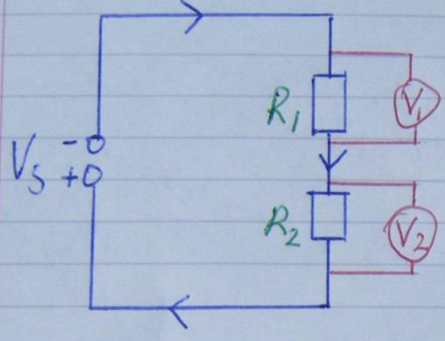
A dimmer switch is an analogue input device.

<u>ie</u> Standard light switch ⇒ lamp on or off.

Dimmer light switch ⇒ lamp can be on or off or light level can be varied in between.

Voltage dividers

This is a method of dividing the supply voltage into smaller voltages.



In a series circuit the current is the same at any point.

Since $V = IR$

then $I = \frac{V}{R}$.

With the current I being constant then the ratio of V/R must be constant.

$$V_S = V_1 + V_2$$

Conclusion

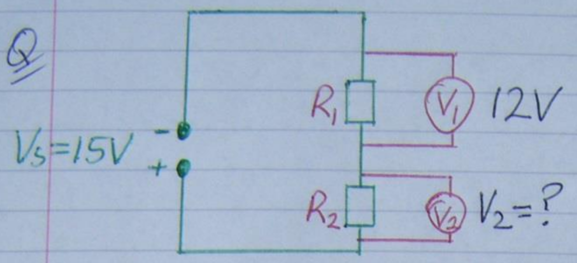
As Resistance R increases then the voltage dropped across the resistance must also increase.

ie $\overset{\leftrightarrow}{I} = \frac{V\uparrow}{R\uparrow}$ and $\overset{\leftrightarrow}{I} = \frac{V\downarrow}{R\downarrow}$

$$\Rightarrow \quad \boxed{\frac{V_1}{R_1} = \frac{V_2}{R_2} \text{ etc}}$$

Ex1

Q



If $R_2 = 24\Omega$ then calculate or find:

a) V_2

b) R_1

A

a) $V_S = V_1 + V_2 \Rightarrow 15 = 12 + V_2$

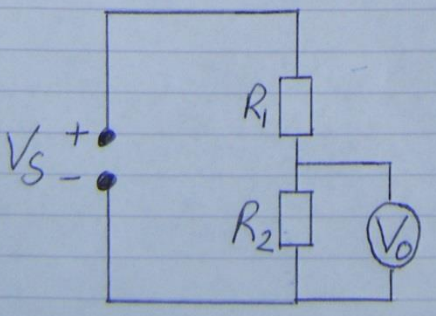
$\Rightarrow V_2 = 15 - 12 = \underline{3V}$

b) $\dfrac{V_1}{R_1} = \dfrac{V_2}{R_2}$

$\Rightarrow \dfrac{12}{R_1} = \dfrac{3}{24} \Rightarrow \dfrac{R_1}{12} = \dfrac{24}{3} = 8$

$\Rightarrow \underline{R_1 = 8 \times 12 = 96\Omega}$

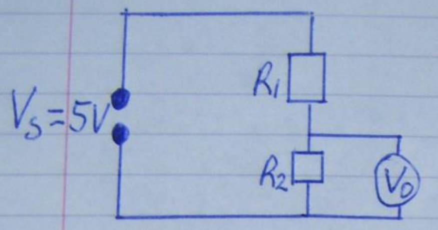
The Bear Equation!!



$$V_0 = \left(\frac{R_2}{R_1 + R_2}\right) V_s.$$

The resistor at the top of the equation is the one that the voltmeter is dropped across.

Ex2



$R_1 = 40k\Omega,\ R_2 = 100k\Omega$

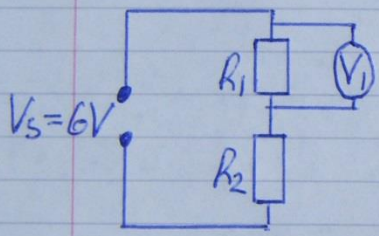
Calculate V_0

$$V_0 = \left(\frac{R_2}{R_1 + R_2}\right) \times V_s$$

$$\Rightarrow V_0 = \left(\frac{100}{40+100}\right) \times 5V$$

$$\Rightarrow V_0 = \frac{100}{140} \times 5V = \underline{\underline{3.57V}}$$

Ex3



$R_1 = 16k\Omega,\ R_2 = 8k\Omega$

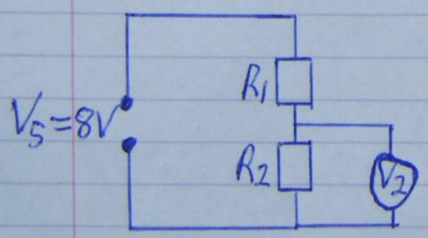
Calculate V_1

$$V_1 = \left(\frac{R_1}{R_1 + R_2}\right) \times V_s$$

$$\Rightarrow V_1 = \left(\frac{16}{16+8}\right) \times 6V$$

$$\Rightarrow V_1 = \frac{16}{24} \times 6V = \underline{\underline{4V}}$$

Ex4



$R_1 = 150k\Omega,\ R_2 = 90k\Omega$

Calculate V_2

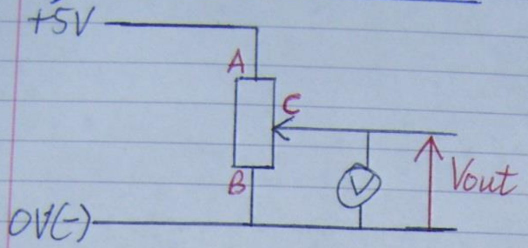
$$V_2 = \left(\frac{R_2}{R_1 + R_2}\right) \times V_s$$

$$\Rightarrow V_2 = \left(\frac{90}{150+90}\right) \times 8V$$

$$\Rightarrow V_2 = \frac{90}{240} \times 8V = \underline{\underline{3V}}$$

Voltage divider Circuits

1) Potentiometer



- The slider C is moved up slowly from B to A.
- The reading on the Voltmeter and hence the output Voltage Vout will increase.

Why?

- As the slider moves up from B to A the resistance being output will increase.
- As the resistance increases the output voltage V_o increases.

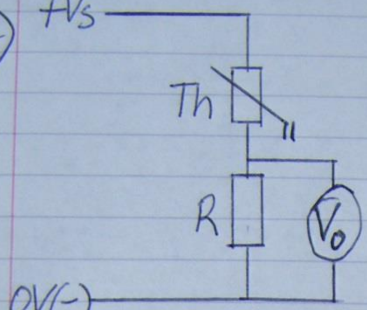
This also happens in reverse when the slider moves down from A to B.

Conclusion

- When the slider C is at B ⇒ Vout = 0V
- When the slider C is at A ⇒ Vout = max
- When the slider C is mid-way between A and B ⇒ Vout $= \frac{1}{2} \times max = \frac{1}{2} \times V_S$.

2) Thermistors and Resistors.

a)



$V_S = V_{Th} + V_R$

- As the temperature increases the resistance of the thermistor decreases.
- As the resistance of the thermistor decreases the voltage across the thermistor decreases.
- The voltage across the resistor increases. V_0 ↑.

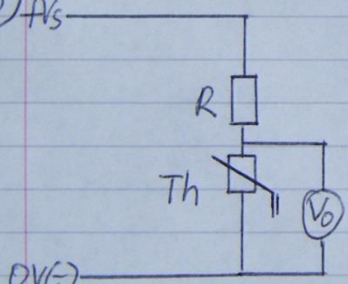
TURD

↔ = ↓ + ↑

$V_S = V_{Th} + V_R$

---

b)



$V_S = V_{Th} + V_R$

- As the temperature increases the resistance of the thermistor decreases.
- As the resistance of the thermistor decreases the voltage across the thermistor decreases.
- As the voltage across the thermistor decreases. V_0 ↓

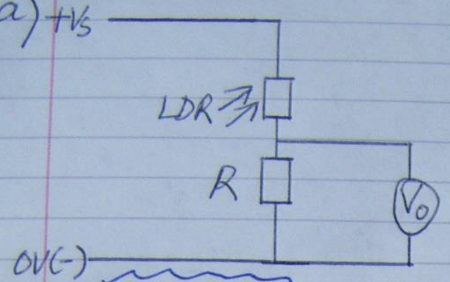
TURD

* TURD works in reverse when the temperature decreases.

ie Temperature decreases ∴ R_{Th} ↑. *

3) LDR's and Resistors

a)



LURD

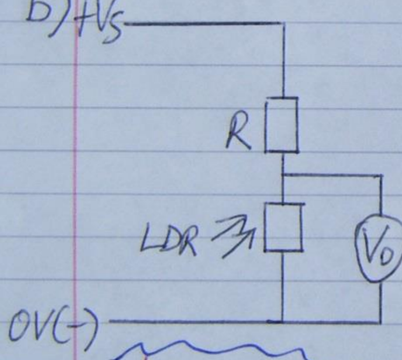
$\leftrightarrow \;=\; \downarrow \;+\; \uparrow$

$V_S = V_{LDR} + V_R$

$V_S = V_{LDR} + V_R$

- As the light Irradiance increases, the resistance of the LDR decreases.
- As the resistance of the LDR decreases, the voltage across the LDR decreases.
- The voltage across the resistor increases. $V_0 \uparrow$

b)



LURD

$V_S = V_{LDR} + V_R$

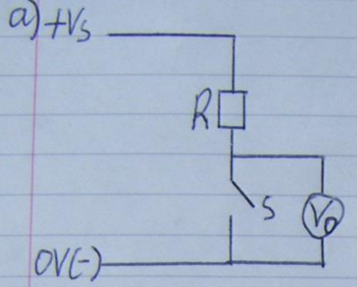
- As the light Irradiance increases, the resistance of the LDR decreases.
- As the resistance of the LDR decreases, the voltage across the LDR decreases.
- As the voltage across the LDR decreases then $V_0 \downarrow$.

* LURD works in reverse when the light Irradiance decreases
ie Light Irradiance decreases $\therefore R_{LDR} \uparrow$ *

4) Switches and Resistors

Switches are digital input devices.

a)



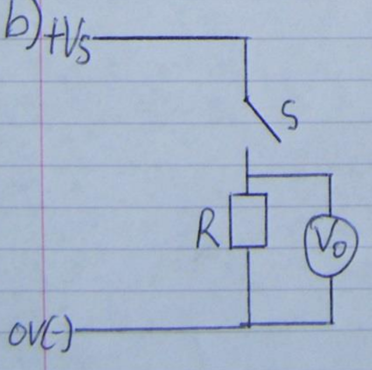
$V_S = V_R + V_{switch}$

Switch	V_o
closed	0 (Low)
Open	1 (high)

- When S is closed a current flows, then the supply voltage Vs is dropped across the resistor R.
- $V_S = V_R$ then $V_{switch} = 0$.
- When S is open then no current flows through the resistor R.
- $V_R = 0$ then $V_S = V_{switch}$.

$V_S = V_R + V_{switch}$

b)



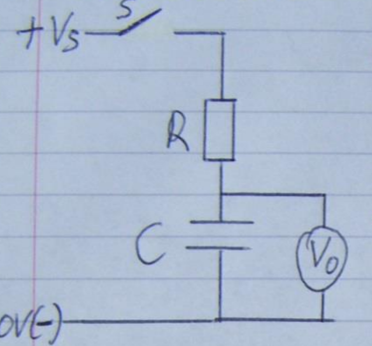
Switch	V_o
closed	1 (high)
Open	0 (Low)

As above, when the switch is closed a current flows and $V_S = V_R$ $\therefore$ $V_o = V_S$.

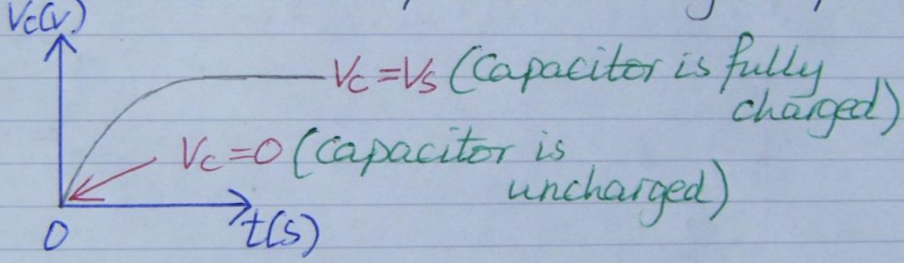
When S is open no current flows $\therefore$ $V_R = 0$ $\therefore$ $V_o = 0V$.

5) Capacitors

- Capacitors store electrical charge and electrical energy.
- Capacitors are used in time-delay circuits.



- When the switch S is closed the capacitor fills up with charge.
- The voltage across the capacitor — V_0 — rises gradually as the capacitor charges up.



The capacitor bucket theory

- Capacitor ⇒ bucket
- charge ⇒ Water
- Resistor ⇒ size of hole in bucket

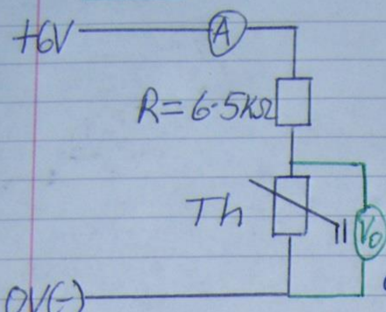
$$t = RC$$

- t → time-delay (s)
- R → Resistance (Ω)
- C → Capacitance (F)

- Small time delay ⇒ Small R and C
- Large time delay ⇒ Large R and C.

* ie Quick bucket fill ⇒ Small bucket + small hole *

Ex5



Temperature (°C)	Thermistor Resistance (Ω)
30	7500
60	5500
90	3500

Calculate or find:

a) Current reading on (A) at 60°C.

b) Output Voltage, (V_0) on the voltmeter at 90°C.

A a) $R_S = 6500 + R_{Th} = 6500 + 5500 = 12{,}000\,\Omega$

$$I = \frac{V_S}{R_S} = \frac{6}{12{,}000} = 5 \times 10^{-4} A$$

$(0{\cdot}0005A)$

b) $$V_0 = \left(\frac{R_{Th}}{6500 + R_{Th}}\right) \times V_S$$

$$\Rightarrow V_0 = \left(\frac{3500}{6500 + 3500}\right) \times 6V$$

$$\Rightarrow V_0 = \frac{3500}{10{,}000} \times 6V$$

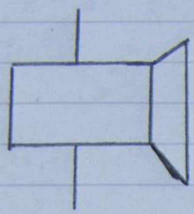
$$\Rightarrow V_0 = 2{\cdot}1V$$

From common sense ✓ $V_0 < 3V$, as the 6·5kΩ will be taking a bigger share of the supply voltage!!

Output devices

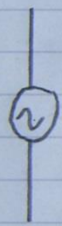
An output device changes electrical energy into some other form of energy.

a) Loudspeaker (Analogue Output device)



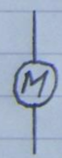
Electrical energy
↓
Sound Energy.

b) Oscilloscope (Analogue Output device)



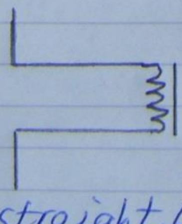
Electrical Energy
↓
Light Energy.

c) Electric Motor (Analogue Output device)



Electrical Energy
↓
Kinetic Energy.

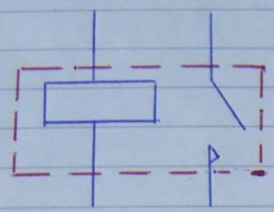
d) Solenoid (Digital Output device)



Electrical Energy
↓
Kinetic Energy

In a straight line!!

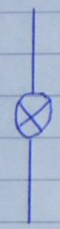
c) Relay



An electromagnet is used to close the contacts of a magnetic reed switch.
This is known as a reed relay.

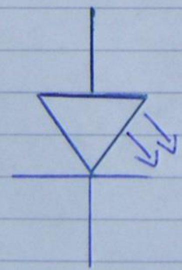
Electrical energy → Kinetic Energy.

f) Lamp (Analogue Output device)



Electrical Energy
↓
Light Energy.

g) LED (Light Emitting Diode)
(Digital Output Device).

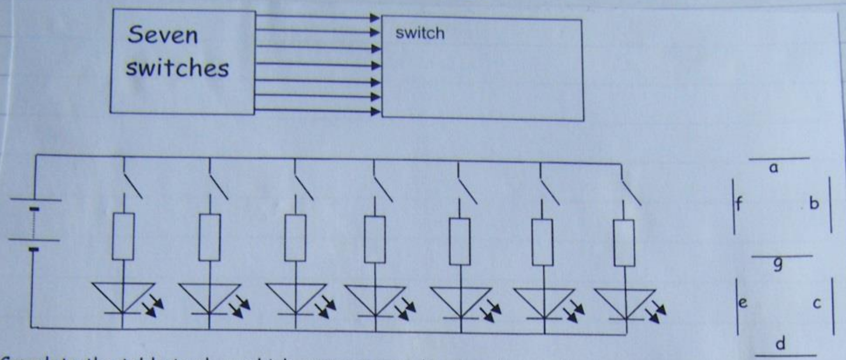


Electrical Energy
↓
Light Energy.

* Lamps and LED's are used for different purposes, lamps for illumination purposes and LED's as warning indicators. *

* The current passing through a lamp is much greater than through an LED *

h) 7 Segment display (Digital Output device)



Complete the table to show which segments are lit when the number appears

Number	Segments lit	Number	Segments lit
0	a, b, c, d, e, f	5	a, f, g, c, d
1	b, c	6	a, f, e, d, c, g
2	a, b, g, e, d	7	a, b, c
3	a, b, c, d, g	8	a, b, c, d, e, f, g
4	f, g, b, c	9	f, a, b, g, c, d.

Each segment in the display is an LED.

∴ Electrical Energy → Light Energy.

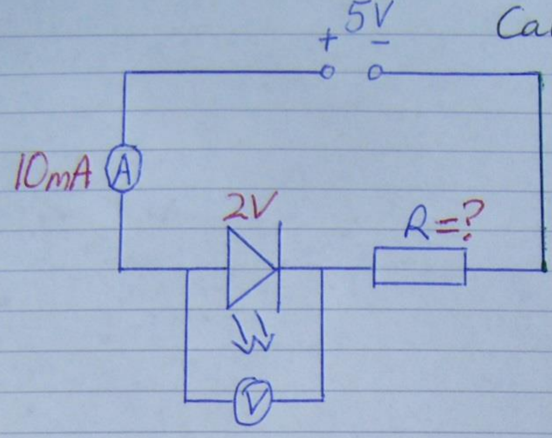
Ex6

Q The voltage dropped across an LED is 2V and the maximum current passing through it is 10mA.

Calculate the resistance connected in series to the LED if it is in series with a 5V supply.

A

Calculate the unknown R.



- $V_S = V_R + V_{LED}$

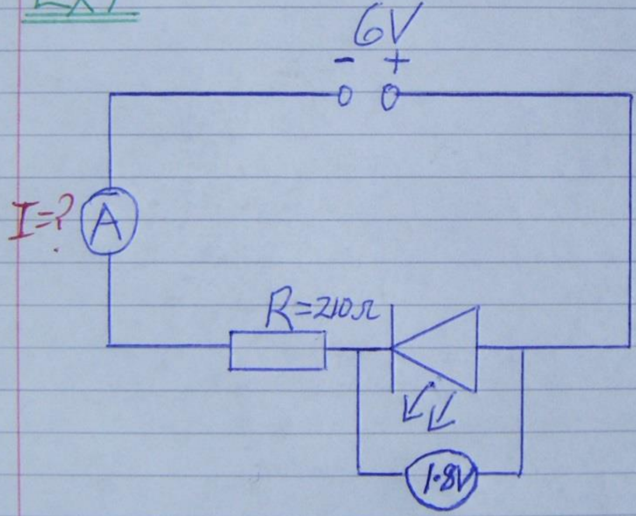
$\Rightarrow 5 = V_R + 2V$

$\Rightarrow V_R = 3V$

- $R = \frac{V_R}{I} = \frac{3}{10 \times 10^{-3}}$

$\Rightarrow R = 300\Omega$

Ex7



Calculate the reading on the ammeter given that R = 210Ω and the voltage across the LED is 1·8V.

- $V_S = V_R + V_{LED}$

$\Rightarrow 6 = V_R + 1{\cdot}8$

$\Rightarrow V_R = 6 - 1{\cdot}8 = 4{\cdot}2V.$

- $I = \frac{V_R}{R} = \frac{4{\cdot}2}{210}$

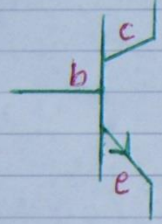
$\Rightarrow I = 0{\cdot}02A$ or $20mA$

Transistors (Process device)

Transistors can be used in electronic circuits as automatic switches.

We look at two types of switch in this course, namely npn transistors and MOSFETS.

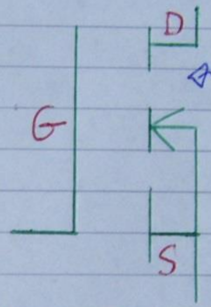
- npn transistor



b → base
c → collector
e → emitter

The npn transistor conducts and switches on at +0·7V
ie $V_{base} \geq 0.7V$
$V_b < 0.7V \Rightarrow$ switch off
$V_b \geq 0.7V \Rightarrow$ switch on

- MOSFET



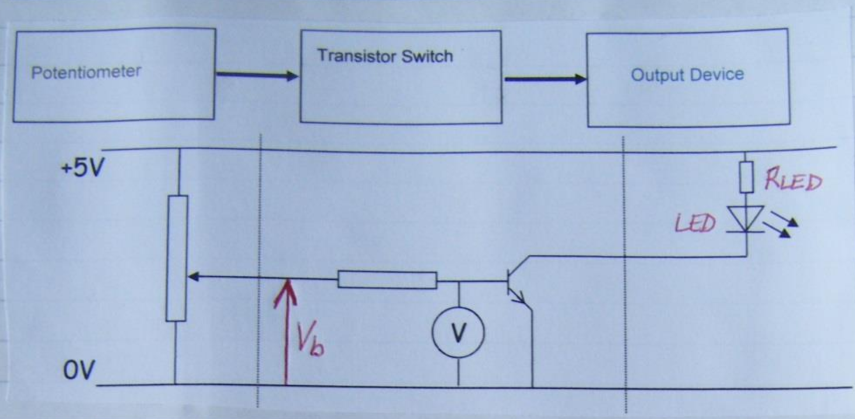
G → Gate (+Ve)
D → Drain (+Ve)
S → Source. (−Ve)

The MOSFET conducts when the gate to source voltage, $V_{GS} \geq 1.8V$ or $2V$
$V_{GS} < 1.8V \Rightarrow$ switch off
$V_{GS} \geq 1.8V \Rightarrow$ switch on.

Metal Oxide Semiconductor Field Effect Transistor. = MOSFET

* These two transistors have different switching voltages but the MOSFET has more functionality. *

Potentiometer with a Transistor



V_b → base voltage

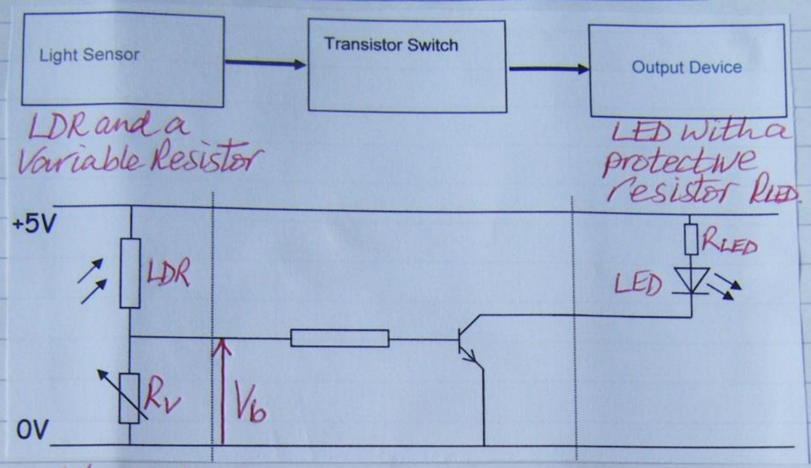
- When the base voltage $V_b < 0{\cdot}7V$
- The npn transistor is switched off
- No current flows through the LED
- The LED will not light up.

- When the base voltage $V_b \geq 0{\cdot}7V$
- The npn transistor conducts and switches on.
- A current flows through the LED
- The LED then lights up.

* Transistor circuits are used in watches, calculators, computers etc *

Light controlled switch circuit

a)



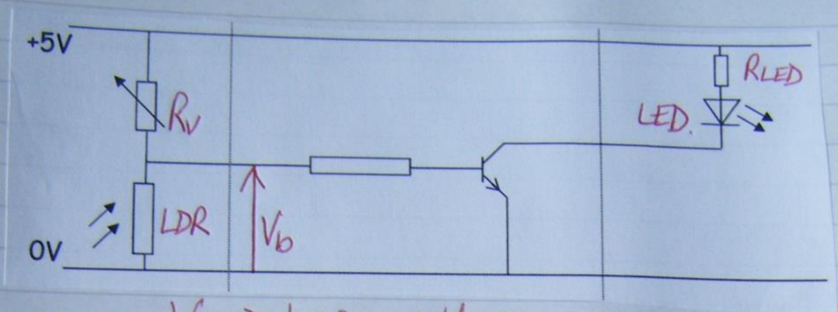
$V_b \Rightarrow$ base voltage.

- When it gets dark (cover the LDR)
- $R_{LDR} \uparrow$ (LURD IN REVERSE!!)
- As $R_{LDR} \uparrow \therefore V_{LDR} \uparrow$
- As $V_{LDR} \uparrow \therefore V_{RV} \downarrow$ $\left(V_S = V_{LDR} + V_{RV}\right)$ ($\leftrightarrow = \uparrow + \downarrow$)
- As $V_{RV} \downarrow \therefore V_b < 0{\cdot}7V$
- As $V_b < 0{\cdot}7V \therefore$ Transistor does not conduct and the LED will not light.

Conclusion

In this circuit the LED will not light up if it is dark.
ie The LED will only light up if it is bright.

b)



V_b → base voltage.

Compared to circuit a) the variable Resistor (R_V) and the LDR swap positions.

- When it gets dark (cover the LDR)
- $R_{LDR} \uparrow$ (LURD IN REVERSE AGAIN)
- As $R_{LDR} \uparrow \therefore V_{LDR} \uparrow$
- As $V_{LDR} \uparrow$ this means that V_b the base voltage $\uparrow$. $\therefore$ $V_b \geq 0{\cdot}7V$
- As $V_b \geq 0{\cdot}7V$ $\therefore$ The transistor conducts and the LED will light up as a current passes through it.

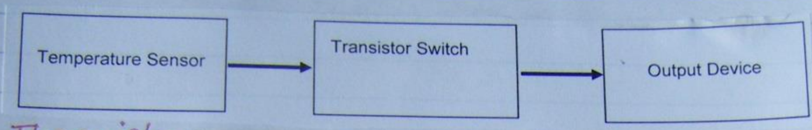
Conclusion

In this circuit the LED will light up if it gets dark.

NB In all of these circuits the voltage at the bottom of the voltage divider decides whether the transistor conducts and then if the output device operates.

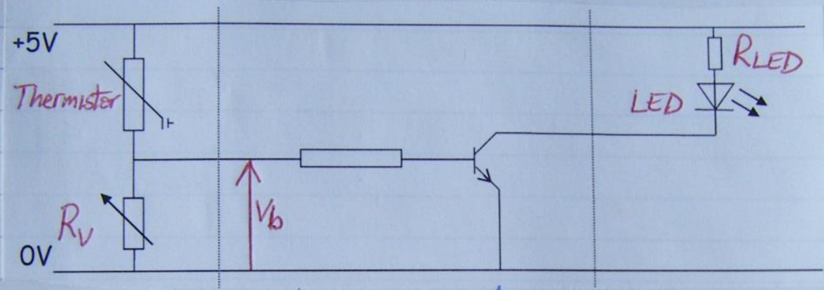
Temperature controlled switch circuit

a)



Thermistor and a variable Resistor

LED with a protective Resistor R_{LED}.

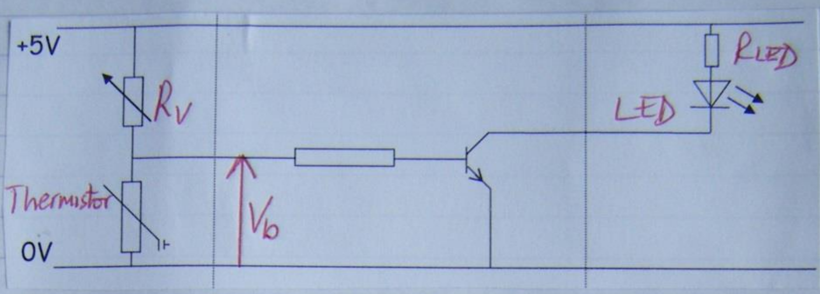


- When the temperature increases
- $R_{Th} \downarrow$ (TURD)
- As $R_{Th} \downarrow$ $\therefore$ $V_{Th} \downarrow$
- As $V_{Th} \downarrow$ $\therefore$ $V_{Rv} \uparrow$ ($V_S = V_{Th} + V_{Rv}$) ($\leftrightarrow = \downarrow + \uparrow$)
- As $V_{Rv} \uparrow$ $\therefore$ $V_b \geq 0.7V$
- As $V_b \geq 0.7V$ the transistor conducts and a current passes through the LED. (ie the transistor has switched on).
- The LED then lights up.

Conclusion

In this circuit the LED lights up when the temperature rises.

b)



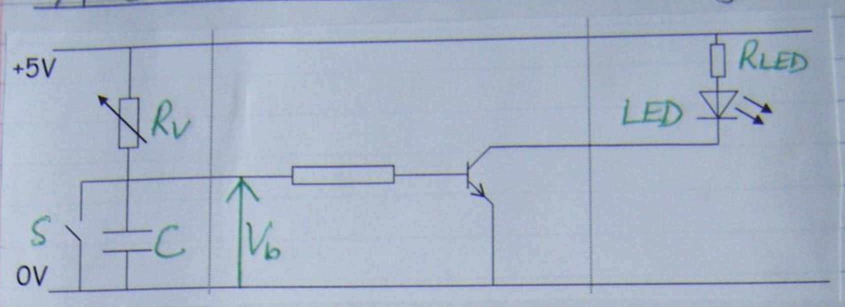
Compared to circuit a) the variable Resistor and the thermistor have changed positions ie they swap positions

- When the temperature increases
- R_{Th} ↓ (TURD)
- As R_{Th} ↓ ∴ V_{Th} ↓
- As V_{Th} ↓ ∴ This means that the $V_b < 0.7V$
- As $V_b < 0.7V$ ∴ The transistor will not conduct and will not switch on.
- The LED will not light up as no current passes through it.

Conclusion

In this circuit the LED will only light up when the temperature decreases.

A switch with Time-delay



$V_b \rightarrow$ base voltage.

- When the push switch is closed, the voltage across the capacitor $V_C = 0V$.
- As $V_C = 0V$ then $V_b = 0V$
- As $V_b = 0V$ the transistor does not switch on and no current flows through the LED ∴ LED does not light up.
- When the push switch is open, $V_C > 0V$
- When $V_C \geq 0.7V$ then $V_b \geq 0.7V$
- The transistor will then conduct and will switch on.
- A current will flow through the LED which will light up.

IMPORTANT POINTS.

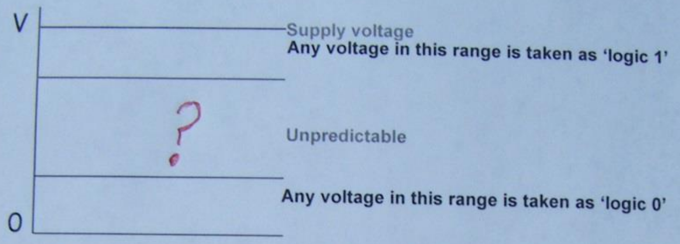
- SMALL TIME-DELAY ⇒ R and C are small.
- LARGE TIME-DELAY ⇒ R and C are large.

$t = RC$

t ⇒ time-delay
R ⇒ Resistance
C ⇒ Capacitance

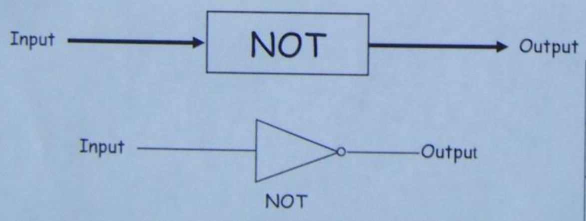
Electronic Logic Levels

To make an electronic logic gate we must represent a (1) or a (0) by an electrical quantity such as voltage. The following diagram will help to see how this is done.



Circuits must be designed so that there are no input or output voltages in the range between the lower logic level and the upper logic level. In this range the output of the gate is unpredictable – sometimes it is a logic level 0 and other times level 1.

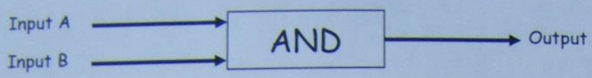
The NOT gate

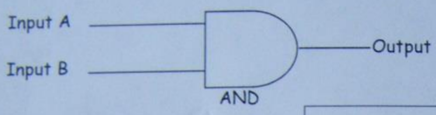


Input	Output
0	1
1	0

The **output** of a **NOT** gate is NOT the same as the **input**.
A NOT gate is also called an INVERTER.

The AND gate

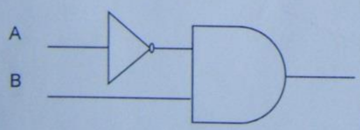




Input		Output
A	B	
0	0	0
0	1	0
1	0	0
1	1	1

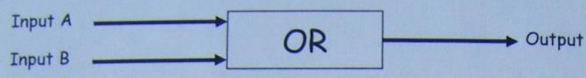
The **output** for an **AND** gate will be high (=1) only when **inputs A** AND **B** are high.

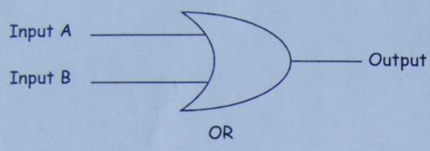
Ex8



Switch A	Switch B	Output
0	0	0
0	1	1
1	0	0
1	1	0

The OR gate



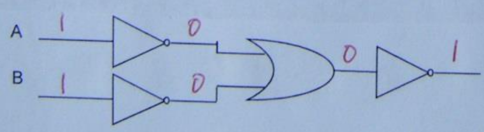


Input		Output
A	*B*	
0	0	0
0	1	1
1	0	1
1	1	1

The **output** of an **OR** gate will be high (=1) when the **input A** OR **B** are high.

The AND, OR and NOT gates may be combined to form more complex electronic systems.

Ex9



Switch A	Switch B	Output
0	0	0
0	1	0
1	0	0
1	1	1

Which signal gate has the same truth table as circuit 7? AND GATE

Problem Solving with Logic diagrams

EX10

Q/ An electronic system is designed to sound an alarm if the temperature during daylight hours rises above a certain level. A switch is used to test the alarm at any time.

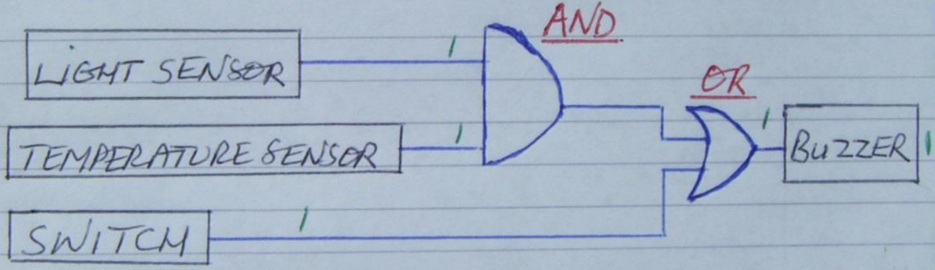
Design the circuit required using the following:

a) Inputs – Light sensor, Temperature sensor and a switch.

b) Process – AND gate and an OR gate.

c) Output – A buzzer.

A/



EXPLANATION

- Day light and high temperature
  ⇒ Light sensor and temperature sensor connected to an AND gate.

- Switch to test the alarm at any time
  ⇒ Connect the switch and the output of the AND gate to an OR gate.

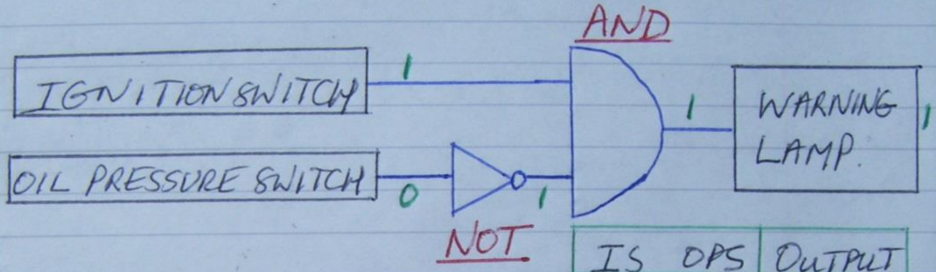
This allows us to test the buzzer at any time regardless of whether the output of the AND gate is 1 or 0.

Ex 11

Q// Draw a logic diagram and a TRUTH TABLE for the following problem:

The oil warning light of a car has to come on when the ignition switch is on AND the oil pressure switch is NOT on. (HINTS IN CAPITAL LETTERS!!)

A//



Truth Table ⇒

IS	OPS	OUTPUT
0	0	0
0	1	0
1	0	1
1	1	0

EXPLANATION

- Ignition switch ON and oil pressure switch NOT on.

⇒ NOT gate at the oil pressure switch to change a logic 0 into a logic 1.

⇒ When the ignition switch is on then two logic 1's into an AND gate gives an output logic 1

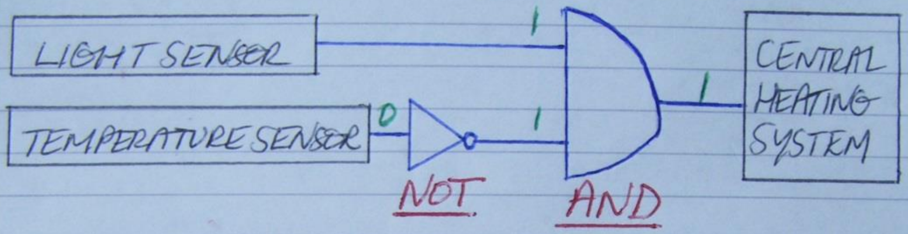
⇒ The warning lamp will then light up when the logic 1 is output from the AND gate.

Ex 12

Q Draw a logic diagram and a TRUTH TABLE for the following problem:

A central heating system has to be switched on during the hours of daylight if the temperature drops below a certain level.

A



TRUTH TABLE

LS	TS	OUTPUT
0	0	0
0	1	0
1	0	1
1	1	0

EXPLANATION

- NOT gate is attached to the output of the Temperature sensor.

⇒ This turns the logic 0 at low temperature in the temperature sensor to logic 1.

⇒ Then the logic 1 from the Light sensor and the logic 1 from the NOT gate then produce a logic 1 from the AND gate. This logic 1 then turns on the central heating system.