Computer Science Illuminated, Seventh Edition
Nell Dale, PhD; John Lewis, PhD

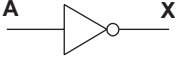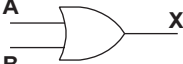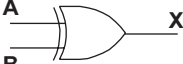Answers are in blue, except for circuit diagrams.

For Exercises 1–17, mark the answers true and false as follows:

A. **True**
B. **False**

1. Logic diagrams and truth tables are equally powerful in expressing the processing of gates and circuits.
   A

2. Boolean expressions are more powerful than logic diagrams in expressing the processing of gates and circuits.
   B

3. A NOT gate accepts two inputs.
   B

4. The output value of an AND gate when both inputs are 1 is 1.
   A

5. The AND and OR gates produce opposite results for the same input
   B

6. The output value of an OR gate when both inputs are 1 is 1.
   A

7. The output of an OR gate when one input is 0 and one input is 1 is 0.
   B

8. The output value of an XOR gate is 0 unless both inputs are 1.
   B

9. The NOR gate produces the opposite results of the XOR gate.
   B

10. A gate can be designed to accept more than two inputs.
    A

11. A transistor is made of semiconductor material.
    A

12. Inverting the output of an AND gate is equivalent to inverting the individual signals first, then passing them through an OR gate.
    A (DeMorgan's law)

13. The sum of two binary digits (ignoring the carry) is expressed by an AND gate.
    B

14. A full adder takes the carry-in value into account.
    A

15. A multiplexer adds all of the bits on its input lines to produce its output.
    B

16. Integrated circuits are classified by the number of gates contained in them.
   A

17. A CPU is an integrated circuit.
    A

For Exercises 18–29, match the gate with the diagram or description of the operation.

A. **AND**
B. **NAND**
C. **XOR**
D. **OR**
E. **NOR**
F. **NOT**

18. Inverts its input.
    F

19. Produces a 1 only if all its inputs are 1 and a 0 otherwise.
    A

20. Produces a 0 only if all its inputs are 0 and a 1 otherwise.
    D

21. Produces a 0 only of its inputs are the same and a 1 otherwise.
    C

22. Produces a 0 of all its inputs are all 1 and a 1 otherwise.
    B

23. Produces a 1 if all its inputs are 0 and a 0 otherwise.
    E

24.
    F

25.
    A

26.
    D

27.
    C

28.

B

29.

E
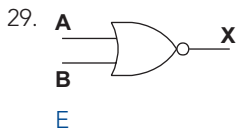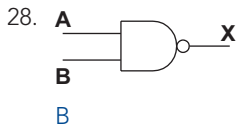
Exercises 30–73 are short answer or design questions.

30. How is voltage level used to distinguish between binary digits?
A voltage level in the range of 0 to 2 volts is interpreted as a binary 0. A voltage level in the range of 2+ to 5 volts is interpreted as a binary 1.

31. Distinguish between a gate and a circuit.
A gate accepts one or more input signals and produces an output signal. Each type of gate performs one logical function. A circuit is a combination of gates designed to accomplish a more-complex logical function.

32. What are the three notational methods for describing the behavior of gates and circuits?
Boolean expressions, logic diagrams, and truth tables

33. Characterize the notations asked for in Exercise 32.
Boolean expressions use the operations of Boolean algebra to describe the behavior of gates and circuits. Logic diagrams use a graphical representation to describe the behavior of gates and circuits. Truth tables define the behavior of gates and circuits by showing all possible input and output combinations of the gates and circuits.

34. How many input signals can a gate receive and output signals can a gate produce?
A gate can accept one or more input signals, but can produce only a single output value.
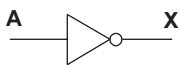
35. Name six types of gates.
NOT, AND, OR, XOR, NAND, and NOR

36. Give the three representations of a NOT gate and say in words what NOT means.
A is the input signal and X is the output signal.

Boolean expression: $X = A'$

Logic diagram:

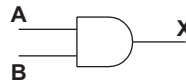Truth table:

A	X
0	1
1	0

NOT takes a binary input value and inverts it.

37. Give the three representations of an AND gate and say in words what AND means.
A and B are the input signals and X is the output signal.

Boolean expression: A • B (A AND B)

Logic diagram:

Truth table:

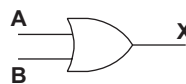| A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

If both input values are 1, AND returns a 1; otherwise, AND returns a 0.

38. Give the three representations of an OR gate and say in words what OR means.
A and B are the input signals and X is the output signal.

Boolean expression: A + B (A OR B)

Logic diagram:

Truth table

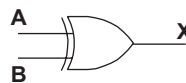| A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

If both input values are 0, OR returns 0; otherwise, OR returns a 1.

39. Give the three representations of an XOR gate and say in words what XOR means.
A and B are the input signals and X is the output signal.

Boolean expression: A ⊕ B (A XOR B)

Logic diagram:

Truth table

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

If both inputs are the same value, XOR returns a 0; otherwise, XOR returns a 1.

40. Give the three representations of a NAND gate and say in words what NAND means.
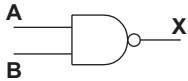A and B are the input signals and X is the output signal.

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Boolean expression: (A · B)' (NOT (A AND B))

Logic diagram:

Truth table

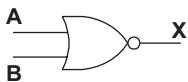| A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

If the inputs are different or both 0, NAND returns a 1; if both are 1, it returns a 0.

41. Give the three representations of a NOR gate and say in words what NOR means.
A and B are the input signals and X is the output signal.

Boolean expression: (A + B)' (NOT (A AND B))

Logic diagram:

Truth table

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

If the inputs are both 0, NOR returns a 1; otherwise, NOR returns a 0.

42. Compare and contrast the AND gate and the NOR gate.
An AND gate produces a 1 as output only if both inputs are 1, whereas a NAND gate produces a 1 as output in all cases / except/ when both inputs are 1. That is, the AND and NAND gates produce opposite results. The values produced by one of these gates can be replicated by inverting the results produced by the other.

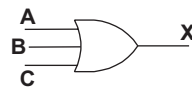43. Draw and label the symbol for a three-input AND gate, then show its behavior with a truth table.
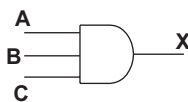
A	B	C	X
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0

1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

X = A • B • C

44. Draw and label the symbol for a three-input OR gate, then show its behavior with a truth table.

A	B	C	X
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

X = A + B + C

45. What is used in a gate to establish how the input values map to the output value?
A transistor

46. How does a transistor behave?
Depending on the voltage of an input signal, a transistor either acts as a wire that conducts electricity or as a resister that blocks the flow of electricity.

47. Of what is a transistor made?
Transistors are made of semiconductor material, which is neither a good conductor of electricity nor a particularly good insulator. Transistors are usually made from silicon.

48. What happens when an electric signal is grounded?
If an electric signal is grounded, the signal flows through an alternative route to the ground where it can do no harm. When a signal is grounded, it is pulled down to 0 volts.

49. What are the three terminals in a transistor and how do they operate?
The *source* is an electric signal. The *base* value regulates a gate that determines whether the connection between the source and the ground (*emitter*) is made. An output line is usually connected to the source. If the base value is high, the source is grounded and the output is low (representing 0). If the base value is low, the gate is closed and the source is not grounded and the output is high (representing 1).

50. How many transistors does it take for each of these gates?
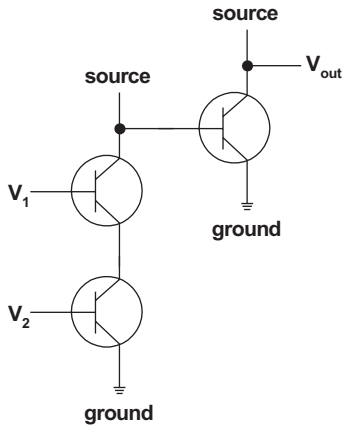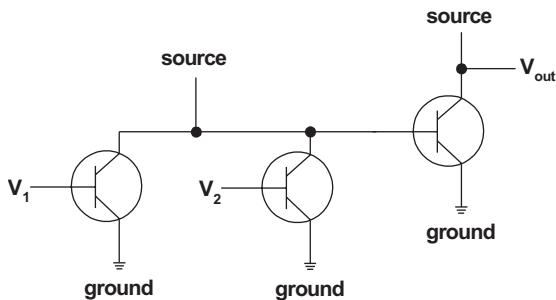A. NOT
1
B. AND
2

C. NOR
   2
D. OR
   2
E. XOR
   8

51. Draw a transistor diagram for an AND gate. Explain the processing.

The NAND gate is the inverse of the AND gate, and the inverse of the inverse is the original. Thus, the output from the NAND gate is input to a NOT gate, giving us the AND.

52. Draw a transistor diagram for an OR gate. Explain the processing.


The NOR gate is the inverse of the OR gate, and the inverse of the inverse is the original. Thus, the output from the NOR gate is input to a NOT gate, giving us the NOR.

53. How can gates be combined into circuits?
    Gates are combined into circuits by using the output of one gate as the input for another. Also, the same input value can be used as input to two different gates.

54. What are the two general categories of circuits, and how do they differ?
    Combinational circuits are circuits in which the input values explicitly determine the output. *Sequential circuits* are circuits in which the output is a function of input values and the current state of the circuit.

55. Draw a circuit diagram corresponding to the following Boolean expression:
    (A + B)(B + C)
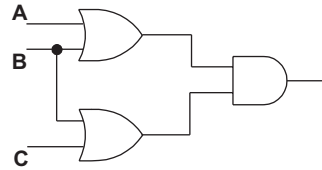
56. Draw a circuit diagram corresponding to the following Boolean expression:
    (AB + C)D
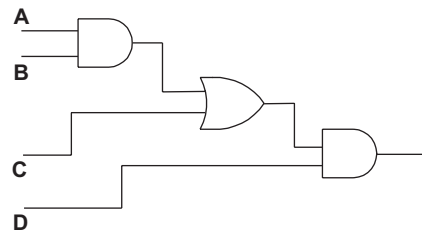
57. Draw a circuit diagram corresponding to the following Boolean expression:
    A'B + (B+C)'
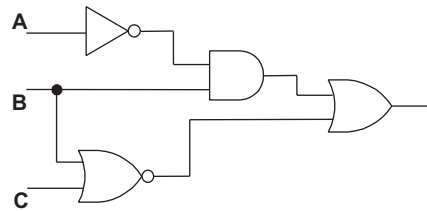
58. Draw a circuit diagram corresponding to the following Boolean expression:
    (AB)' + (CD)'
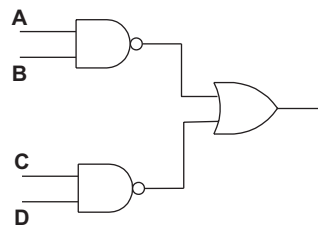
59. Show the behavior of the following circuit with a truth table:
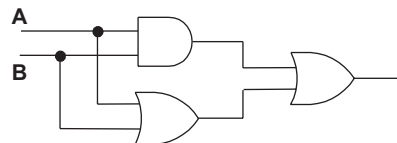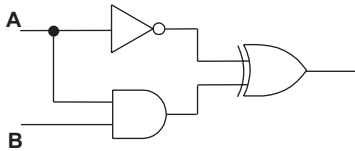

A	B	AB	A + B	AB + (A + B)
0	0	0	0	0
0	1	0	1	1
1	0	0	1	1
1	1	1	1	1

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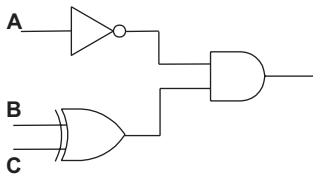
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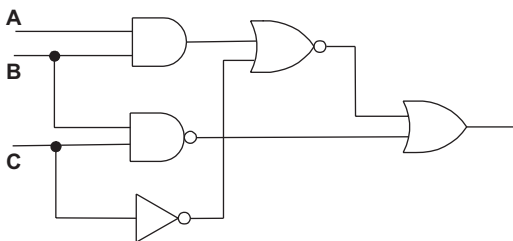60. Show the behavior of the following circuit with a truth table:

A	B	A'	AB	A' ⊕ (AB)
0	0	1	0	1
0	1	1	0	1
1	0	0	0	0
1	1	0	1	1

61. Show the behavior of the following circuit with a truth table:

A	B	C	A'	B ⊕ C	A'(B ⊕ C)
0	0	0	1	0	0
0	0	1	1	1	1
0	1	0	1	1	1
0	1	1	1	0	0
1	0	0	0	0	0
1	0	1	0	1	0
1	1	0	0	1	0
1	1	1	0	0	0

62. Show the behavior of the following circuit with a truth table:

A	B	C	AB	(BC)'	C'	(AB + C')'	(BC)' + (AB + C')'
0	0	0	0	1	1	0	1
0	0	1	0	1	0	1	1
0	1	0	0	1	1	0	1
0	1	1	0	0	0	1	1
1	0	0	0	1	1	0	1
1	0	1	0	1	0	1	1
1	1	0	1	1	1	0	1
1	1	1	1	0	0	0	0

63. What is circuit equivalence?
Circuit equivalence is when two circuits produce the same output from the same input value combination.

64. Name six properties of Boolean algebra and explain what each means.
Commutative: The commutative property says that binary operations AND and OR may be applied left to right or right to left. (A AND B is the same as B AND A; A OR B is the same as B OR A)

Associative: The associative property says that given three Boolean variables, they may be ANDed or ORed right to left or left to right. ((A AND B) AND C is the same as A AND (B AND C); (A OR B) OR C is the same as A OR (B OR C))

Distributive: The distributive property says that given three Boolean variables, the first AND the result of the second OR the third is the same as the first AND the second OR the first AND the third. (A AND (B OR C) = (A AND B) OR (A AND C)) Also, the first OR the result of second AND the third is the same as the first OR the second AND the result of the first OR the third. (A OR (B AND C) = (A OR B) AND (A OR C))

Identity: The identity property says that any value A AND the OR identity always returns A and that any value A OR the AND identity always returns A. (A AND 1 = A; A OR 0 = A)

Compliment: The compliment property says that any value AND the compliment of that value equals the OR identity and that any value OR the compliment of that value equals the OR identity. (A AND (A') = 0; A OR (A') = 1)

DeMorgan's law: DeMorgan's law says that the compliment of A AND B is the same as the compliment of A OR the compliment of B and the compliment of A OR B is the same as the compliment of B AND the compliment of A. ((A AND B)' = A' OR B'; (A OR B)' = A' AND B')

65. Differentiate between a half adder and a full adder.
A half adder is a circuit that computes the sum of two bits and produces the appropriate carry bit. A full adder is a circuit that computes the sum of two bits, taking into account the carry bit.

66. What is the Boolean expression for a full adder?
C is the carry in.
Sum is (A ⊕ B) ⊕ C
Carry out is (A AND B) OR ((A ⊕ B) AND C)

67. What is a multiplexer?
A multiplexer is a circuit that uses input control signals to determine which of several data input lines is to be routed to the output.

68. A. Circuits used for memory are what type of circuits?
Memory circuits are sequential circuits because they are dependent on the existing state of the circuit as well as input to the circuit.

   B. How many digits does an S-R latch store?
One binary digit

   C. The design for an S-R latch shown in Figure 4.12 guarantees what about the outputs X and Y?
The values of X and Y are always compliments.

69. What is an integrated circuit or chip?

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An integrated circuit or chip is a piece of silicon into which many gates have been embedded.

70. Define the abbreviations SSI, MSI, LSI, and VLSI.
Each of these abbreviations refers to the number of gates contained in an integrated circuit.

SSI (Small-scale integration): Contains 1 to 10 gates.

MSI (Medium-scale integration): Contains 10 to 100 gates.

LSI (Large-scale integration): Contains 100 to 100,000 gates.

VLSI (Very-large-scale integration): Contains more than 100,000 gates.

71. In the chip shown in Figure 4.13, what are the pins sued for?
Eight are used for inputs to gates, four for outputs from the gates, one for ground, and one for power.

72. Draw a circuit using two full adders that adds two two-bit binary values. Show its corresponding truth table.
A circuit using two full adders that adds two two-bit binary numbers of the form:

```
    A B
  + C D
  ---------
    X Y Z
```
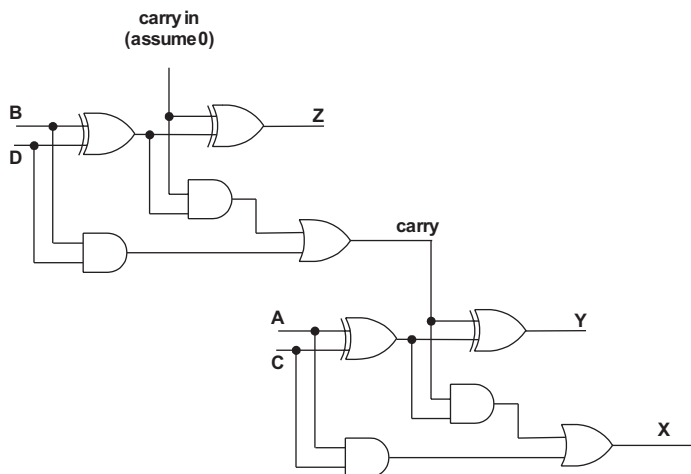

A	B	C	D	X	Y	Z
0	0	0	0	0	0	0
0	0	0	1	0	0	1
0	0	1	0	0	1	0
0	0	1	1	0	1	1
0	1	0	0	0	0	1
0	1	0	1	0	1	0
0	1	1	0	0	1	1
0	1	1	1	1	0	0
1	0	0	0	0	1	0
1	0	0	1	0	1	1
1	0	1	0	1	0	0
1	0	1	1	1	0	1
1	1	0	0	0	1	1
1	1	0	1	1	0	0
1	1	1	0	1	0	1
1	1	1	1	1	1	0

73. How can the XOR operation be expressed using other operators?
(A OR B) AND (NOT (A AND B))