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.

Ans:

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 semiconductos.

Ans:

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 is obtained by using trivalent atoms like aluminum 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) $(E_g)_C < (E_g)_{Si} < (E_g)_{Ge}$

Ans:

(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.

Ans:

(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 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.

(b) reduces the majority carrier current to zero.

(c) potential barrier is reduced.

(d) None of the above.

Ans:

(c) is the correct option

The potential barrier reduces for a p-n junction when 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.

Ans:

For a half-wave rectifier, the output frequency is equal to the input frequency, in this case, the output 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 $2 \times 50 = 100$ 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?

Ans:

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 $\lambda = 6000 \text{ nm} = 6000 \times 10^{-9}$ m

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

$E = hc/\lambda$

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

Substituting the values in the equation, we get

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

But, 1.6×10^{-19} J = 1 eV

Therefore, $E = 3.313 \times 10^{-20} \text{ J} = 3.313 \times 10^{-20} / 1.6 \times 10^{-19} = 0.207$ 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.

Given that $n_i = 1.5 \times 10^{16} m^{-3}$. Is the material n-type or p-type?

Ans:

Following values are given in the question:

Number of silicon atoms, $N = 5 \times 10^{28}$ atom/m^3

Number of arsenic atoms, $n_{AS} = 5 \times 10^{22}$atom/$m^3$

Number of indium atoms, $n_{IN} = 5 \times 10^{22}$atom/$m^3$

$n_i = 1.5 \times 10^{16}$electron/m^3

$n_e = 5 \times 10^{22} - 1.5 \times 10^{6} = 4.99 \times 10^{22}$

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

$n_h = 4.51 \times 10^9$

Here, $n_e > n_H$, therefore the material is an n-type semiconductor.

Q 9 . Find the input signal voltage and base current for a CE – transistor amplifier, the voltage of audio signal across the collector resistance of $2k\Omega$ is 2 V. Assume that the transistor have current amplification factor equals to 100 and the given base resistance is

$1k\Omega$

Ans:

Collector resistance, $R_C = 2k\Omega = 2000\Omega$

Voltage of audio signal across the collector resistance, V = 2V

Current amplification factor of the transistor, $\beta = 100$

Base resistance, $R_B = 1k\Omega = 1000\Omega$

Input Signal = V_i

Base current = I_B

We have amplification relation as:

$$\frac{V}{V_i} = \beta \frac{R_C}{R_B}$$

Voltage amplification

$$V_i = \frac{V}{\beta} \frac{R_B}{R_C} = \frac{2 \times 1000}{100 \times 2000} = 0.01V$$

Therefore, the input signal voltage of the amplifier is 0.01 V.

Below is the relation of base resistance:

$$R_B = \frac{V_i}{I_B}$$

$$= \frac{0.01}{1000} = 10^{-6} \times 10\mu A$$

Therefore, the base current of the amplifier is 10 A.

Q 10. Calculate the output ac signal, if two amplifiers are connected in series one after another (cascaded). Where the voltage gain for first amplifier is 20 and for the second it is 40. And the input signal is provided for 0.01 volt, calculate the output ac signal.

Ans:

Voltage gain, V_1 for first amplifier = 20

Voltage gain, V_2 for second amplifier = 40

Input signal voltage, V_i = 0.01V

Output voltage of AC signal = V_0

By multiplying the voltage gains of each stage, we can calculate the total voltage gain of the two stage cascade amplifier

$$V = V_1 \times V_2$$

= 20 × 40

= 800

We know that:

$$V = \frac{V_o}{V_i}$$

$$V_o = V \times V_i$$

= 800 × 0.01 = 8 V

Therefore, the output AC signal is 8V.

Q 11.Is it possible for a p – n photodiode to detect a wavelength of 5000 nm, if it is fabricated from a semiconductor with a band gap of 3.2 eV?

Ans:

Energy band gap for the photodiode = $E_g = 3.2\, eV$

Wavelength, λ = 5000 nm = $5000 \times 10^{-9} m$

We know from the relation of energy:

$$E = \frac{hc}{\lambda}$$

Where, h = Planck's constant = $6.626 \times 10^{-34}\, Js$

C = Speed of light

= $3 \times 10^{8}\, m/sec \therefore E = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{5000 \times 10^{-9}}$

$3.975 \times 10^{-20} J$

But $1.6 \times 10^{-19} J = 1\, eV \therefore E = 3.975 \times 10^{-20} j$

$= \frac{3.975 \times 10^{-20}}{1.6 \times 10^{-19}} = 0.248\, eV$

Therefore, the energy of a signal of wavelength 5000nm is 0.248eV which is less than the energy band gap of the photodiode. Hence, the detection of the signal by the photodiode is not possible.

Additional Exercises

Q 12. We have $5 \times 10^{28}\, per\, m^3$ silicon atoms with us. Which is doped with $5 \times 10^{22}\, per\, m^3$ of Indium and $5 \times 10^{20}\, per\, m^3$ of Arsenic simultaneously. Find out the total number of holes and the electrons. We are given, $n_i = 1.5 \times 10^{16}\, m^{-3}$. Also find if the material n – type or p – type?

Ans:

No.of Atoms (Silicon), N = $5 \times 10^{28}\, atoms/m^3$

No.of Atoms (Arsenic), $n_{As} = 5 \times 10^{28}\, atoms/m^3$

No.of Atoms (indium), $n_{In} = 5 \times 10^{20}\, atoms/m^3$

No.of thermally generated electrons, $n_i = 1.5 \times 10^{16}\, electrons/m^3$

No.of electrons, $n_e = 5 \times 10^{22} - 1.5 \times 10^{16} \approx 4.99 \times 10^{22}$

No.of holes = n_h

In the case of thermal equilibrium, the concentration of electrons and holes in a semiconductor are related as: $n_e n_h = n_i^2$

$$\therefore n_h = \frac{n_i^2}{n_e}$$

$$= \frac{\left(1.5\times10^{16}\right)^2}{4.99\times10^{22}} \approx 4.51 \times 10^9$$

Therefore, there are approximately 4.99×10^{22} and holes are around 4.51×10^9 . Since the number of electrons here is more than that of the holes. So, the material we have is an n – type semiconductor.

Q 13. Calculate the ratio between conductivity at 600 k and that at 300 k when an intrinsic semiconductor having energy gap E_g eV.

Whose whole is much smaller than electron mobility and independent of temperature. Assume that the temperature dependence of intrinsic carrier concentration is given by

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

Where n_0 is a constant.

Ans: Energy gap of the given intrinsic semiconductor, $E_g = 1.2\ eV$

We can write the temperature dependence intrinsic carrier – concentration:

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

Where k_B = Boltzmann constant = $8.62 \times 10^{-5} eV/K$

T = temperature

n_0 = Constant

Initial temperature, T_1 = 300 K

We can write the intrinsic – concentration at this temperature as:

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

Final temperature, T_2 = 600 K

We can write the intrinsic – concentration at this temperature as:

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

The ratio between the conductivity at 600 K and at 300 K is equal to the ratio between the respective intrinsic carrier-concentrations at these temperatures.

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

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

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

$$= exp\,[11.6] = 1.09\times\ 10^{5}$$

Therefore, the ratio between the conductivity is $1.09\times\ 10^{5}$.

Q 14. The current I for a p – n junction diode 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 ($8.62\times\ 10^{-5}eV/K$) and T is the absolute temperature. It is 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 increasedto 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?

Ans:

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

$I = I_0\, exp\left(\frac{eV}{2K_BT} - 1\right)$ I_0 = Reverse saturation current = $5\times\ 10^{-12}$ k_B = Boltzmann constant = $8.62\times\ 10^{-5}eV/K$ = $1.376\times\ 10^{-23}JK^{-1}$

V = Voltage across the diode.

(a) Forward voltage, V = 0.6 V

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

$$= 5\times\ 10^{-12}\times\ esp\,[22.36] = 0.0256\ A$$

Therefore, the forward current is about 0.0256 A.

(b) For forward voltage, V = 0.7 V, we can write:

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

$$= 5\times\ 10^{-12}\times\ exp\,[26.25] = 1.257\ A$$

Hence, the increase in current, $\Delta I = I' - I$

= 1.257 – 0.0256 = 1.23 A

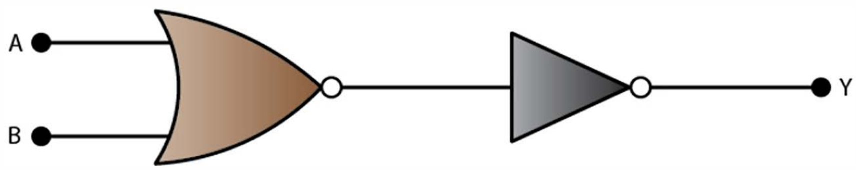
(c) Dynamic Resistance = $\frac{Change\ \ in\ \ voltage}{Change\ \ in\ \ current}$

$$= \frac{0.7-0.6}{1.23} = \frac{0.1}{1.23} = 0.081\Omega$$

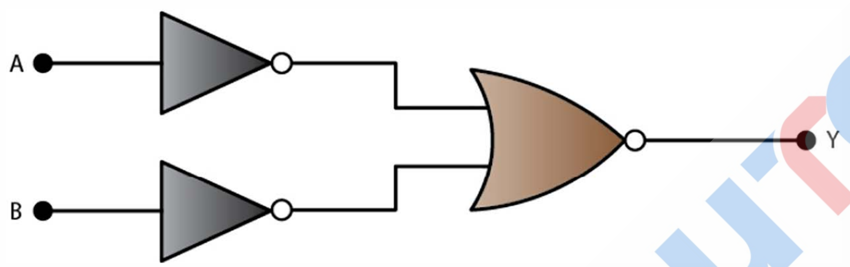
(d) If the reverse bias voltage changes from 1 V to 2 V, then the current (I) will almost remain equal to I_0 in both cases. Therefore, the dynamic resistance in the reverse bias will be infinite.

Q 15. From the provided two circuits, show that circuit (a) and circuit (b) acts as OR gate and AND gate respectively.

a)



b)



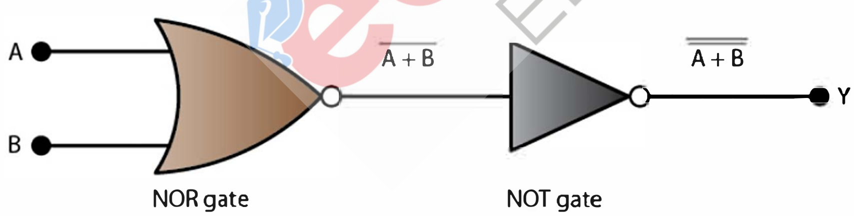
Ans:

(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 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

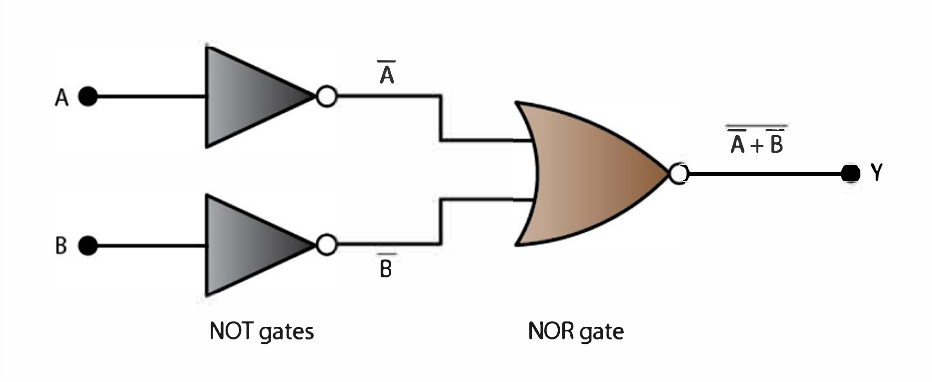
$\therefore\ Y = A + B$

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.

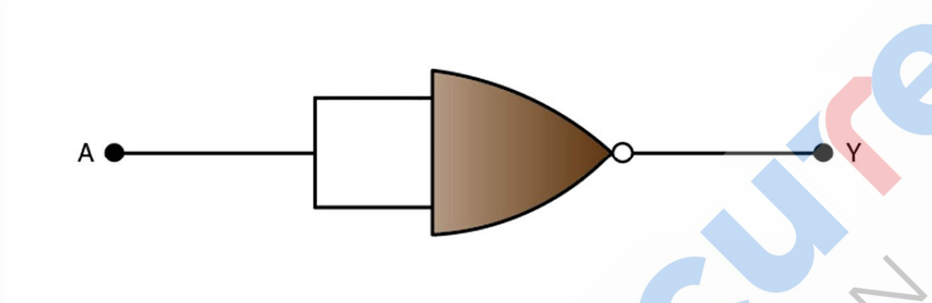


Hence, the output of the given circuit can be written as:

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

Hence, this circuit functions as an AND gate.

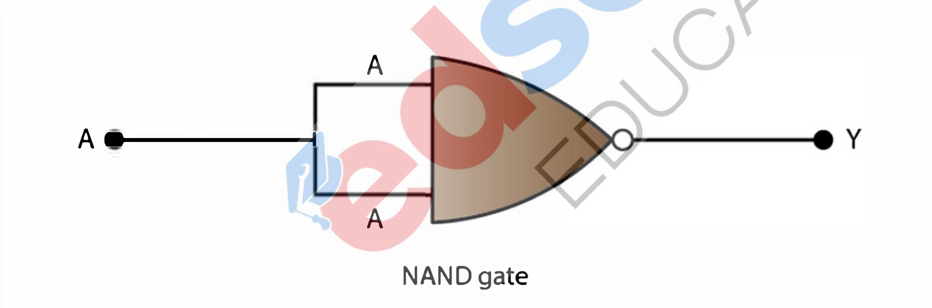
Q 16. Write the truth table for a NAND gate connected as shown in the figure.



And then find out the exact login operation carried out by the given circuit.

Ans:

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



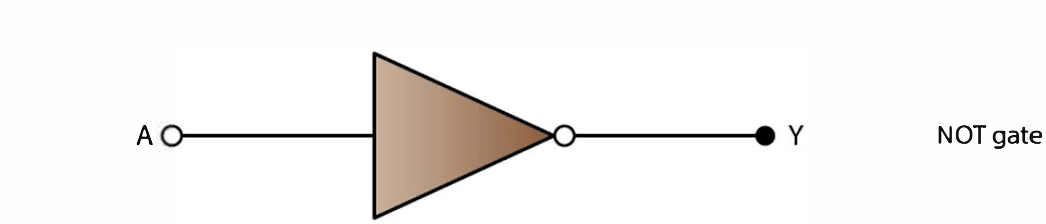
Hence, the output can be written as:

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

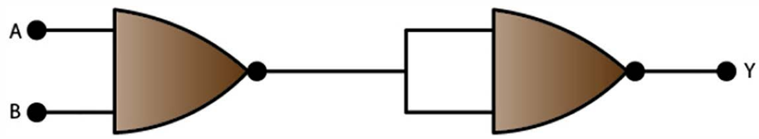
We can make the truth table for eq(1) as:

A	Y
0	1
1	0

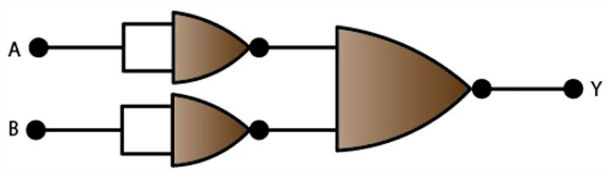
Below is the symbol of the NOT gate:



Q 17. You have two circuits consisting NAND gates arranged to perform different logical operations. Identify the logical operation carried by the two circuits (Shown in figure).



(a)



(b)

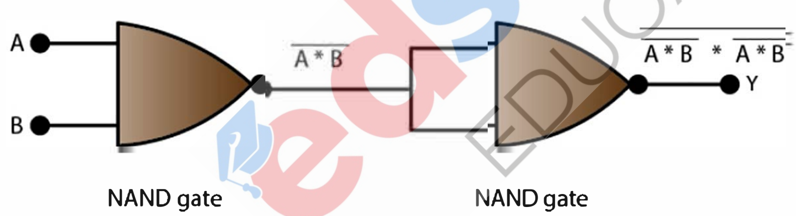
Ans:

In the given circuits,

Inputs: A and B

Output: Y

(a) Following is the circuit which shows that the output of the left NAND gate will be $\overline{A.B}$

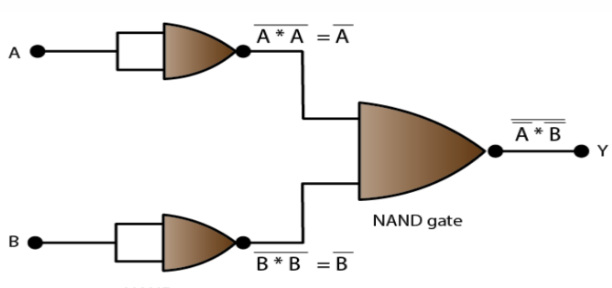


Therefore, the output for these two NAND gate is given as:

$$Y = \overline{(\overline{A.B}).(\overline{A.B})} = \overline{\overline{AB}} + \overline{\overline{AB}} = AB$$

Therefore, this circuit works as an NAND gate.

(b) $\bar{A}$ is the output of the upper left of the NAND gate and $\bar{B}$ is the output of the lower half of the NAND gate, as shown in the following figure.



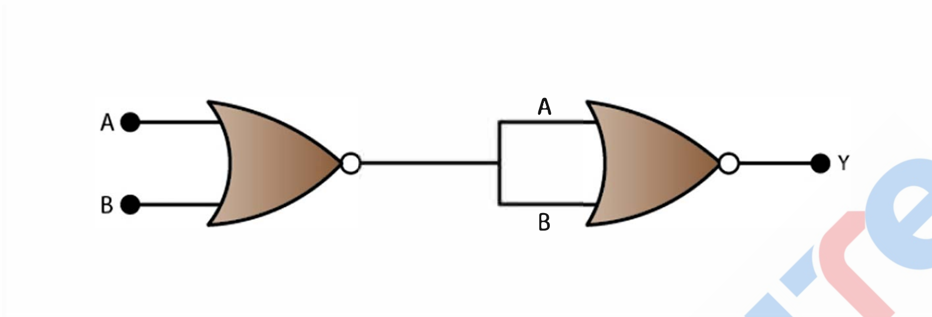
Hence, the output from this combination of NAND gates can be shown as:

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

Therefore, we can say that this circuit is working as an OR gate.

Q 18. Draw the truth table for the circuit having NOR gates and find out the logic operation (OR, AND, NOT) which is formed by this circuit.

(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 thetruth table of OR, AND, NOT gates and find the correct one.)

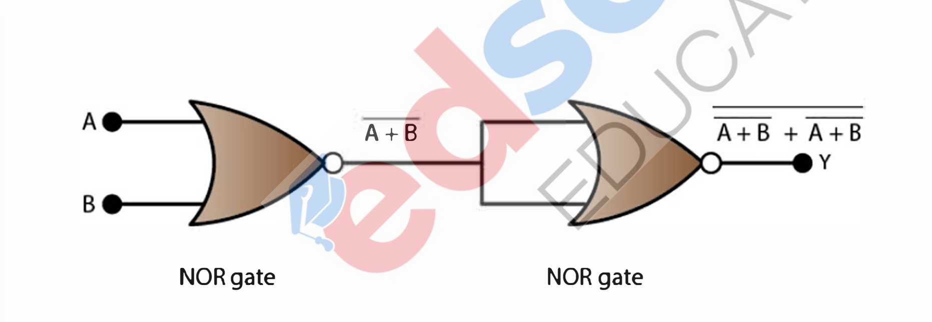


Ans

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:

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

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

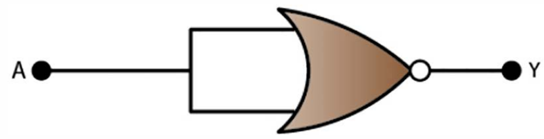
Following is the truth table for the given operation:

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

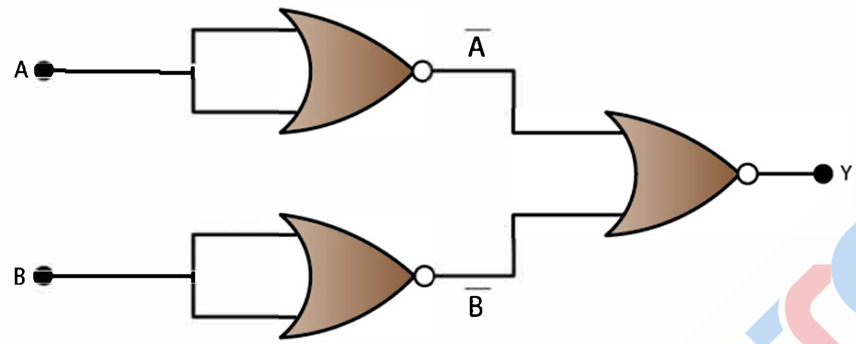
This is the truth table of an OR gate.

Therefore, this circuit functions as an OR gate.

Q 19. Find out the truth table forming by combining the OR gates only. (as shown in the following figure). Identify the logic operation (OR, AND, NOT) performed by the two circuits



(a)

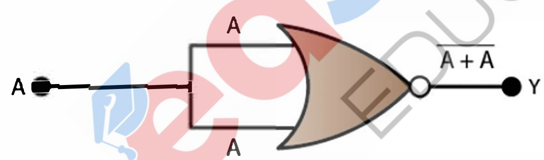


(b)

Ans:

(a) Here, A is acting as both the outputs for the NOR gate and Y is the output, as shown in the following figure.

So, the output of the circuit is $\overline{A + A}$.



NOR gate

Output, Y = $\overline{A + A} = \bar{A}$

The truth table for the circuit is given as:

A	Y($\bar{A}$)
0	1
1	0

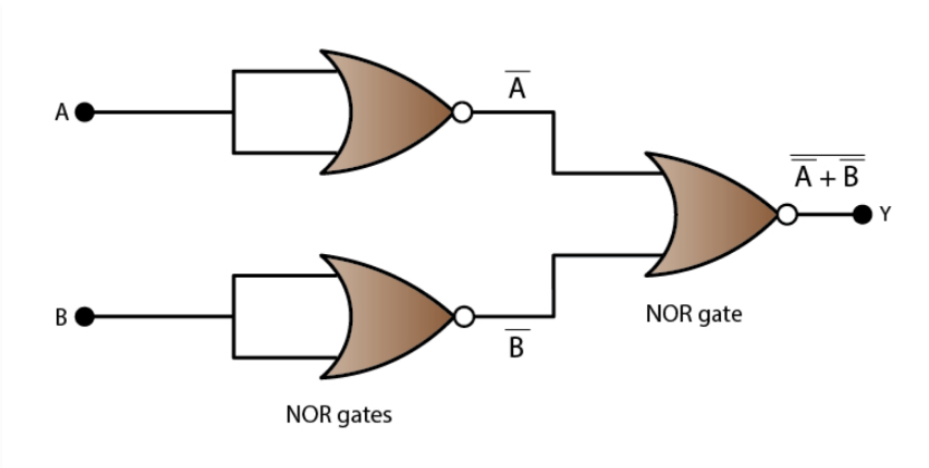
Here, we obtain the truth table for a NOT gate. Hence, the circuits works as a NOT gate.

(b) For the given circuit,

Inputs: A and B

Output: Y

From the solution obtained from (a) we conclude that the output for the first two NOR gates are $\bar{A}\ and\ \bar{B}$



$\bar{A}$ *and* $\bar{B}$ are the inputs for the last NOR gate. Therefore, below is the table that has the output for the given circuit:

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