Grade 12 A/L ICT · Lesson 4

4.1 Logic Gates and Truth Tables: NOT, AND, OR, XOR, NAND, NOR, XNOR

Syllabus 4.1. A **logic gate** is a small circuit that takes one or more **binary inputs** (0 or 1) and gives one **binary output**. In this part you learn the seven basic gates – **NOT, AND, OR, XOR** and the combinational gates **NAND, NOR, XNOR** – how to **draw their symbols**, how to write their **truth tables**, and why **NAND and NOR are universal gates** that can build any other gate.

1. What is a logic gate?

Inside every CPU and every digital chip, decisions are made with **logic gates**. Each gate follows a simple rule: for every possible mix of 0s and 1s at the inputs, the output is either 0 or 1. We write that rule as a **truth table**. A **0** means LOW / false / OFF. A **1** means HIGH / true / ON.

> 💡 A truth table lists **every** input combination. With n inputs there are **2^n rows**. One input → 2 rows. Two inputs → 4 rows. Three inputs → 8 rows.

Seven basic logic gates



The seven basic logic gates

2. Basic gates: NOT, AND, OR, XOR

NOT (inverter) has **one** input. It **flips** the bit: F = A′ (also written ¬A or Ā). If A is 0, F is 1; if A is 1, F is 0.

A	F = NOT
0	1
1	0

AND outputs 1 only when **every** input is 1. Write F = A · B (or A ∧ B). Think of it as "A **and** B must both be true".

A	B	F = AND
0	0	0
0	1	0

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1	0	0
1	1	1

OR outputs 1 when **at least one** input is 1. Write F = A + B (or A ∨ B). "A **or** B (or both)".

A	B	F = OR
0	0	0
0	1	1
1	0	1
1	1	1

XOR (exclusive OR) outputs 1 when the inputs are **different**. Write F = A ⊕ B. Same inputs → 0; different → 1. It is the gate that makes the **sum bit** of a half adder (Lesson 4.4).

A	B	F = XOR
0	0	0
0	1	1
1	0	1
1	1	0

🧱 **Worked example: Complete the truth table for F = A · B. What is F when A = 1 and B = 1?**
AND is 1 only when both inputs are 1, so F = **1**. The four rows are 00→0, 01→0, 10→0, 11→**1**.

3. Combinational gates: NAND, NOR, XNOR

A **combinational gate** is a basic gate with a **NOT** stuck on its output. **NAND** = NOT-AND: F = (A · B)′. It is 0 only when both inputs are 1. **NOR** = NOT-OR: F = (A + B)′. It is 1 only when both inputs are 0. **XNOR** = NOT-XOR: F = (A ⊕ B)′. It is 1 when the inputs are the **same** (equality gate).

A	B	F = NAND
0	0	1
0	1	1
1	0	1
1	1	0

A	B	F = NOR
0	0	1

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0	1	0
1	0	0
1	1	0

A	B	F = XNOR
0	0	1
0	1	0
1	0	0
1	1	1

💡 A small **circle** on a gate symbol means NOT (inversion). NAND looks like AND with a circle; NOR looks like OR with a circle; XNOR looks like XOR with a circle.

🧱 **Worked example: For inputs A = 1, B = 0 find the outputs of AND, OR, XOR, NAND, NOR and XNOR.**
AND = 0, OR = 1, XOR = 1, NAND = 1, NOR = 0, XNOR = 0.

4. Truth tables for expressions (up to three inputs)

For an expression such as **F = A · B + A′ · C** you make an 8-row table (A, B, C from 000 to 111). Work out each product term, then OR them.

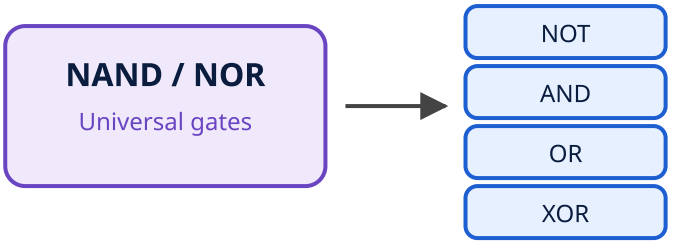
🧱 **Worked example: Build the truth table for F = A · B + A′ · C.**
F is 1 for the rows ABC = 001, 011, 110, 111 (decimal 1, 3, 6, 7). F is 0 for 000, 010, 100, 101.

A	B	C	A·B	A′·C	F
0	0	0	0	0	0
0	0	1	0	1	1
0	1	0	0	0	0
0	1	1	0	1	1
1	0	0	0	0	0
1	0	1	0	0	0
1	1	0	1	0	1
1	1	1	1	0	1

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5. Universal gates: NAND and NOR

A gate is **universal** if you can build **every** other gate from copies of it alone. **NAND** and **NOR** are universal. That matters in factories: a chip designer can stock one type of gate and still make any circuit.



NAND and NOR can build any other gate

NOT from NAND
Tie both inputs together: A NAND A = A′.

AND from NAND
NAND once, then invert the output with another NAND: (A NAND B)′ = A · B.

OR from NAND
Invert each input, then NAND: A′ NAND B′ = A + B (De Morgan).

🧱 **Worked example: Show that A NAND A equals NOT A, for A = 0 and A = 1.**
A = 0: 0 NAND 0 = 1 = NOT 0. A = 1: 1 NAND 1 = 0 = NOT 1. So NAND with tied inputs is an inverter.

💡 You can also build everything from NOR alone: A NOR A = A′, and so on. In exams, be ready to draw a NOT, AND or OR using only NAND (or only NOR) gates.

🚀 **Beyond the syllabus (2026 update)** *Not required for the exam – read for interest.* In 2026, CPUs still use CMOS transistors that behave as tiny NAND and NOR gates. A modern phone SoC contains tens of billions of such gates. Quantum computers use different “gates” (Hadamard, CNOT) that work on qubits, not bits – but the idea of building big circuits from a small set of universal gates is the same.

Key Words

Logic gate – A circuit with binary inputs that produces one binary output.

Truth table – A table that lists every input combination and the matching output.

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NOT – Inverter: output is the opposite of the single input. F = A′.	**AND** – Output is 1 only if every input is 1. F = A · B.
OR – Output is 1 if at least one input is 1. F = A + B.	**XOR** – Exclusive OR: output is 1 when inputs differ. F = A ⊕ B.
NAND – NOT-AND: F = (A · B)′. A universal gate.	**NOR** – NOT-OR: F = (A + B)′. A universal gate.
XNOR – NOT-XOR: output is 1 when inputs are equal.	**Universal gate** – A gate that can be used alone to build any other gate (NAND, NOR).
Inversion bubble – The small circle on a gate symbol that means NOT.	**Combinational gate** – A gate made by adding NOT to a basic gate (NAND, NOR, XNOR).

Sample Q&A

1. What is a logic gate?

> **Answer:** A small digital circuit that takes one or more binary inputs and produces one binary output according to a fixed rule.

2. Write the truth table for a 2-input AND gate.

> **Answer:** AB: 00 → 0, 01 → 0, 10 → 0, 11 → 1.

3. How does XOR differ from OR?

> **Answer:** OR is 1 when any input is 1 (including both). XOR is 1 only when the inputs are different – both 1 gives 0.

4. Why are NAND and NOR called universal gates?

> **Answer:** Because any other gate (NOT, AND, OR, XOR, …) can be built using only NAND gates, or only NOR gates.

5. How do you make a NOT gate from a NAND gate?

> **Answer:** Connect both NAND inputs to the same signal A. Then A NAND A = A′.

6. How many rows does a truth table for three inputs have?

> **Answer:** 2^3 = 8 rows (000 through 111).

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MCQ

1. Which gate outputs 1 only when every input is 1?

A. XOR
B. NOR
C. AND
D. OR
E. NOT

2. The output of a NOT gate when the input is 1 is

A. unchanged
B. 2
C. 1
D. undefined
E. 0

3. Which gate is also called the exclusive OR?

A. XOR
B. OR
C. NAND
D. AND
E. XNOR

4. NAND is the same as

A. NOR followed by NOT
B. OR followed by NOT
C. XOR followed by NOT
D. AND followed by NOT
E. NOT followed by AND

5. Which two gates are universal?

A. OR and XOR
B. AND and OR
C. NAND and NOR
D. XOR and XNOR
E. NOT and AND

6. For A = 1, B = 1 the XOR output is

A. B
B. 0
C. 1
D. A
E. 2

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7. For A = 0, B = 0 the NOR output is

A. 1
B. undefined
C. A
D. B
E. 0

8. A small circle on a gate symbol means

A. AND
B. power supply
C. inversion (NOT)
D. ground
E. clock

9. How many rows are in a truth table with 3 inputs?

A. 9
B. 3
C. 6
D. 4
E. 8

10. XNOR output is 1 when the inputs are

A. both 0 only
B. equal
C. undefined
D. both 1 only
E. different

11. A NAND B equals A′ when

A. B = 1
B. A = 1
C. B = 0
D. A = 0
E. B is tied to A (B = A)

12. Which expression is OR?

A. A ⊕ B
B. (A · B)′
C. A · B
D. A + B
E. A′

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13. Which term means: “A circuit with binary inputs that produces one binary output”?

A. NOR
B. Inversion bubble
C. XOR
D. Logic gate
E. NOT

14. Which term means: “A table that lists every input combination and the matching output”?

A. Truth table
B. NAND
C. AND
D. XNOR
E. Combinational gate

15. Which term means: “Inverter: output is the opposite of the single input. F = A′”?

A. NOT
B. Logic gate
C. Universal gate
D. OR
E. NOR

16. Which term means: “Output is 1 only if every input is 1. F = A · B”?

A. Truth table
B. Inversion bubble
C. XOR
D. XNOR
E. AND

17. Which term means: “Output is 1 if at least one input is 1. F = A + B”?

A. NAND
B. OR
C. Universal gate
D. Combinational gate
E. NOT

18. Which term means: “Exclusive OR: output is 1 when inputs differ. F = A ⊕ B”?

A. Inversion bubble
B. AND
C. XOR
D. NOR
E. Logic gate

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19. Which term means: "NOT-AND: F = (A · B)′. A universal gate"?

A. XNOR
B. NAND
C. Truth table
D. OR
E. Combinational gate

20. Which term means: "NOT-OR: F = (A + B)′. A universal gate"?

A. XOR
B. Logic gate
C. Universal gate
D. NOR
E. NOT

Structured Questions

1. Draw the truth table for a 2-input OR gate and state when the output is 0. *(2 marks)*

> Rows: 00 → 0, 01 → 1, 10 → 1, 11 → 1 (1 each); output is 0 only when both inputs are 0 (1).

2. Explain the difference between AND and NAND using their truth tables. *(3 marks)*

> AND: 11 → 1, other rows 0 (1); NAND is the opposite of AND: 11 → 0, other rows 1 (1); NAND = (A·B)′ (1).

3. Why are universal gates useful? Name the two universal gates. *(2 marks)*

> One gate type can build every other gate / simplifies chip design (1); NAND and NOR (1).

4. Show how to obtain NOT and AND using only NAND gates. *(2 marks)*

> NOT: A NAND A = A′ (1); AND: (A NAND B) then NAND the result with itself to invert → A·B (2).

5. For F = A · B + A′ · C, find F when ABC = 011 and when ABC = 101. *(2 marks)*

> 011: A=0,B=1,C=1 → A·B=0, A′·C=1 → F=1 (1); 101: A=1,B=0,C=1 → A·B=0, A′·C=0 → F=0 (1).

Summary

- A logic gate maps binary inputs to one binary output; a truth table lists every case.
- NOT flips; AND needs all 1s; OR needs any 1; XOR needs different inputs.
- NAND, NOR and XNOR are the negated forms of AND, OR and XOR.
- NAND and NOR are universal – each alone can build every other gate.
- With n inputs a truth table has 2^n rows; three inputs → 8 rows.

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MCQ answer key – 4.1

1. **C** – AND is 1 only for the all-1s row.
2. **E** – NOT flips 1 to 0.
3. **A** – XOR = exclusive OR.
4. **D** – NAND = $(A \cdot B)'$.
5. **C** – Only NAND and NOR can build every other gate alone.
6. **B** – Same inputs → XOR = 0.
7. **A** – NOR is 1 only when both inputs are 0.
8. **C** – The bubble is inversion.
9. **E** – $2^3 = 8$.
10. **B** – XNOR is the equality gate.
11. **E** – A NAND A = A'.
12. **D** – + denotes OR in Boolean algebra.
13. **D** – Logic gate – A circuit with binary inputs that produces one binary output.
14. **A** – Truth table – A table that lists every input combination and the matching output.
15. **A** – NOT – Inverter: output is the opposite of the single input. F = A'.
16. **E** – AND – Output is 1 only if every input is 1. F = $A \cdot B$.
17. **B** – OR – Output is 1 if at least one input is 1. F = A + B.
18. **C** – XOR – Exclusive OR: output is 1 when inputs differ. F = $A \oplus B$.
19. **B** – NAND – NOT-AND: F = $(A \cdot B)'$. A universal gate.
20. **D** – NOR – NOT-OR: F = $(A + B)'$. A universal gate.

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