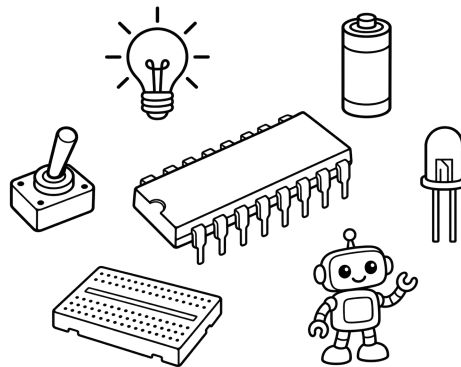


# ICT

INFORMATION AND COMMUNICATION TECHNOLOGY

GRADE 10



## UNIT 4

### Logic Gates with Boolean Functions

Student Workbook



"The King of ICT"

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#### STUDENT DETAILS

**Name:**

\_\_\_\_\_

**School:**

\_\_\_\_\_

**Institution:**

\_\_\_\_\_

**Contact:**

\_\_\_\_\_

BEFORE WE START

## What This Unit Is About

Read this page with your teacher

### AT THE END OF THIS UNIT YOU WILL BE ABLE TO

- ☐ Explain how signals help us to make decisions, and what a logic gate is.
- ☐ Draw the symbols of the AND, OR, NOT, NAND and NOR gates.
- ☐ Write Boolean expressions such as  $Q = A.B$ ,  $Q = A + B$  and  $Q = \bar{A}$ .
- ☐ Build truth tables for gates and circuits with two and three inputs.
- ☐ Draw the circuit of a Boolean expression, and write the expression of a circuit.
- ☐ Read Venn diagrams and the pins of a 14-pin integrated circuit (VCC and GND).
- ☐ Use logic gates for real problems: doors, lamps, alarms and street lights.

### THREE RULES FOR THE COMPUTER ROOM

- **Always** ask your teacher before you touch a battery, a chip (IC) or the wires.
- **Never** connect a circuit to the wall socket (mains electricity).
- **Always** save your simulator work with your name.

### HOW TO USE THIS BOOK

Each chapter has three parts. First you **read** the chapter with your teacher. Then you **do** the practical task: a logic gate simulator or a small circuit. Last you **write** the exercises in this book.

**You will need:** a pencil, an eraser and a ruler to draw neat gates and wires, your textbook (pages 113 - 137), and a logic gate simulator such as MM Logic, Logisim or CircuitVerse.

### THE WORDS YOU WILL LEARN

|                |                  |                    |                    |
|----------------|------------------|--------------------|--------------------|
| Signal         | Logic circuit    | Logic gate         | Binary values      |
| Input          | Output           | Basic logic gate   | Combinational gate |
| AND gate       | OR gate          | NOT gate           | Complement         |
| NAND gate      | NOR gate         | Boolean expression | Truth table        |
| Series circuit | Parallel circuit | Venn diagram       | Integrated circuit |
| Pin            | VCC / GND        | Simulator          | Sensor             |

"A computer makes millions of decisions with only two answers: 1 and 0. Learn them well."

- THE KING OF ICT



CHAPTER 1

# Signals, Logic Gates and the AND Gate

## ? TWO KEYS, ONE DOOR

"Our computer lab door has a door lock and a padlock. Today I have only the door key!"

"Then we cannot open it. We need both keys."

We make decisions like this every day. A computer makes decisions too: it uses **signals** and **logic gates**.

## 4.1 Signals in daily life

People communicate in many ways. We use **signals** to make decisions every day. In the same way, the computer also uses signals.

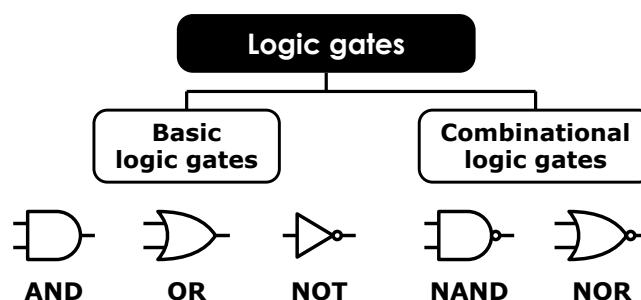
| The signal                                                            | What it tells us                                    |
|-----------------------------------------------------------------------|-----------------------------------------------------|
| <b>In the past:</b> drumming                                          | A way to communicate a message.                     |
| <b>Railway station:</b> the guard blows a horn and waves a green flag | The train is going to leave.                        |
| <b>Railway:</b> a green light or a red light                          | Green: the train may start. Red: it must stop.      |
| <b>A safe:</b> two keys are used                                      | Both keys are needed to open the safe.              |
| <b>A car:</b> a light comes on, or there is a sound                   | At least one door is not closed properly.           |
| <b>A car:</b> a signal for the front seats                            | Someone in a front seat is not wearing a seat belt. |

## 4.2 Logic gates

Circuits that build logical conditions using **binary values** (1 and 0) and make decisions are called **logic circuits**. The computer is made of a large number of complex digital circuits, designed by connecting many basic logic circuits called **logic gates**. The Central Processing Unit (CPU) is made up of a large number of logic gates.

### i A LOGIC GATE

- gives an **output** after considering one **input** or several inputs.
- has devices such as **transistors**, **diodes** and **resistors** inside it.
- is a **basic** or a **combinational** logic gate.



### 4.3 The AND gate

The door of your computer lab is locked with a key and a padlock. You can open it only when you have **both** the door key and the padlock key. With only one key, or with no key, the door stays shut.

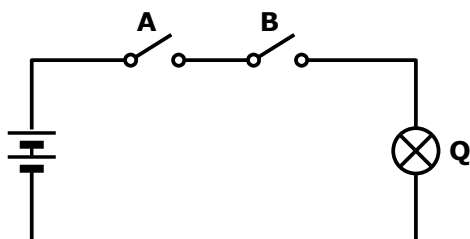


Figure 4.4 - the electronic circuit of the AND gate

Two switches **A** and **B**, a bulb **Q** and two batteries are joined in **series** (one path). The switches are the inputs and the bulb is the output. The bulb is on only when **both** switches are closed. A closed switch and a bulb that is on are shown by **1**. An open switch and a bulb that is off are shown by **0**.

Table 4.1 - the bulb of the AND circuit

| A      | B      | Q            |
|--------|--------|--------------|
| Open   | Open   | Switched off |
| Open   | Closed | Switched off |
| Closed | Open   | Switched off |
| Closed | Closed | Switched on  |

Table 4.2 - truth table of AND

| A | B | Q |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

#### ! OBSERVATION

If at least one input is 0, the output of an AND gate is 0.

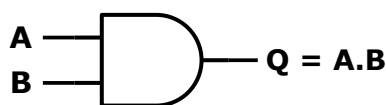


Figure 4.5 - the symbol and the Boolean expression

The logic of the AND gate is "A AND B". In **Boolean expressions** it is written **A.B**, so the output is **Q = A.B**.

A table that shows the output for every input is a **truth table**. Two inputs give  $2^2 = 4$  **states** (rows).

### 4.4 AND gates with three inputs

An AND gate has at least two inputs, and there are AND gates with more inputs. An AND gate with three inputs A, B and C works like two AND gates: first **P = A.B**, then **Q = P.C**. So the Boolean expression is **Q = A.B.C**.

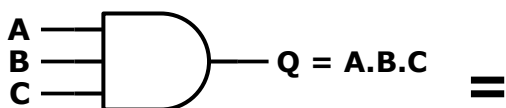


Figure 4.6 - AND with three inputs

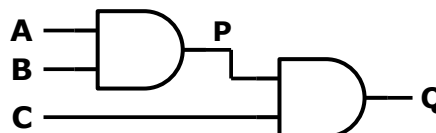


Figure 4.7 - the same, with two AND gates

#### i TIP - EIGHT STATES

Three inputs give  $2^3 = 8$  **states**. Write the inputs in order, like counting in binary: 000, 001, 010, 011, 100, 101, 110, 111. Then no state is missing.

"Two keys open the door. Hard work and practice open your future."

- THE KING OF ICT



## > DO IT - PRACTICAL 1 (TEXTBOOK ACTIVITY, PAGE 117)

Build the AND gate. Work with your teacher. Use only a small battery (two 1.5 V cells).

|   |                                                                                                       |
|---|-------------------------------------------------------------------------------------------------------|
| 1 | With your teacher, join switch A, switch B and bulb Q in <b>series</b> with the battery (Figure 4.4). |
| 2 | Close only A, then only B, then both. Is the bulb on or off each time? Compare with Table 4.1.        |
| 3 | Open a logic gate simulator (MM Logic, Logisim or CircuitVerse). Join two AND gates like Figure 4.7.  |
| 4 | Connect three inputs A, B, C and an output lamp Q. Try all 8 inputs, from 000 to 111.                 |
| 5 | Check your answers in the exercise "Complete Table 4.3". Save your work with your name.               |

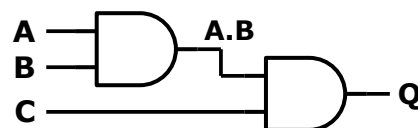
### A Complete Table 4.3

10 marks

Textbook Activity, page 118. Fill A.B with the AND rule for two inputs. Then fill  $Q = A.B.C$ .

Table 4.3 - truth table for AND with three inputs

| A | B | C | A.B | $Q = A.B.C$ |
|---|---|---|-----|-------------|
| 0 | 0 | 0 | 0   |             |
| 0 | 0 | 1 |     | 0           |
| 0 | 1 | 0 | 0   |             |
| 0 | 1 | 1 |     |             |
| 1 | 0 | 0 | 0   | 0           |
| 1 | 0 | 1 |     |             |
| 1 | 1 | 0 |     | 0           |
| 1 | 1 | 1 |     |             |



**Hint:** A.B is the output of the first gate. Q is 1 in only one state.

### B Find P and Q

8 marks

Textbook Activity, page 117 (Figure 4.7). Write P and Q (1 or 0) in the boxes.

1

2

3

4

"You do not learn ICT by reading. You learn it by doing."

- THE KING OF ICT



## C Fill in the blanks

8 marks

Use the words in the box.

### WORD BANK

|               |        |        |       |
|---------------|--------|--------|-------|
| circuits      | gates  | diodes | basic |
| combinational | series | four   | A.B   |

1. Circuits that make decisions using binary values are called logic .....
2. The Central Processing Unit is made of a large number of logic .....
3. Inside a logic gate there are transistors, ..... and resistors.
4. AND, OR and NOT are ..... logic gates.
5. NAND and NOR are ..... logic gates.
6. In the AND gate circuit, the two switches and the bulb are joined in .....
7. A truth table for an AND gate with two inputs has ..... states (rows).
8. The Boolean expression of the AND gate is  $Q = \dots\dots\dots$

## D True or false

6 marks

Write T or F in the box.

1. ☐ A logic gate gives an output after considering one input or several inputs.
2. ☐ The Central Processing Unit is made of only a few logic gates.
3. ☐ If at least one input of an AND gate is 0, the output is 0.
4. ☐ NAND is a basic logic gate.
5. ☐ An AND gate with three inputs has 8 states in its truth table.
6. ☐ An AND gate can never have more than two inputs.

## E Answer these

4 marks

Write full sentences.

1. What is a logic circuit? (2 marks)

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2. Write the observation of the AND gate (textbook p. 116). (2 marks)

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"Be the 1 in your class: the one who tries, the one who helps."

- THE KING OF ICT



CHAPTER 2

# The OR Gate and the NOT Gate

## ? TWO DOORS, MANY ROUTES

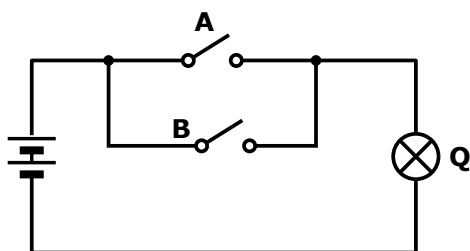
"Can I get down from the back door of the bus?"

"Yes! This bus has two doors. You can use the front door **OR** the back door."

One way is enough - this is how an **OR gate** works. A **NOT gate** is different: it always gives the other value.

## 4.5 The OR gate

A passenger in a two-door bus can get down from the front door **or** the back door. If there are several routes to your home, you can use **any** of them.



Here switches **A** and **B** are joined in **parallel** (side by side, on two paths). The bulb **Q** is on when switch **A** **or** switch **B**, **or both**, are closed. It is off only when both switches are open.

Figure 4.8 - the electronic circuit of the OR gate

Table 4.4 - the bulb of the OR circuit

| A      | B      | Q            |
|--------|--------|--------------|
| Open   | Open   | Switched off |
| Open   | Closed | Switched on  |
| Closed | Open   | Switched on  |
| Closed | Closed | Switched on  |

Table 4.5 - truth table of OR

| A | B | Q |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

## ! OBSERVATION

At least one input should be 1 for the output of an OR gate to be 1. When all the inputs are 0, the output is always 0.

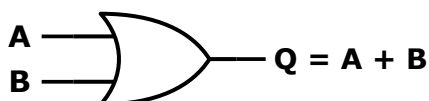


Figure 4.10 - the symbol and the Boolean expression

## ! A + B IS NOT ADDITION

In Boolean algebra the OR operation is written **A + B** (say "A OR B"). It is **not** the addition you use in Mathematics, and not the sign of a plus number. Look at the last row of Table 4.5: 1 + 1 gives **1**.

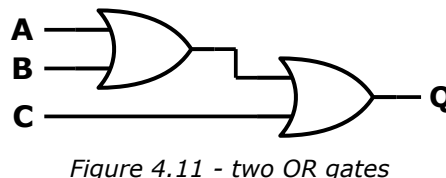
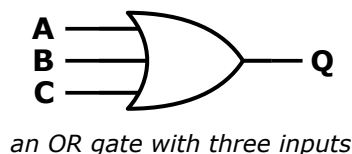
"There is always more than one road home. If one is closed, take another."

- THE KING OF ICT



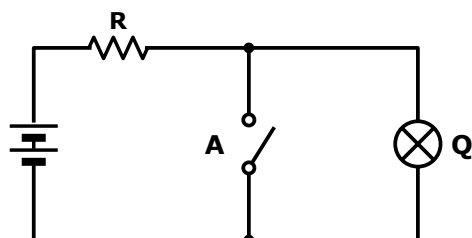
## 4.6 OR gates with three inputs

Like the AND gate, an OR gate can have more than two inputs. An OR gate with three inputs A, B and C gives the same output as two OR gates (Figure 4.11). You will write its Boolean expression and its truth table in the exercises.



## 4.7 The NOT gate

The task of the NOT gate is to give the **complement** of its input as the output. The complement of 0 is 1, and the complement of 1 is 0.



Switch **A** is joined **across** the bulb **Q**, with a resistor **R**. When switch **A** is **closed**, no electricity runs through the bulb, so it is **off**. When switch **A** is **open**, the bulb is **on**. The output is the complement of the input.

Figure 4.12 - the electronic circuit of the NOT gate

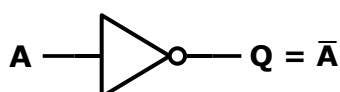


Figure 4.13 - the NOT gate

Table 4.6 - NOT

| A | Q |
|---|---|
| 0 | 1 |
| 1 | 0 |

### ★ REMEMBER

The NOT gate has only **one** input. The bar over the letter means NOT. Say "NOT A" or "A bar".

### > DO IT - PRACTICAL 2 (TEXTBOOK ACTIVITY, PAGE 120)

An OR gate with three inputs, and a NOT gate. **Ask your teacher first.**

|   |                                                                                                                 |
|---|-----------------------------------------------------------------------------------------------------------------|
| 1 | In the simulator, add an <b>OR</b> gate with three inputs A, B, C and an output lamp.                           |
| 2 | Build the same thing with two OR gates (Figure 4.11): A and B into the first, its output and C into the second. |
| 3 | Try all 8 inputs on both circuits. Are the outputs always the same? Write them in the exercise.                 |
| 4 | Add a <b>NOT</b> gate. Give it 0, then 1. What does the lamp show each time?                                    |
| 5 | With your teacher, join two switches <b>side by side</b> (in parallel) with a bulb. Save your work.             |

## A Complete the truth tables

8 marks

Write the Boolean expression in the output heading, and the outputs.

OR gate

| Input |   | Output |
|-------|---|--------|
| A     | B |        |
| 0     | 0 |        |
| 0     | 1 |        |
| 1     | 0 |        |
| 1     | 1 |        |

NOT gate

| Input | Output |
|-------|--------|
| A     |        |
| 0     |        |
| 1     |        |

## B An OR gate with three inputs

9 marks

Textbook Activity, page 120. Look at Figure 4.11 in 4.6.

- Write the Boolean expression of the OR gate with three inputs. (1 mark)

Q = .....

- Construct the truth table. (8 marks)

Remember: when all the inputs are 0, the output is 0.

| A | B | C | Q |
|---|---|---|---|
| 0 | 0 | 0 |   |
| 0 | 0 | 1 |   |
| 0 | 1 | 0 |   |
| 0 | 1 | 1 |   |
| 1 | 0 | 0 |   |
| 1 | 0 | 1 |   |
| 1 | 1 | 0 |   |
| 1 | 1 | 1 |   |

## C Is the bulb on?

4 marks

Card 1: AND circuit. Card 2: OR circuit. Cards 3 and 4: NOT circuits. Write 1 (on) or 0 (off).

**1**

Bulb Q ☐

1 = on  
0 = off

**2**

Bulb Q ☐

1 = on  
0 = off

**3**

Bulb Q ☐

1 = on  
0 = off

**4**

Bulb Q ☐

1 = on  
0 = off

"A gate never guesses. Give it the inputs, and it gives the right output."

- THE KING OF ICT



### D Find the output

6 marks

Write the output (1 or 0) of each gate in its box.

|   |  |   |  |   |  |
|---|--|---|--|---|--|
| 1 |  | 2 |  | 3 |  |
| 4 |  | 5 |  | 6 |  |

### E AND, OR or NOT?

6 marks

Which gate does each one work like? Tick one box.

| It works like ...                                    | AND gate                 | OR gate                  | NOT gate                 |
|------------------------------------------------------|--------------------------|--------------------------|--------------------------|
| You can get down from a two-door bus by either door. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| A safe opens only when both keys are used.           | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| The output is always the complement of the input.    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| You can reach home by any one of several routes.     | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| The lab door opens only with both of its keys.       | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| In Figure 4.12 the bulb is on only when A is open.   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

## CHAPTER 3

# NAND, NOR and Integrated Circuits

### ? GATES INSIDE EVERY MACHINE

"Do our washing machine, the microwave oven and my calculator all have logic gates inside?"

Yes! The work of computers, calculators, washing machines, microwave ovens, mobile phones, modern televisions, digital clocks and air conditioners is based on logic gates. We join basic gates to make **combinational** gates, and we pack many gates into small **integrated circuits**.

## 4.8 Combinational logic gates

Some circuits are designed with several logic gates to get the output we need. Such **combinational** logic circuits are designed using the basic logic gates. Two of them are the **NAND** gate and the **NOR** gate.

"Small switches control big machines. Small habits control big futures."

- THE KING OF ICT



## 4.9 The NAND gate

NAND means **NOT AND**. It gives the complement of the AND operation: the output of an AND gate goes into a NOT gate. So a NAND gate is the same as an AND gate and a NOT gate connected in series.

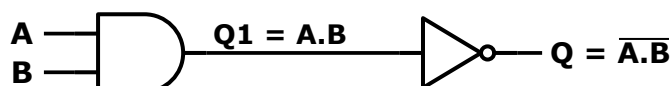


Figure 4.14 - AND, then NOT

Table 4.7 - truth table of NAND

| A | B | $Q1 = A.B$ | $Q = \overline{A.B}$ |
|---|---|------------|----------------------|
| 0 | 0 | 0          | 1                    |
| 0 | 1 | 0          | 1                    |
| 1 | 0 | 0          | 1                    |
| 1 | 1 | 1          | 0                    |

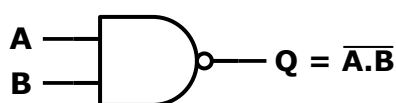
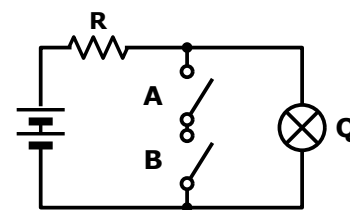


Figure 4.15 - the NAND symbol

### ! OBSERVATION

When both (or all) inputs of a NAND gate are 1, the output is always 0.



its electronic circuit

## 4.10 The NOR gate

NOR means **NOT OR**: the complement of the OR operation. The output of an OR gate goes into a NOT gate, so a NOR gate is the same as an OR gate and a NOT gate connected in series.



Figure 4.17 - OR, then NOT

Table 4.9 - truth table of NOR

| A | B | $Q1 = A + B$ | $Q = \overline{A + B}$ |
|---|---|--------------|------------------------|
| 0 | 0 | 0            | 1                      |
| 0 | 1 | 1            | 0                      |
| 1 | 0 | 1            | 0                      |
| 1 | 1 | 1            | 0                      |

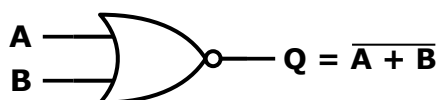
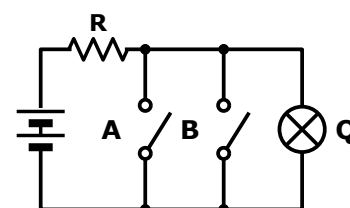


Figure 4.18 - the NOR symbol

### ! OBSERVATION

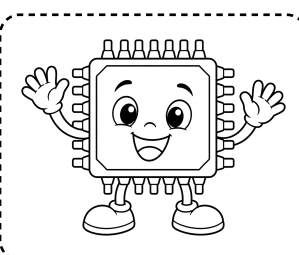
When all the inputs of a NOR gate are 0, the output is always 1.



its electronic circuit

"Small chips do great work. So can you."

- THE KING OF ICT

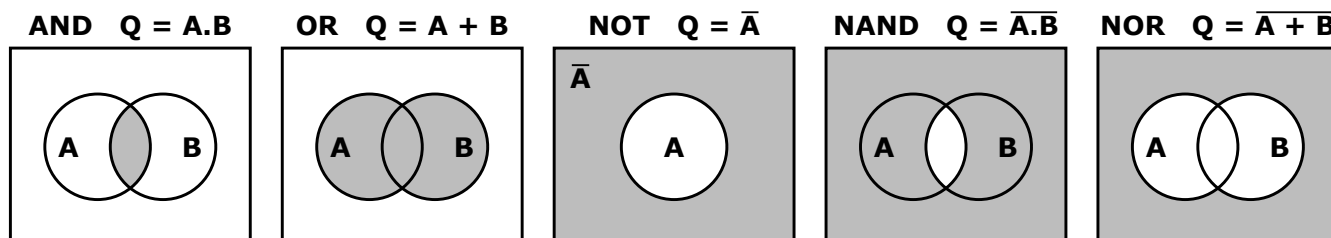


Colour me!



## 4.11 Venn diagrams of the gates

A gate can also be shown with a **Venn diagram**. Circle A is where  $A = 1$  and circle B is where  $B = 1$ . The **shaded** part shows where the output Q is 1 (textbook pages 135 - 137).



## 4.12 The five gates at a glance

This is the summary of the textbook (page 134). Learn it well - it is the key to every exercise.

| Gate | Symbol | Boolean expression     | Q for A B =<br>0 0, 0 1, 1 0, 1 1 | Q is 1 when ...         |
|------|--------|------------------------|-----------------------------------|-------------------------|
| AND  |        | $Q = A.B$              | <b>0, 0, 0, 1</b>                 | all the inputs are 1    |
| OR   |        | $Q = A + B$            | <b>0, 1, 1, 1</b>                 | at least one input is 1 |
| NOT  |        | $Q = \bar{A}$          | A = 0, 1: <b>1, 0</b>             | the input is 0          |
| NAND |        | $Q = \overline{A.B}$   | <b>1, 1, 1, 0</b>                 | at least one input is 0 |
| NOR  |        | $Q = \overline{A + B}$ | <b>1, 0, 0, 0</b>                 | all the inputs are 0    |

## 4.13 Integrated circuits

**Integrated circuits (ICs)** are used to build electronic circuits. A complex circuit, like the circuit of a modern television or a mobile phone, has many circuits. An IC is a circuit designed for a certain function with devices such as transistors, resistors, capacitors and diodes, made very small and packed into one. A microprocessor is made of a large number of ICs which use logic gates.

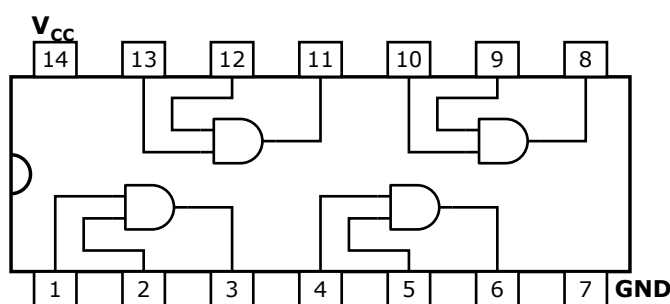


Figure 4.22 - a logic IC with four AND gates

- It has **14 pins**.
- Inputs: pins **1, 2, 4, 5, 9, 10, 12, 13**.
- Outputs: pins **3, 6, 8, 11**.
- Pin 14 is **VCC** and pin 7 is **GND**: the IC gets its power here.
- There are ICs with OR, NOT, NAND and NOR gates too.



### > DO IT - PRACTICAL 3 (TEXTBOOK ACTIVITY, PAGE 122)

NAND and NOR gates in the simulator. **Ask your teacher first.**

|   |                                                                                                                      |
|---|----------------------------------------------------------------------------------------------------------------------|
| 1 | In the simulator, build Figure 4.16 (two AND gates and a NOT gate) and, next to it, one NAND gate with three inputs. |
| 2 | Try all 8 inputs on both. Do they give the same output? Use them to check your NAND exercise.                        |
| 3 | Build an OR gate followed by a NOT gate (Figure 4.17). Compare it with one NOR gate. Save your work.                 |

### > DO IT - PRACTICAL 4 (TEXTBOOK ACTIVITY, PAGE 124)

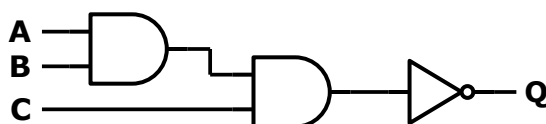
A NAND IC on a breadboard. Only your teacher connects the power. Never use mains electricity.

|   |                                                                                                                   |
|---|-------------------------------------------------------------------------------------------------------------------|
| 1 | Your teacher sets up a NAND IC on a breadboard: pin <b>14</b> to VCC and pin <b>7</b> to GND (5 V).               |
| 2 | Two switches go to the input pins <b>1</b> and <b>2</b> . An LED with a resistor shows the output, pin <b>3</b> . |
| 3 | Try the inputs 0 0, 0 1, 1 0 and 1 1. Is the LED on or off? Compare with the NAND truth table.                    |

#### A A NAND gate with three inputs

9 marks

*Textbook Activity, page 122. The NAND gate is the same as AND, AND, then NOT.*



1. Write the Boolean expression. (1 mark)

Q = .....

2. Construct the truth table. (8 marks)

| A | B | C | Q |
|---|---|---|---|
| 0 | 0 | 0 |   |
| 0 | 0 | 1 |   |
| 0 | 1 | 0 |   |
| 0 | 1 | 1 |   |
| 1 | 0 | 0 |   |
| 1 | 0 | 1 |   |
| 1 | 1 | 0 |   |
| 1 | 1 | 1 |   |

#### B Shade the Venn diagrams

5 marks

*Shade the part where the output is 1.*

1

$Q = A \cdot B$

2

$Q = A + B$

3

$Q = \bar{A}$

4

$Q = \bar{A} \cdot B$

5

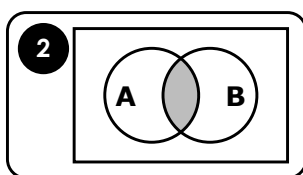
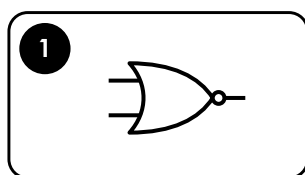
$Q = \bar{A} + B$



# C Name the gate

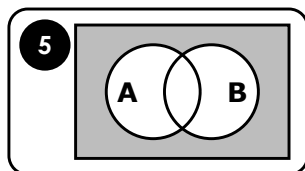
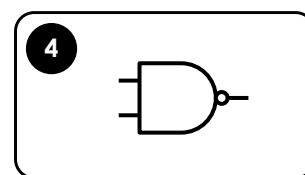
8 marks

Each card shows a symbol, a Venn diagram or a truth table. Write the name of the gate.



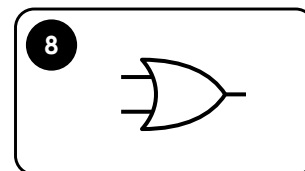
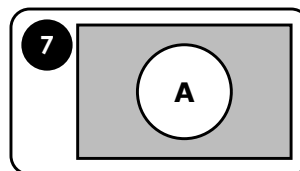
3

| A | B | Q |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |



6

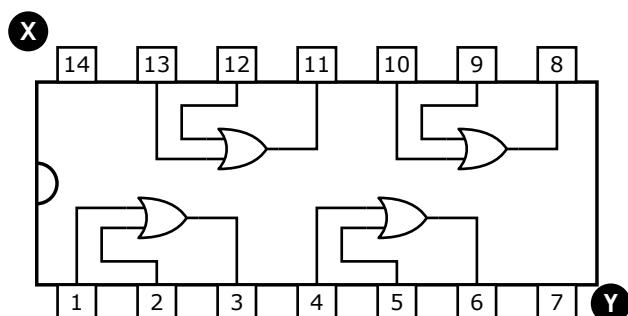
| A | B | Q |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |



# D Label the IC

6 marks

This IC has four OR gates (textbook page 135).



- Write the names of the pins at **X** and **Y**. (2 marks)

X: .....

Y: .....

- Write the input pins. (2 marks)

- Write the output pins. (2 marks)

# E Read the IC

4 marks

Textbook Activity, page 124. Figure 4.19 is a NOR IC. Figure 4.20 is a NAND IC.

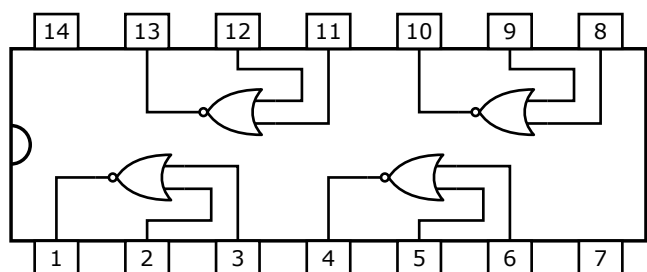


Figure 4.19 - NOR IC

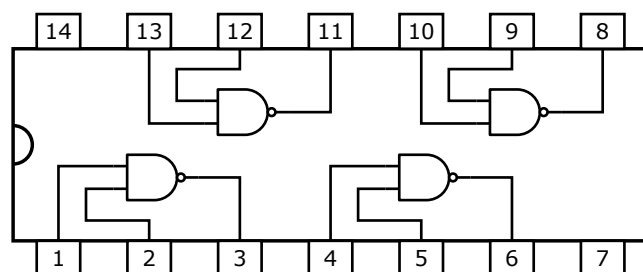


Figure 4.20 - NAND IC

- NOR IC: if pin 2 = 0 and pin 3 = 0, what is the value of pin 1? .....
- NOR IC: if pin 5 = 1 and pin 6 = 0, what is the value of pin 4? .....
- NAND IC: if pin 1 = 1 and pin 2 = 1, what is the value of pin 3? .....
- NAND IC: if pin 12 = 0 and pin 13 = 1, what is the value of pin 11? .....



## F NAND and NOR outputs

8 marks

Write the output Q. It is the complement of the column before it.

NAND gate

| A | B | A.B | Q = $\overline{A.B}$ |
|---|---|-----|----------------------|
| 0 | 0 | 0   |                      |
| 0 | 1 | 0   |                      |
| 1 | 0 | 0   |                      |
| 1 | 1 | 1   |                      |

NOR gate

| A | B | A + B | Q = $\overline{A + B}$ |
|---|---|-------|------------------------|
| 0 | 0 | 0     |                        |
| 0 | 1 | 1     |                        |
| 1 | 0 | 1     |                        |
| 1 | 1 | 1     |                        |

## G Choose the correct answer

8 marks

Underline your answer.

- NAND means  
(a) NOT AND                      (b) NOT OR                      (c) AND OR                      (d) NEW AND
- Which gate gives the output 1 only when all its inputs are 0?  
(a) AND                      (b) OR                      (c) NAND                      (d) NOR
- A NAND gate has the inputs 1 and 1. Its output is  
(a) 0                      (b) 1                      (c) 2                      (d) 11
- The Boolean expression of the NOR gate is  
(a)  $Q = \overline{A.B}$                       (b)  $Q = A + B$                       (c)  $Q = \overline{A + B}$                       (d)  $Q = A.B$
- In the Venn diagram of a gate, only the overlap of A and B is shaded. The gate is  
(a) OR                      (b) AND                      (c) NOR                      (d) NAND
- Integrated circuits are made with transistors, resistors, capacitors and  
(a) diodes                      (b) valves                      (c) switches                      (d) bulbs
- In the 14-pin AND IC of the textbook, which pin is GND?  
(a) 1                      (b) 7                      (c) 8                      (d) 14
- Which of these is a combinational logic gate?  
(a) AND                      (b) OR                      (c) NOT                      (d) NOR

### CHAPTER 4

## Designing and Using Logic Circuits

### ? WHO SWITCHES ON THE STREET LIGHTS?

"The street lights near our school come on by themselves in the evening. Who switches them on?"

A light sensor, a timer and a few logic gates! In this chapter you design circuits from **Boolean expressions**, and you see logic gates at work in doors, lamps, alarms and street lights.



## 4.14 From a Boolean expression to a circuit

Let us design the circuit of the Boolean expression  $Q = A.(\bar{A} + B) + \bar{B}$  (textbook page 125). It has two inputs, A and B. Work from the inside of the brackets:

| Step | Part of the expression      | Gate     | Its inputs                      |
|------|-----------------------------|----------|---------------------------------|
| 1    | $\bar{A}$                   | NOT gate | A                               |
| 2    | $\bar{A} + B$               | OR gate  | $\bar{A}$ and B                 |
| 3    | $A.(\bar{A} + B)$           | AND gate | A and $\bar{A} + B$             |
| 4    | $\bar{B}$                   | NOT gate | B                               |
| 5    | $A.(\bar{A} + B) + \bar{B}$ | OR gate  | $A.(\bar{A} + B)$ and $\bar{B}$ |

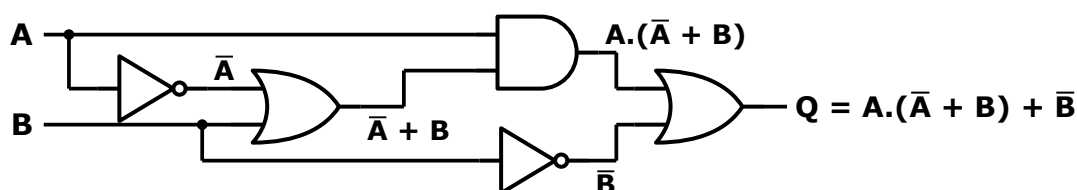
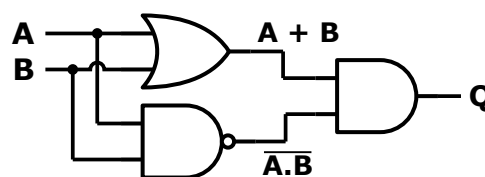


Figure 4.21 - the circuit of  $Q = A.(\bar{A} + B) + \bar{B}$

## 4.15 From a circuit to a Boolean expression

Work from **left to right**. Write the expression of each gate on its output wire. The expression on the last wire is Q.

In this circuit (textbook Activity, page 126) the OR gate gives  $A + B$  and the NAND gate gives  $\bar{A}.B$ . The AND gate joins them:



$$Q = (A + B).\bar{A}.B$$

## 4.16 The truth table of a circuit

Make a column for the output of every gate. Fill the columns from left to right, using the truth tables of the gates. The last column is the output Q. Two inputs give 4 states; three inputs give 8 states.

The truth table of  $Q = A.(\bar{A} + B) + \bar{B}$

| A | B | $\bar{A}$ | $\bar{A} + B$ | $A.(\bar{A} + B)$ | $\bar{B}$ | Q |
|---|---|-----------|---------------|-------------------|-----------|---|
| 0 | 0 | 1         | 1             | 0                 | 1         | 1 |
| 0 | 1 | 1         | 1             | 0                 | 0         | 0 |
| 1 | 0 | 0         | 0             | 0                 | 1         | 1 |
| 1 | 1 | 0         | 1             | 1                 | 0         | 1 |

"Every big circuit is just small gates joined with care."

- THE KING OF ICT



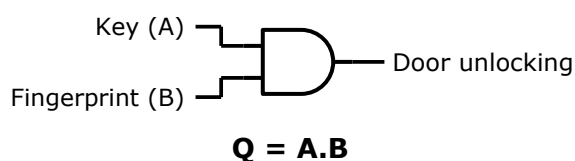
## 4.17 Logic gates solve problems

To solve a problem, find the **inputs** and the **output**, decide which gates are needed, then draw the circuit and write the Boolean expression (textbook pages 129 - 130).

### SCENARIO 1 - DOOR OPENING

A door opens only when it is unlocked with a key **and** the fingerprint reader recognises a fingerprint that was authorised before.

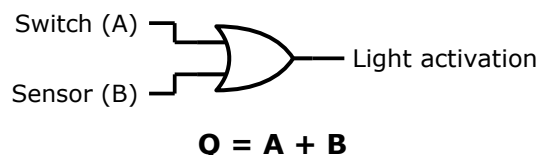
Both conditions must be true, so an **AND** gate is used.



### SCENARIO 2 - LIGHT ON

An electric lamp turns on when its switch is on **or** a sensor detects darkness.

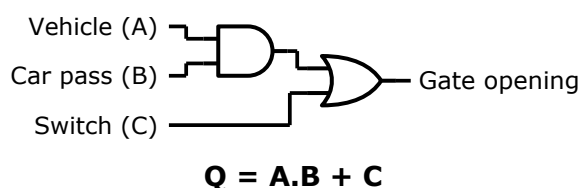
One true condition is enough, so an **OR** gate is used.



### SCENARIO 3 - GATE OPENING

A gate opens when a registered vehicle arrives **and** a car pass is present. It can also be opened by turning a switch on.

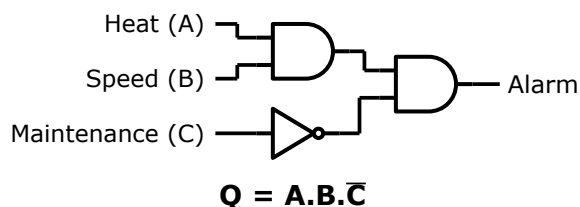
An **AND** gate for the vehicle and the car pass; its output and the switch go into an **OR** gate.



### SCENARIO 4 - MACHINE-FAULT ALARM

An alarm rings when the heat sensor is triggered **and** the speed limit is exceeded, but **no** maintenance procedure has been carried out.

Heat **AND** speed, **AND NOT** maintenance: two **AND** gates and a **NOT** gate.



## 4.18 A home alarm system

This alarm tells the owner when there is a thief. It protects two windows, the front door and the back door. Each window and door has a **sensor**: the input is **1** when it is open and **0** when it is closed. The sensors are joined with **OR** gates, so the alarm is on when one, several or all of the inputs are 1. When all the inputs are 0, there is no alarm.

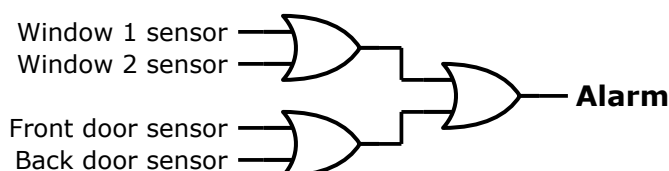


Figure 4.28 - the home alarm system

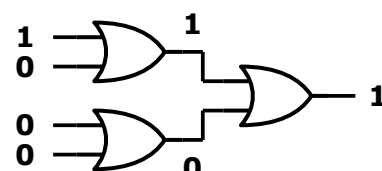


Figure 4.30 - window 1 is open: alarm!

"Logic is not only in computers. Use it in every decision you make."

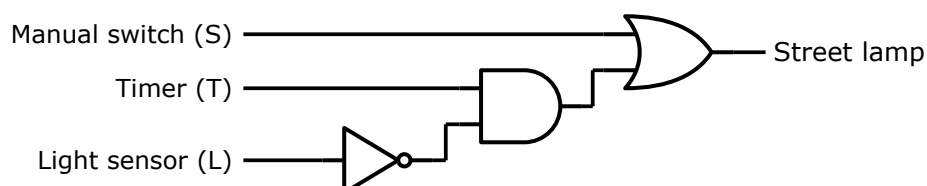
- THE KING OF ICT



## 4.19 Circuits to control street lights

Figure 4.31 controls street lights with a light sensor, a timer and a manual switch.

- The **manual switch** is 1 when it is closed.
- The **timer** is 1 from 6 pm to 6 am, and 0 from 6 am to 6 pm.
- The **light sensor** is 1 when there is light, and 0 when it is dark.
- The lamp is on when the switch is closed, **or** when the timer is 1 **and** it is dark.
- On a gloomy day with rain clouds the sensor may be 0, but the lamp stays off between 6 am and 6 pm.



$$Q = S + T.\bar{L}$$

Figure 4.31 - the circuit to control street lights

### > DO IT - PRACTICAL 5 (TEXTBOOK ACTIVITY, PAGE 127)

Use Multimedia Logic (MM Logic) or another logic gate simulator. **Ask your teacher first.**

|   |                                                                                                                                  |
|---|----------------------------------------------------------------------------------------------------------------------------------|
| 1 | Draw Figure 4.21 ( $Q = A.(\bar{A} + B) + \bar{B}$ ). Try the four inputs and check the truth table in 4.16.                     |
| 2 | Draw the circuits (b) to (f) of textbook Activity 2. Use them to check your answers in the exercises.                            |
| 3 | Build the home alarm (Figure 4.28). Set every input to 0, then "open" one window (input 1).                                      |
| 4 | Build the street lights (Figure 4.31). Try day (timer 0, light 1), night (timer 1, light 0) and a gloomy day (timer 0, light 0). |
| 5 | Watch each gate as you change the inputs. Save your work with your name.                                                         |

### A Draw the circuits

6 marks

Textbook Activity 1, page 126. Draw the circuit of each Boolean expression.

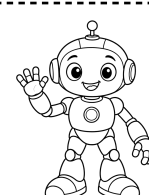
(a)  $Q = A + A.B$

(b)  $Q = A.(A + B)$

(c)  $Q = (A + B).(A.C)$

"A circuit is only a puzzle. Work from left to right, one gate at a time."

- THE KING OF ICT



Colour me!



## B Truth tables of the expressions

8 marks

Textbook Activity 1. Complete the table. Half a mark for each cell.

| A | B | A.B | A + A.B | A + B | A.(A + B) |
|---|---|-----|---------|-------|-----------|
| 0 | 0 |     |         |       |           |
| 0 | 1 |     |         |       |           |
| 1 | 0 |     |         |       |           |
| 1 | 1 |     |         |       |           |

Look at the columns  
A + A.B and A.(A + B).  
What do you notice?

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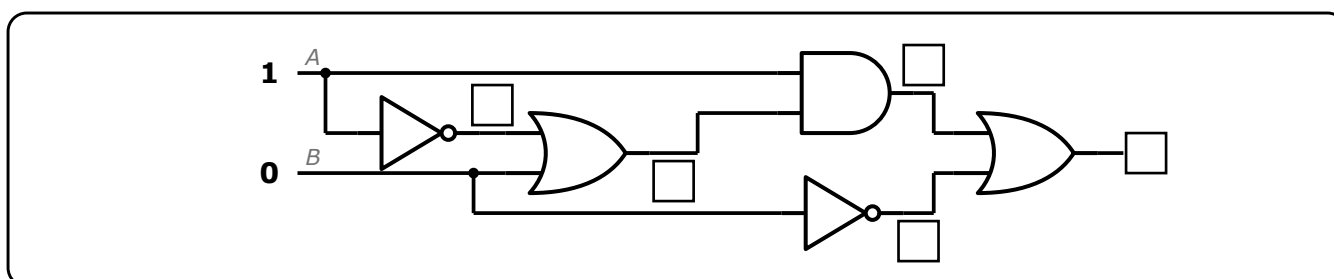


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## C Values on the wires

5 marks

This is Figure 4.21 with A = 1 and B = 0. Write 1 or 0 in every box.



## D The street lights

8 marks

Use Figure 4.31. Write 1 (lamp on) or 0 (lamp off) for every state.

| Switch S | Timer T | Light L | Lamp Q |
|----------|---------|---------|--------|
| 0        | 0       | 0       |        |
| 0        | 0       | 1       |        |
| 0        | 1       | 0       |        |
| 0        | 1       | 1       |        |
| 1        | 0       | 0       |        |
| 1        | 0       | 1       |        |
| 1        | 1       | 0       |        |
| 1        | 1       | 1       |        |

$$Q = S + T.L$$

**Hint:** first find NOT L, then T AND NOT L, then the OR gate.

## E From words to expressions

6 marks

These come from the textbook, pages 113 and 133. 1 mark for Q, 1 mark for the gate(s).

1. A safe opens only when key X **and** key Y are both used.

Q = ..... Gate(s): .....

2. A car has four doors W, X, Y and Z (1 = not closed properly). A light comes on when at least one door is not closed properly.

Q = ..... Gate(s): .....

3. The street lamp is on when the timer T is 1 **and** the light sensor L is **not** 1.

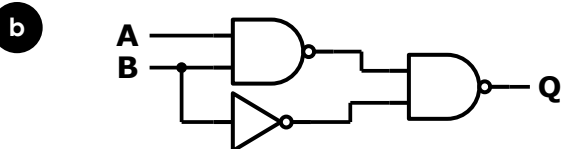
Q = ..... Gate(s): .....



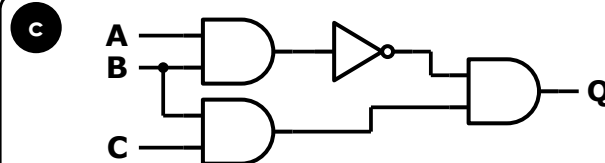
## F Write the Boolean expressions

8 marks

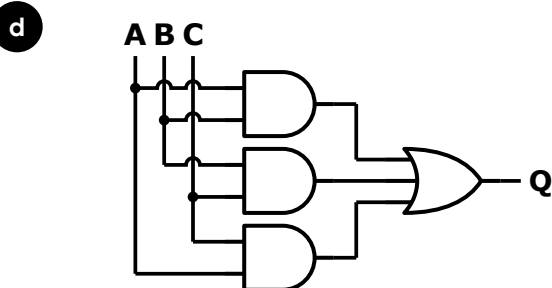
Textbook Activity 2, pages 126 - 127. Write the Boolean expression of each circuit.



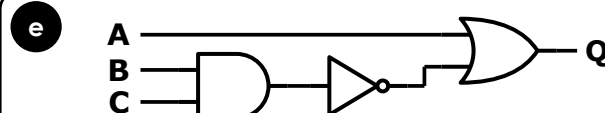
Q = .....



Q = .....



Q = .....



Q = .....

## G Will it open? Will it ring?

8 marks

Use scenarios 3 and 4 from section 4.17. Write 1 (yes) or 0 (no).

Scenario 3: the gate ( $Q = A.B + C$ )

| No | Vehicle A | Pass B | Switch C | Opens? |
|----|-----------|--------|----------|--------|
| 1  | 1         | 1      | 0        |        |
| 2  | 1         | 0      | 0        |        |
| 3  | 0         | 0      | 1        |        |
| 4  | 0         | 1      | 0        |        |

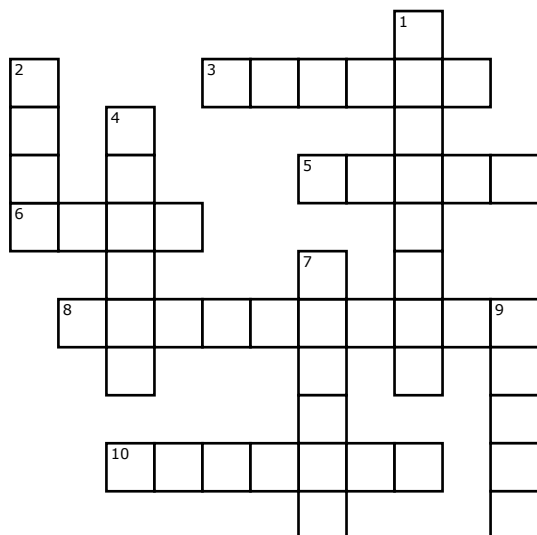
Scenario 4: the machine-fault alarm ( $Q = A.B.\bar{C}$ )

| No | Heat A | Speed B | Maint. C | Alarm? |
|----|--------|---------|----------|--------|
| 1  | 1      | 1       | 0        |        |
| 2  | 1      | 1       | 1        |        |
| 3  | 1      | 0       | 0        |        |
| 4  | 0      | 1       | 0        |        |

## H Crossword

10 marks

All the words are in this unit. Write one letter in each square.



### ACROSS

3. A horn, a flag or a light that helps us to decide (6)
5. It warns the owner when a window is opened (5)
6. NOT AND (4)
8. The NOT gate gives this of its input (10)
10.  $Q = A.B$  is a ... expression (7)

### DOWN

1. The switches of the OR gate circuit are joined in ... (8)
2. A ... diagram shows where the output is 1 (4)
4. It detects darkness, heat or an open door (6)
7. The switches of the AND gate circuit are joined in ... (6)
9. In Figure 4.31 it is 1 from 6 pm to 6 am (5)



REVISION

# Unit 4 in One Page

Read this the night before the test

| Topic                        | The key facts                                                                                                            |
|------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| <b>Signals</b>               | We use signals (a horn, a flag, a light) to make decisions. A computer also uses signals.                                |
| <b>Logic gates</b>           | Basic circuits that give an output from one or more inputs (1 or 0). The CPU is made of a large number of logic gates.   |
| <b>Two types</b>             | Basic logic gates: AND, OR, NOT. Combinational logic gates: NAND, NOR (made of basic gates).                             |
| <b>AND gate</b>              | $Q = A.B$ . The output is 1 only when all inputs are 1. Switches in series.                                              |
| <b>OR gate</b>               | $Q = A + B$ (not addition!). The output is 1 when at least one input is 1. Switches in parallel.                         |
| <b>NOT gate</b>              | $Q = \bar{A}$ . The output is the complement of the input: 0 gives 1, 1 gives 0.                                         |
| <b>NAND gate</b>             | $Q = \bar{A.B}$ . AND, then NOT. When all inputs are 1, the output is 0.                                                 |
| <b>NOR gate</b>              | $Q = \bar{A + B}$ . OR, then NOT. When all inputs are 0, the output is 1.                                                |
| <b>Truth tables</b>          | Two inputs: $2^2 = 4$ states. Three inputs: $2^3 = 8$ states. Write the inputs in order: 0 0, 0 1, 1 0, 1 1.             |
| <b>Expression to circuit</b> | One gate for every NOT, AND and OR. Start inside the brackets.                                                           |
| <b>Circuit to expression</b> | Write the expression on the output wire of every gate, from left to right.                                               |
| <b>Venn diagrams</b>         | The shaded part shows where the output is 1.                                                                             |
| <b>ICs</b>                   | 14 pins. Pin 14 is VCC and pin 7 is GND. AND IC: inputs 1, 2, 4, 5, 9, 10, 12, 13; outputs 3, 6, 8, 11.                  |
| <b>Gates at work</b>         | Door: key AND fingerprint. Lamp: switch OR sensor. Home alarm: OR gates. Street lights: switch OR (timer AND NOT light). |

## ★ TICK WHEN YOU CAN DO IT

- ☐ I can name the basic and the combinational logic gates.
- ☐ I can draw the five gate symbols and write their Boolean expressions.
- ☐ I can complete truth tables with two and three inputs.
- ☐ I can draw the circuit of a Boolean expression.
- ☐ I can write the Boolean expression of a circuit.
- ☐ I can read Venn diagrams and the pins of a logic IC.
- ☐ I can use logic gates for alarms, doors and street lights.

"Check every gate twice. A careful student never loses easy marks."

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WORD POWER

# Unit 4 Word List

Twenty-seven words you must know

| Word                           | What it means                                                                    |
|--------------------------------|----------------------------------------------------------------------------------|
| <b>Signal</b>                  | Something (a sound, a light, a flag) that helps us to make a decision.           |
| <b>Logic circuit</b>           | A circuit that builds logical conditions with binary values and makes decisions. |
| <b>Logic gate</b>              | A basic logic circuit that gives an output from one or more inputs.              |
| <b>Binary values</b>           | The two values 1 and 0.                                                          |
| <b>Input / Output</b>          | What goes into a gate / what comes out of it.                                    |
| <b>Basic logic gates</b>       | The AND, OR and NOT gates.                                                       |
| <b>Combinational gates</b>     | Gates made from basic gates: NAND and NOR.                                       |
| <b>AND gate</b>                | $Q = A.B$ . The output is 1 only when all its inputs are 1.                      |
| <b>OR gate</b>                 | $Q = A + B$ . The output is 1 when at least one input is 1.                      |
| <b>NOT gate</b>                | $Q = \bar{A}$ . The output is the complement of the input.                       |
| <b>Complement</b>              | The other value: the complement of 0 is 1, and of 1 is 0.                        |
| <b>NAND gate</b>               | NOT AND. $Q = \bar{A.B}$ . An AND gate followed by a NOT gate.                   |
| <b>NOR gate</b>                | NOT OR. $Q = \overline{A + B}$ . An OR gate followed by a NOT gate.              |
| <b>Boolean expression</b>      | A gate or a circuit written with letters, like $Q = A.(A + B)$ .                 |
| <b>Truth table</b>             | A table that shows the output for every input.                                   |
| <b>Series</b>                  | Joined one after the other, on one path (the AND gate circuit).                  |
| <b>Parallel</b>                | Joined side by side, on two paths (the OR gate circuit).                         |
| <b>Venn diagram</b>            | Circles in a box. The shaded part shows where the output is 1.                   |
| <b>Integrated circuit (IC)</b> | A small chip with many devices and logic gates packed into one.                  |
| <b>Pin</b>                     | A metal leg of an IC. A logic IC in the textbook has 14 pins.                    |
| <b>VCC / GND</b>               | The power pins of the IC: pin 14 and pin 7.                                      |
| <b>Simulator</b>               | Software that shows how logic circuits work, like MM Logic.                      |
| <b>Sensor</b>                  | A device that detects light, darkness, heat or an open door.                     |
| <b>Timer</b>                   | In Figure 4.31 it gives 1 from 6 pm to 6 am, and 0 from 6 am to 6 pm.            |
| <b>Digital circuit</b>         | A circuit that works with binary values. A computer has many of them.            |
| <b>Microprocessor</b>          | A chip made of a large number of ICs which use logic gates.                      |
| <b>CPU</b>                     | The Central Processing Unit. It is made of a large number of logic gates.        |

"Learn the words today, and the ideas will follow tomorrow."

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END OF UNIT

**Unit 4 Test**

Time: 45 minutes

Total: 40 marks

Name \_\_\_\_\_

Class \_\_\_\_\_

Marks **1 Choose the correct answer****8 marks***Underline your answer.*

- Which gate gives the output 1 only when all its inputs are 1?  
(a) OR (b) AND (c) NOR (d) NOT
- The Boolean expression of the NAND gate is  
(a)  $Q = \overline{A.B}$  (b)  $Q = A + B$  (c)  $Q = \overline{A + B}$  (d)  $Q = A.B$
- How many states does the truth table of a gate with three inputs have?  
(a) 3 (b) 4 (c) 6 (d) 8
- In the electronic circuit of the OR gate, the two switches are joined  
(a) in series (b) to the IC (c) in parallel (d) to GND
- A NOR gate has the inputs 0 and 0. Its output is  
(a) 0 (b) 1 (c) 2 (d) 00
- In the 14-pin AND IC, pin 14 is  
(a) GND (b) an input (c) an output (d) VCC
- Which gates are needed to draw the circuit of  $Q = A.B + C$ ?  
(a) AND and OR (b) two ANDs (c) two ORs (d) NOT and OR
- A - The complement of 1 is 0. B -  $A + B$  means A plus B. C - The CPU is made of many logic gates. Which are correct?  
(a) A, B only (b) B, C only (c) A, C only (d) A, B and C

**2 Fill in the blanks****8 marks***One word or sign in each blank.*

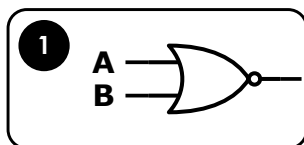
- A logic gate gives an ..... after considering its inputs.
- The output of a NOT gate is the ..... of its input.
- NAND means NOT .....
- When all the inputs of a NOR gate are 0, the output is always .....
- A truth table for two inputs has ..... states.
- In the 14-pin AND IC, pin 7 is .....
- The OR gate is used in a home ..... system with window and door sensors.
- In Boolean algebra, the OR operation is written A ..... B.



### 3 Look at the gates

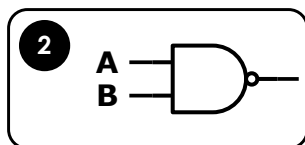
8 marks

Write the name of each gate and its Boolean expression.



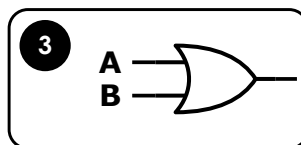
Name: .....

$Q = \dots\dots\dots$



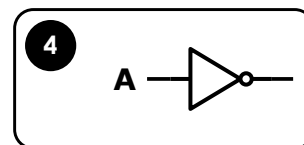
Name: .....

$Q = \dots\dots\dots$



Name: .....

$Q = \dots\dots\dots$



Name: .....

$Q = \dots\dots\dots$

### 4 Answer these

16 marks

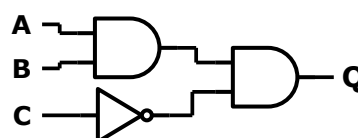
Write in the space given.

1. Draw the logic circuit of  $Q = A + A.B$ . Label the inputs and the output. (3 marks)

2. Complete the truth table of the NOR gate. Fill both columns. (4 marks)

| A | B | $A + B$ | $Q = \overline{A + B}$ |
|---|---|---------|------------------------|
| 0 | 0 |         |                        |
| 0 | 1 |         |                        |
| 1 | 0 |         |                        |
| 1 | 1 |         |                        |

3. Write the Boolean expression of this circuit. (3 marks)



$Q = \dots\dots\dots$

4. A door opens only when it is unlocked with a key and the fingerprint reader recognises the fingerprint. Which gate is used? Write the Boolean expression (key A, fingerprint B). (2 marks)

5. Write the input pins and the output pins of the AND IC (Figure 4.22). (2 marks)

6. In the street light circuit, the timer is 1 and the light sensor is 0. The manual switch is open (0). Is the lamp on? Explain. (2 marks)