Q 1. In an n-type silicon, which of the following statement is true:

(a) Electrons are majority carriers and trivalent atoms are the dopants.

(b) Electrons are minority carriers and pentavalent atoms are the dopants.

(c) Holes are minority carriers and pentavalent atoms are the dopants.

(d) Holes are majority carriers and trivalent atoms are the dopants.

Solution:

Here, (c) is the correct option.

For n-type silicon, the majority carriers are electrons while the minority carriers are holes. An n-type semiconductor is obtained by dropping pentavalent atoms like phosphorus in silicon atoms.

Q2. Which of the statements given in Exercise 14.1 is true for p-type semiconductors?

Solution:

Here, (d) is the correct explanation.

For p-type semiconductor, holes are the majority carriers while electrons are the minority carriers. p-type semiconductor is obtained by using trivalent atoms like aluminium in silicon atoms.

Q 3. Carbon, silicon and germanium have four valence electrons each. These are characterised by valence and conduction bands separate by energy band gap respectively equal to $(E_g)_{Si}$, $(E_g)_c$ and $(E_g)_{Ge}$. Which of the following statements is true?.

(a) $(E_g)_{Si} < (E_g)_{Ge} < (E_g)_C$

(b) $(E_g)_C < (E_g)_{Ge} > (E_g)_{Si}$

(c) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$

(d) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

Solution:

(C) is the correct option.

Out of carbon, germanium, and silicon, carbon has the maximum energy bandgap whereas germanium has the least energy bandgap.

For all these elements the energy band gap can be related as: $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$

Q 4. In an unbiased p – n junction, holes diffuse to n – region from p – region because

(a) free electrons in the n-region attract them.

(b) they move across the junction by the potential difference.

(c) hole concentration in p-region is more as compared to n-region.

(d) All of the above.

Solution:

(c) is the correct option.

The usual tendency of the charge carriers is to disperse towards the lower concentration region from the higher concentration region. So it can be said that in an unbiased p-n junction, holes disperse from p-region to the n-region as the p-region has a greater concentration of holes than in n-region.

Q 5. When a forward bias is applied to a p-n junction, it

(a) raises the potential barrier.

(b) reduces the majority carrier current to zero.

(c) potential barrier is reduced.

(d) None of the above.

Solution:

(c) is the correct option

The potential barrier reduces for a p-n junction when a forward bias is applied.

In the above case, the potential barrier across the junction reduces as the applied voltage is opposed by the potential barrier.

Q 6. In half-wave rectification, what is the output frequency if the input frequency is 50 Hz. What is the output frequency of a full-wave rectifier for the same input frequency?

Solution:

For a half-wave rectifier, the output frequency is equal to the input frequency, in this case, the input frequency of the half-wave rectifier is 50 Hz.

On the other hand, the output frequency for a full-wave rectifier is twice the input frequency. Therefore, the output frequency is 2 × 50 = 100 Hz.

Q 7. A p-n photodiode is fabricated from a semiconductor with a bandgap of 2.8 eV. Can it detect a wavelength of 6000 nm?

Solution:

No, the photodiode cannot detect the wavelength of 6000 nm because of the following reason:

The energy bandgap of the given photodiode, E_g = 2.8 eV

The wavelength is given by λ = 6000 nm = 6000 × 10^{-9} m

We can find the energy of the signal from the following relation:

E = hc/λ

In the equation, h is the Planck's constant = 6.626 × 10^{-34} J and c is the speed of light = 3 × 10^8 m/s.

Substituting the values in the equation, we get

E = (6.626 x 10^{-34} x 3 x 10^8) / 6000 x 10^{-9} = 3.313 x 10^{-20} J

But, 1.6 × 10^{-19} J = 1 eV

Therefore, E = 3.313 × 10^{-20} J = 3.313 x 10^{-20} / 1.6 x 10^{-19} = 0.207 eV

The energy of a signal of wavelength 6000 nm is 0.207 eV, which is less than 2.8 eV − the energy band gap of a photodiode. Hence, the photodiode cannot detect the signal.

Q 8. The number of silicon atoms per m^3 is 5 × 10^{28}. This is doped simultaneously with 5 × 10^{22} atoms per m^3 of Arsenic and 5 × 10^{20} per m^3 atoms of Indium. Calculate the number of electrons and holes.

Solution:

Following values are given in the question:

Number of silicon atoms, N = 5 × 10 ^{28} atoms/m^3

Number of arsenic atoms, n_{AS} =5×10^{22}atoms/m^3

Number of indium atoms, n_{In}=5×10^{22}atoms/m^3

n_i=1.5×10^{16}electrons/m^3

n_e=5×10^{22}−1.5×10^{16}=4.99×10^{22}

Let us consider the number of holes to be n_h

In the thermal equilibrium, $n_e n_h$ = n_i^2

Calculating, we get

n_h=4.51×10^9

Here, $n_e > n_h$, therefore the material is a n-type semiconductor.

Q 9: In an intrinsic semiconductor the energy gap E_g is 1.2eV. Its hole mobility is much smaller than electron mobility and independent of temperature. What is the ratio between conductivity at 600K and that at 300K? Assume that the temperature dependence of intrinsic carrier concentration n_i is given by

$$n_i = n_0 exp\left[-\frac{E_g}{2k_B T}\right]$$

where, n_0 is constant.

Solution:

Energy gap in an intrinsic semiconductor, E_g = 1.2 eV

The temperature dependence of the intrinsic carrier-concentration is given as

$$n_i = n_0 exp\left[-\frac{E_g}{2k_B T}\right]$$

Here, k_B is the Boltzmann constant = 8.62 x 10^{-5} eV/K

T is the temperature

n_0 is a constant

Initial temperature, T_1 = 300 K

The intrinsic carrier concentration at the temperature 300 K can be written as

$$n_{i1} = n_0 exp\left[-\frac{E_g}{2k_B \times 300}\right] \quad --(1)$$

Final temperature, T_2 = 600 K

The intrinsic carrier concentration at the temperature 600 K can be written as

$$n_{i2} = n_0 exp\left[-\frac{E_g}{2k_B \times 600}\right] \quad --(2)$$

The ratio between conductivity at 600K and that at 300K is equal to the ratio between the respective carrier concentration at these temperatures.

$$\frac{n_{i2}}{n_{i1}} = \frac{n_0 exp\left[-\frac{E_g}{2k_B \times 600}\right]}{n_0 exp\left[-\frac{E_g}{2k_B \times 300}\right]}$$

$$= exp\frac{E_g}{2k_B}\left[\frac{1}{300} - \frac{1}{600}\right]$$

$$= exp\frac{1.2}{2 \times 8.62 \times 10^{-5}}\left[\frac{1}{300} - \frac{1}{600}\right]$$

$$= exp\frac{1.2}{17.24 \times 10^{-5}}\left[\frac{2-1}{600}\right]$$

= exp (11.6) = 1.09 x 10^5

There the ratio between the conductivities is 1.09 x 10^5.

Q 10. In a p-n junction diode, the current I can be expressed as

$$I = I_0 exp\left(\frac{eV}{2k_BT} - 1\right)$$

where I_0 is called the reverse saturation current, V is the voltage across the diode and is positive for forward bias and negative for reverse bias, and I is the current through the diode, k_B is the Boltzmann constant (8.6×10^{-5} eV/K) and T is the absolute temperature. If for a given diode $I_0 = 5 \times 10^{-12}$ A and T = 300 K, then
(a) What will be the forward current at a forward voltage of 0.6 V?
(b) What will be the increase in the current if the voltage across the diode is increased to 0.7 V?
(c) What is the dynamic resistance?
(d) What will be the current if reverse bias voltage changes from 1 V to 2 V?

Solution:

In a p-n junction diode, the expression for current is given as

$$I = I_0 exp\left(\frac{eV}{2k_BT} - 1\right)$$

Here, $I_0 = 5 \times 10^{-12}$ A

T = 300 K

k_B is the Boltzmann constant = 8.6×10^{-5} eV/k = $8.6 \times 10^{-5} \times 1.6 \times 10^{-19}$ = 1.376×10^{-23} J/K

(a) Forward voltage, V = 0.6 V

$$I = 5 \times 10^{-12} exp\left(\frac{1.6 \times 10^{-19} \times 0.6}{2 \times 1.376 \times 10^{-23} \times 300} - 1\right)$$

$$I = 5 \times 10^{-12} exp(22.36)$$

= 0.0256 A

(b) Voltage across the diode is increased to 0.7 V

$$I' = 5 \times 10^{-12} exp\left(\frac{1.6 \times 10^{-19} \times 0.7}{2 \times 1.376 \times 10^{-23} \times 300} - 1\right)$$

$$I' = 5 \times 10^{-12} exp(26.25)$$

I' = 1.257 A

Change in current, $\Delta I = I' - I$

= 1.257 − 0.0256

= 1.23 A

Change is voltage = 0.7 − 0.6 = 0.1 V

(c) Dynamic resistance = Change in voltage/ Change in current
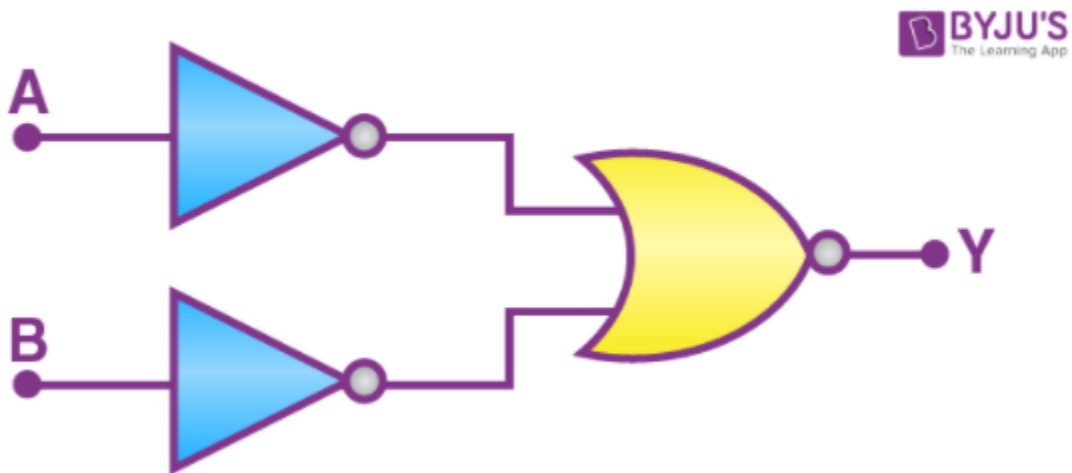
= 0.1/1.23

= 0.081 Ω

(d) If the reverse bias voltage changes from 1 V to 2 V, the current will almost remain equal to I_0 in both cases. Therefore, the dynamic resistance in the reverse bias will be infinite.

Q 11. You are given the two circuits as shown in Fig. 14.36. Show that circuit (a) acts as OR gate while the circuit (b) acts as AND gate.
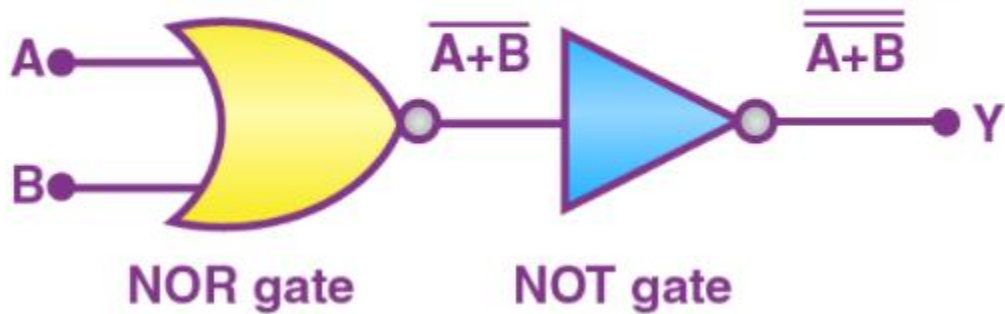
a)
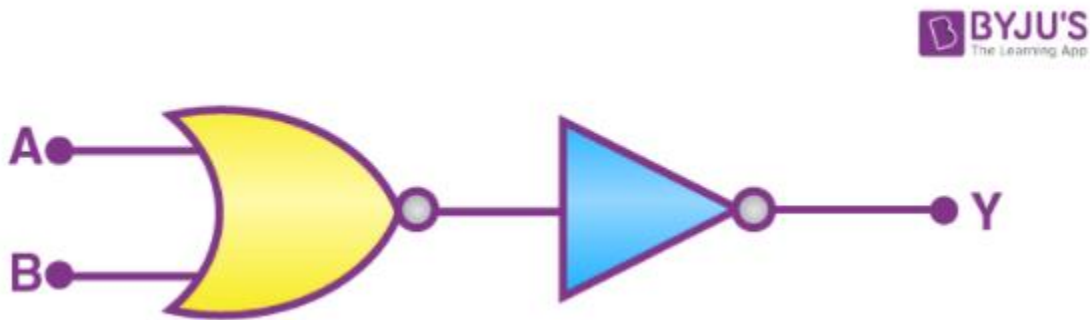
b)

Solution:

(a) Input for the circuit : A and B

Output for the circuit: Y

Here, the left half of the circuits works as the NOR gate, while if we look at the right half of the circuit then it is a NOT gate.

We can show it in the figure as:

Now, the output for the NOR gate = $\overline{A+B}$

We are giving the output from NOR gate to the input at NOT gate. So, its output will be: $\overline{\overline{A+B}}$ = A + B
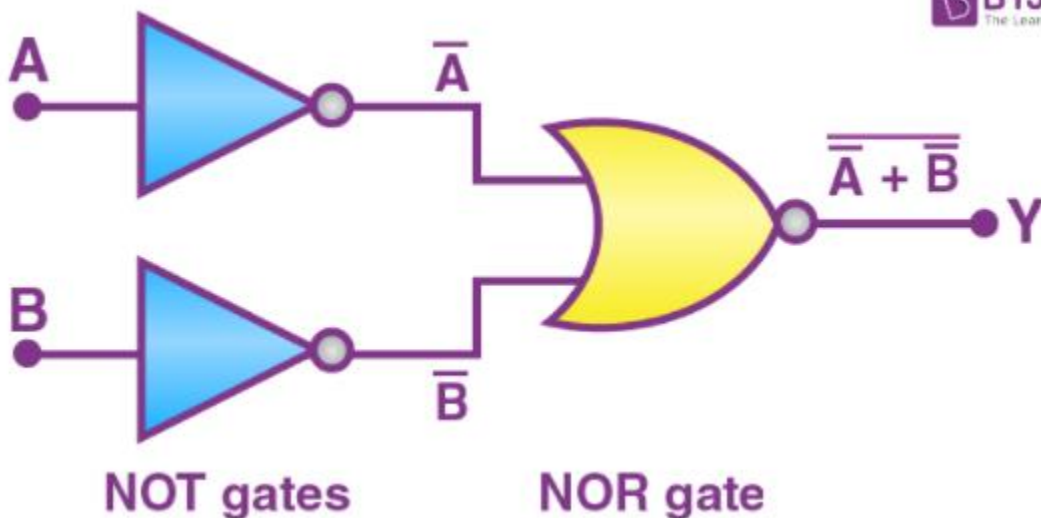
$$\therefore Y = A + B$$

Hence, this circuit functions as an OR Gate.

(b) Input for the circuit : A and B

Output for the circuit: Y

We can observe from the figure that the output from first half of the circuits goes to the input of the next half which is working as NOR gate.
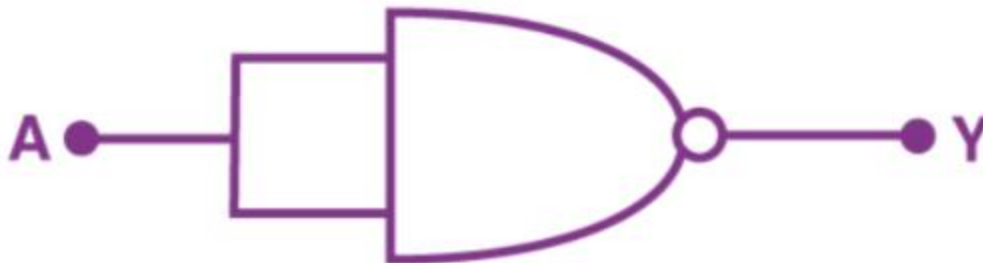

Hence, the output of the given circuit can be written as:

$$Y = \overline{\bar{A}+\bar{B}} = \bar{\bar{A}}.\bar{\bar{B}} = A.B$$
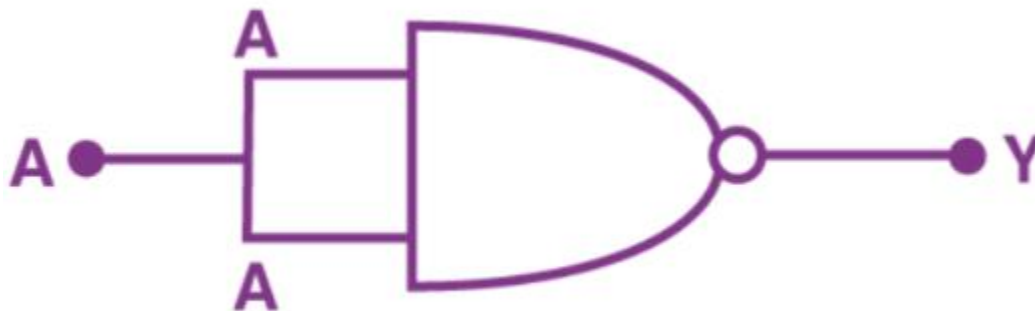
Hence, this circuit functions as an AND gate.

Q 12. Write the truth table for a NAND gate connected as given in Fig. 14.37

Hence identify the exact logic operation carried out by this circuit.

Solution:

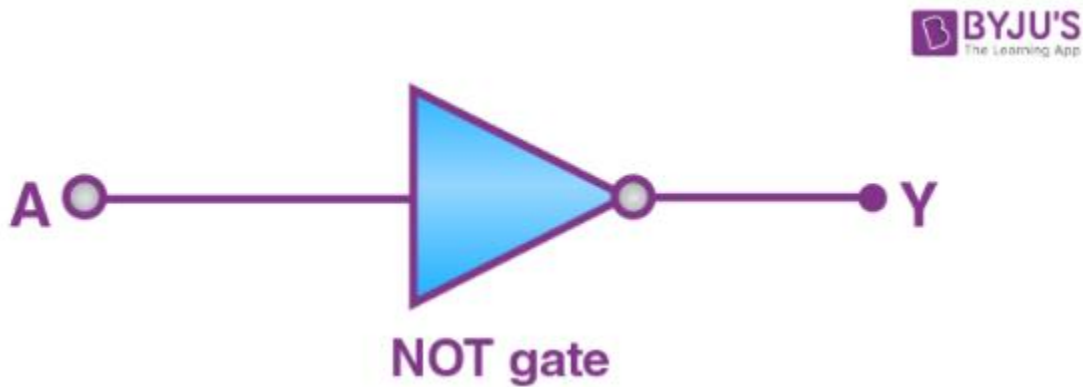From the figure, we know A is the input and we are getting an output B.

NAND gate

Hence, the output can be written as:
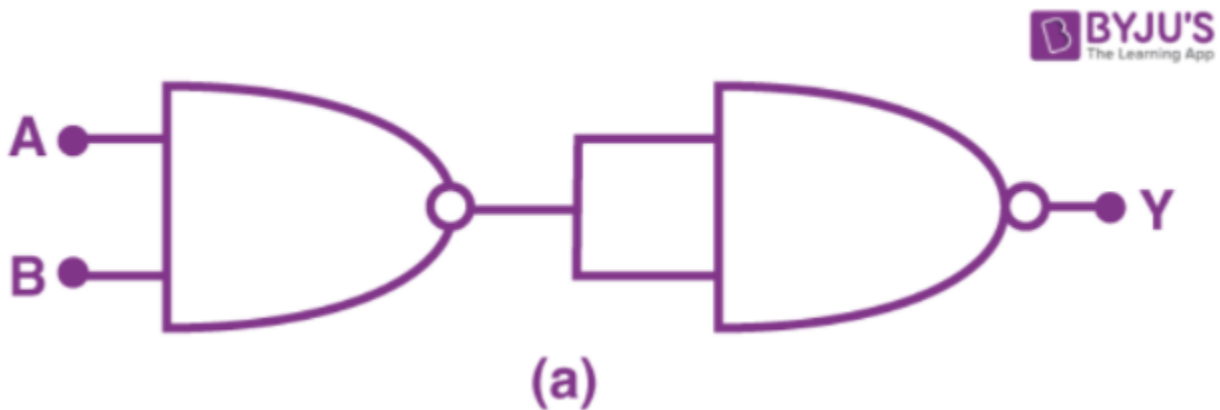
$$Y = \overline{A.A} = \bar{A} + \bar{A} = \bar{A}$$
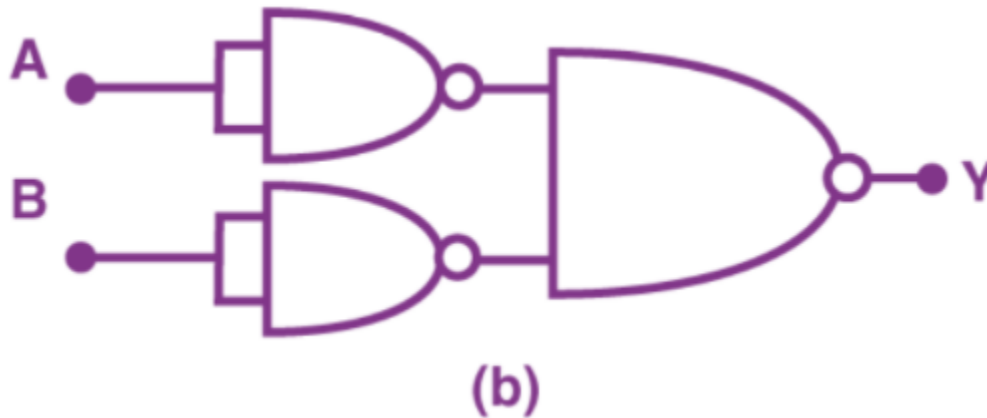
We can make the truth table for equation (1) as:

A	Y= $\bar{A}$
0	1
1	0

Below is the symbol of the NOT gate:

Q 13. You are given two circuits as shown in Figure, which consists of NAND gates. Identify the logic operation carried out by the two circuits.

(a)

(b)

Solution:

(a) The Boolean expression for NAND gate is $Y = \overline{AB}$

Let Y' be the output of the NAND gate.

Therefore, Final output of the combination, $Y = \overline{Y'.Y'}$

$Y = \overline{\overline{A.B} \cdot \overline{A.B}}$

$Y = \overline{\overline{A.B}} + \overline{\overline{A.B}}$

Y = A.B

The given circuit acts as an AND gate.

(b) Boolean expression for NOT gate is $Y = \bar{A}$

The output Y_1 of the first NOT gate is $Y_1 = \bar{A}$

The output Y_2 of the second NOT gate is $Y_2 = \bar{B}$

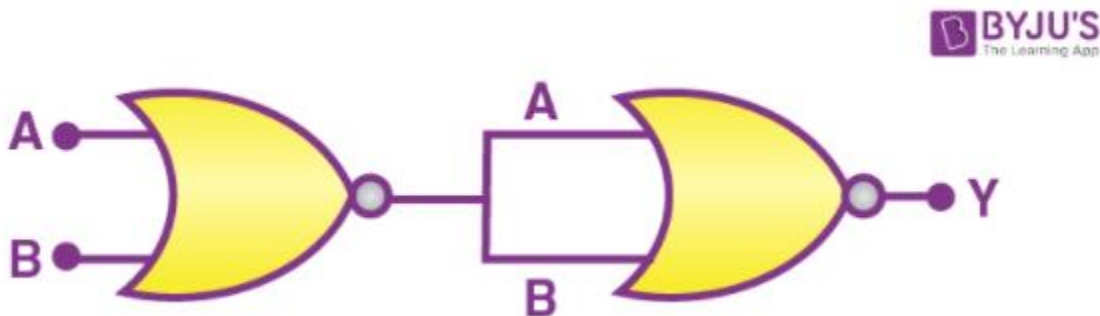The output of the combination

$Y = \overline{Y_1.Y_2}$

$Y = \overline{\bar{A}.\bar{B}}$

$Y = \bar{\bar{A}} + \bar{\bar{B}}$

Y = A + B

This is the Boolean expression for OR gate.

Q 14. Write the truth table for circuit given in Fig. 14.39 below consisting of NOR gates and identify the logic operation (OR, AND, NOT) which this circuit is performing


(Hint: A = 0, B = 1 then A and B inputs of second NOR gate will be 0 and hence Y=1. Similarly, work out the values of Y for other combinations of A and B. Compare with the truth table of OR, AND, NOT gates and find the correct one.)

Solution:

Input for the circuit: A and B

Output from the first circuit (i.e NOR gate) is $\overline{A+B}$.

From the figure, we can observe that the input for the second gate is automatically the output from that first one.
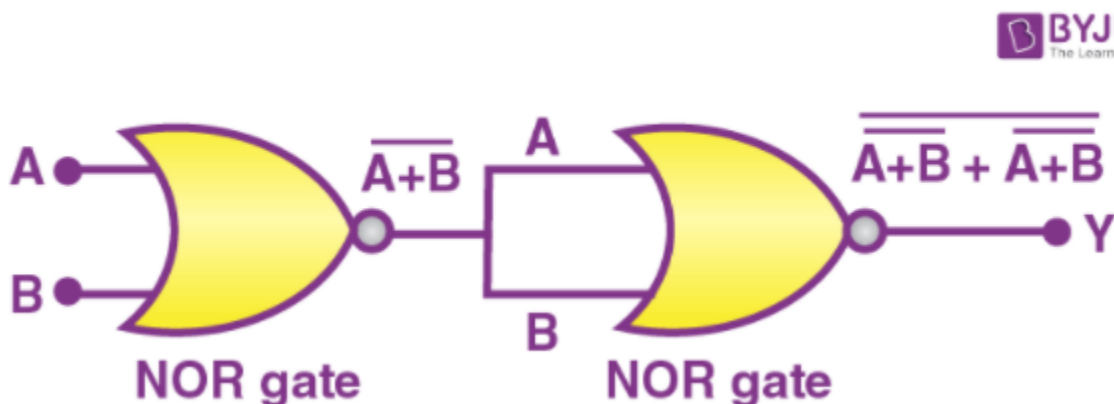
Therefore, the output obtained from this combination is given as:

$$Y = \overline{\overline{A+B}+\overline{A+B}} = \overline{\overline{A}.\overline{B}+\overline{A}.\overline{B}}$$

$$= \overline{\overline{A}.\overline{B}} = \overline{\overline{A}}+\overline{\overline{B}} = A+B$$

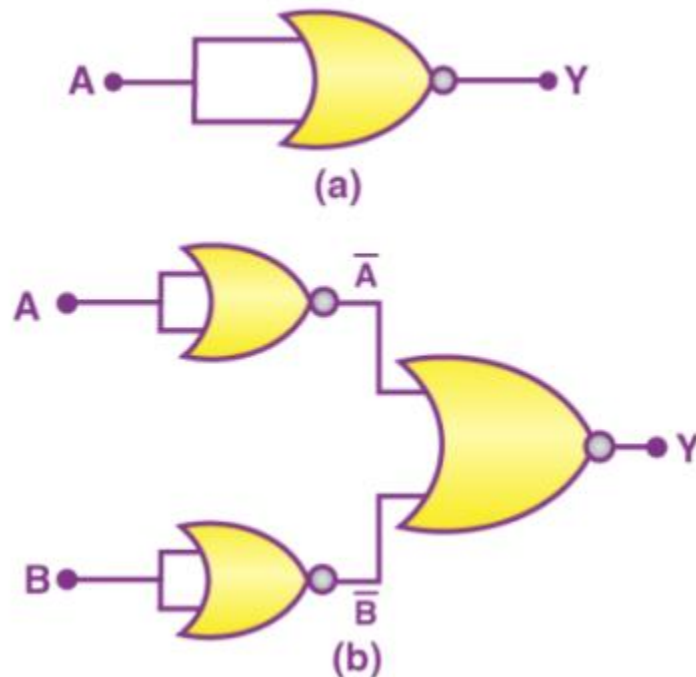Following is the truth table for the given operation:

A	B	Y (= A + B)
0	0	0
0	1	1
1	0	1
1	1	1

This is the truth table of an OR gate.

Therefore, this circuit functions as an OR gate.

Q 15. Write the truth table for the circuits given in Figure consisting of NOR gates only. Identify the logic operations (OR, AND, NOT) performed by the two circuits.

(a)

(b)

Solution:

In figure (a) A acts as the two inputs of the NOR gate and Y is the output. Hence, the output of the circuit is

$$\overline{A + A}$$

So, the output $Y = \overline{A}$

Therefore, the gate is a NOT gate.

The truth table is given as

A	$Y = \overline{A}$
0	1
1	0

(b) In figure (b), A and B are the inputs and Y is the output of the given circuit. By using the result obtained in

solution (a), we can infer that the outputs of the first two NOR gates are $\overline{A}$ and $\overline{B}$. This is the input of the NOR

gate. Therefore, the output of the circuit is $\mathbf{Y} = \overline{\overline{A} + \overline{B}} = \mathbf{A.B}$. So, this acts as an AND gate. The truth

table is given below

A	B	Y= A.B
0	0	0
0	1	0
1	0	0
1	1	1