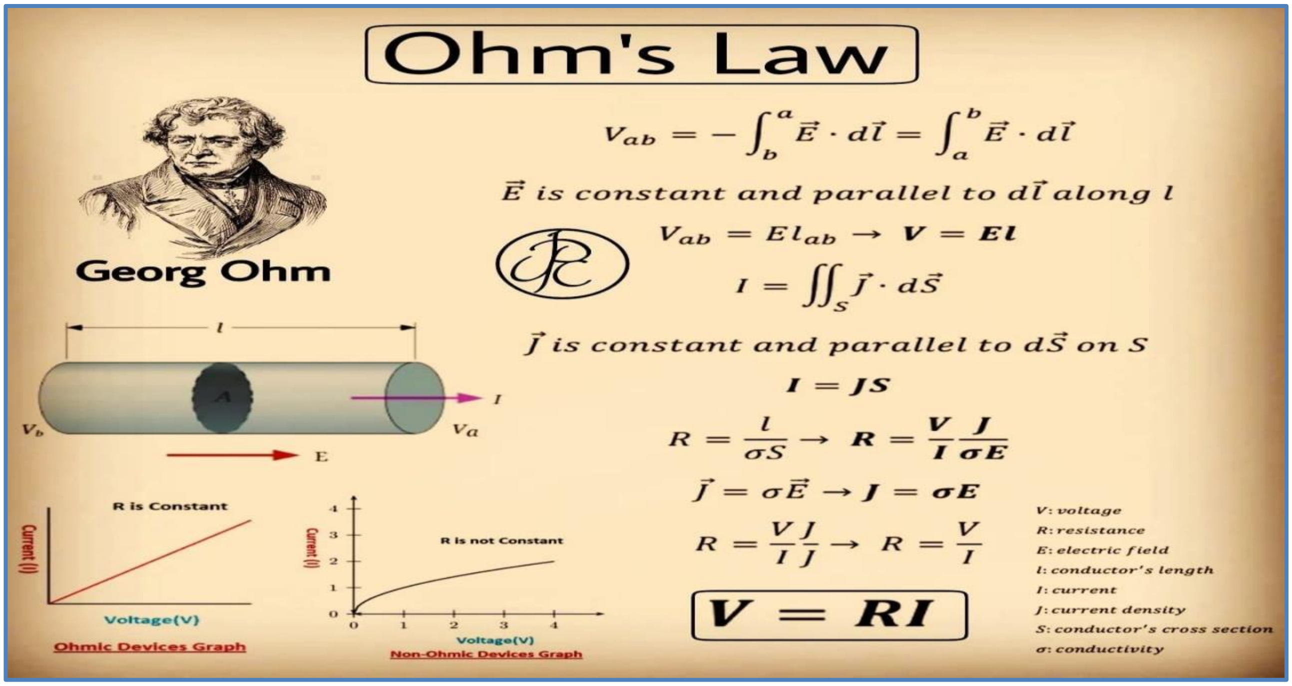
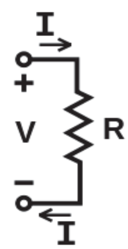
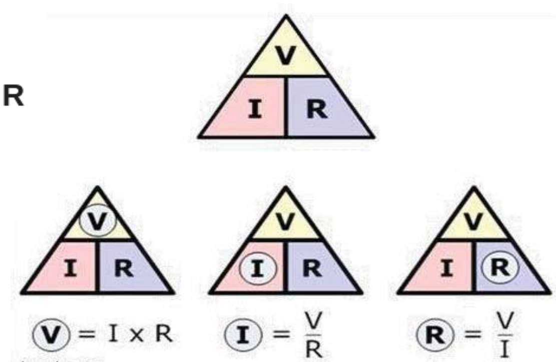


Ohm's Law

The ratio of potential difference (V) between any two points on a conductor to the current (I) flowing between them, is constant, provided the temperature of the conductor does not change.

$$\frac{V}{I} = \text{constant} \quad \text{or} \quad \frac{V}{I} = R$$





Where
R: resistance in (Ohm's)
V: is the voltage measured across the resistance (Volts).
I: is the current through the resistance (Amperes).

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Example-5

A coil of copper wire has resistance of 90 Ω at 20°C and is connected to a 230V supply. By how much must the voltage be increased in order to maintain the current constant if the temperature of the coil rises to 60°C ? Take the temperature coefficient of resistance of copper as 0.00428 from 0°C.

Solution

As seen from section 1.10

$$\frac{R_2}{R_1} = \frac{1+\alpha_0 t_2}{1+\alpha_0 t_1} \qquad \frac{R_{60}}{R_{20}} = \frac{1+60\times 0.00428}{1+20\times 0.00428} \qquad \therefore R_{60} = 90\times\ 1.2568/1.0856 = 104.2\ \Omega$$

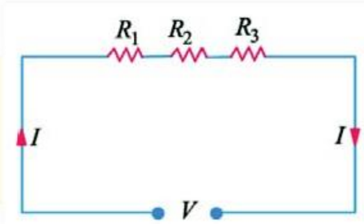
Now, current at 20°C = 230/90 = 23/9 A

Since the wire resistance has become 104.2 Ω at 60°C, then

The new voltage required for keeping the current constant at its previous value

= 104.2 × 23/9 = 266.3 V

∴ increase in voltage required = 266.3 – 230 = **36.3 V**



Example-6

Three resistors are connected in series across a 12-V battery. The first resistor has a value of 1 Ω, second has a voltage drop of 4 V and the third has a power dissipation of 12 W. Calculate the value of the circuit current.

Solution. Let the two unknown resistors be R_2 and R_3 and I the circuit current

$$\therefore \quad I^2 R_3 = 12 \quad \text{and} \quad IR_3 = 4 \quad \therefore\ R_3 = \frac{3}{4}R_2^2. \quad \text{Also,}\quad I = \frac{4}{R_2}$$

Now, $\quad I(1+R_2+R_3) = 12$

Substituting the values of I and R_3, we get

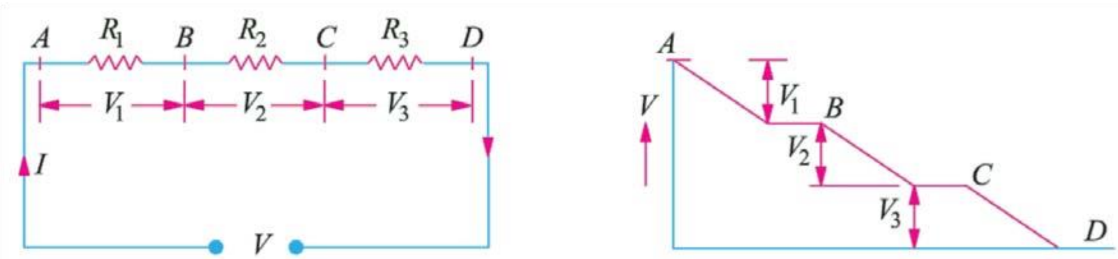
$$\frac{4}{R_2}\left(1+R_2+\frac{3}{4}R_2^2\right) = 12 \quad \text{or} \quad 3R_2^{\,2} - 8R_2 + 4 = 0$$

$$\therefore \qquad R_2 = \frac{8\pm\sqrt{64-48}}{6} \qquad \therefore\ R_2 = 2\,\Omega \quad \text{or} \quad \frac{2}{3}\Omega$$

$$\therefore \qquad R_3 = \frac{3}{4}R_2^2 = \frac{3}{4}\times 2^2 = 3\,\Omega \quad \text{or} \quad \frac{3}{4}\left(\frac{2}{3}\right)^2 = \frac{1}{3}\Omega$$

$$\therefore \qquad I = \frac{12}{1+2+3} = \mathbf{2\ A} \quad \text{or} \quad I = \frac{12}{1+(2/3)+(1/3)} = \mathbf{6\ A}$$

Resistance in Series



$\therefore V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3$ ……… Ohm's Law

But $V = IR$

where R is the equivalent resistance of the series combination.

$\therefore IR = IR_1 + IR_2 + IR_3$ or $R = R_1 + R_2 + R_3$

Characteristics Of A Series Circuit

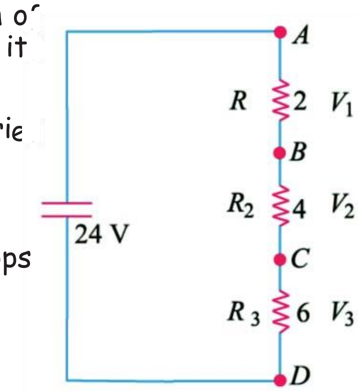
As seen from above, the main characteristics of a series circuit are:

1. Same current flows through all parts of the circuit.
2. Different resistors have their individual voltage drops.
3. Voltage drops are additive.
4. Applied voltage equals the sum of different voltage drops.
5. Resistances are additive.
6. Powers are additive.

Voltage Divider Rule

Since in a series circuit, same current flows through each of the given resistors, voltage drop varies directly with its resistance.

In Figure is shown a 24-V battery connected across a series combination of three resistors.



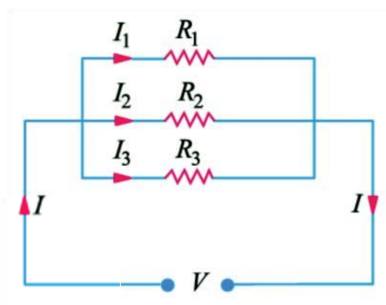
Total resistance $R = R_1 + R_2 + R_3 = 12\ \Omega$
According to Voltage Divider Rule, various voltage drops are:

$$V_1 = V \cdot \frac{R_1}{R} = 24 \times \frac{2}{12} = 4\ \text{V}$$

$$V_2 = V \cdot \frac{R_2}{R} = 24 \times \frac{4}{12} = 8\ \text{V}$$

$$V_3 = V \cdot \frac{R_3}{R} = 24 \times \frac{6}{12} = 12\ \text{V}$$

Resistances in Parallel



$$I = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I = \frac{V}{R} \text{ where } V \text{ is the applied voltage.}$$

R = equivalent resistance of the parallel combination.

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{or} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$G = G_1 + G_2 + G_3$$

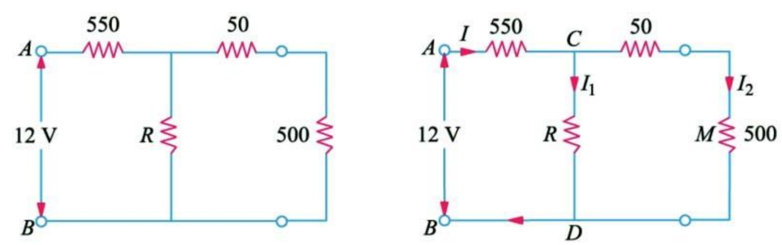
Characteristics Of A Parallel Circuit

As seen from above, the main characteristics of a parallel circuit are:

1. Same voltage acts across all parts of the circuit
2. Different resistors have their individual current.
3. Branch currents are additive.
4. Conductance's are additive.
5. Powers are additive.

Example-7

What is the value of the unknown resistor R in Figure if the voltage drop across the 500 Ω resistor is 2.5 volts ? All resistances are in ohm.



Solution. By direct proportion, drop on 50 Ω resistance = 2.5 × 50/500 = 0.25 V

Drop across CMD or CD = 2.5 + 0.25 = 2.75 V

Drop across 550 Ω resistance = 12 − 2.75 = 9.25 V

$$I = 9.25/550 = 0.0168 \text{ A}, \; I_2 = 2.5/500 = 0.005 \text{ A}$$

$$I_1 = 0.0168 - 0.005 = 0.0118 \text{ A}$$

$$\therefore \quad 0.0118 = 2.75/R; \quad R = \mathbf{233\ \Omega}$$

Example-8

Calculate the effective resistance of the following combination of resistances and the voltage drop across each resistance when a potential difference (P.D.) of 60 V is applied between points A and B.

Solution. Resistance between A and C.

$= 6 \parallel 3 = 2\ \Omega$

Resistance of branch $ACD = 18 + 2 = 20\ \Omega$

Now, there are two parallel paths between points A and D of resistances 20 Ω and 5 Ω

Hence, resistance between A and $D = 20 \parallel 5 = 4\ \Omega$

$\therefore$Resistance between A and $B = 4 + 8 = 12\ \Omega$

Total circuit current = 60/12 = 5 A

Current through 5 Ω resistance $= 5 \times \frac{20}{25} = 4$ A

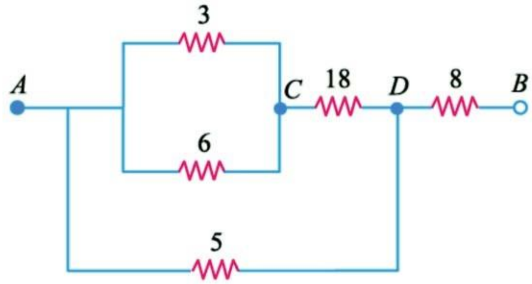
Current in branch $ACD = 5 \times \frac{5}{25} = 1$ A

$\therefore$ P.D. across 3 Ω and 6 Ω resistors = 1 × 2 = **2 V**

P.D. across 18 Ω resistors = 1 × 18 = **18 V**

P.D. across 5 Ω resistors = 4 × 5 = **20 V**

P.D. across 8 Ω resistors = 5 × 8 = **40 V**



Example-9

A circuit consists of four 100-W lamps connected in parallel across a 230-V supply. Inadvertently, a voltmeter has been connected in series with the lamps. The resistance of the voltmeter is 1500 Ω and that of the lamps under the conditions stated is six times their value then burning normally. What will be the reading of the voltmeter ?

Solution. The circuit is shown in Fig. 1.18. The wattage of a lamp is given by :

$$W = I^2 R = V^2/R$$

$\therefore \quad 100 = 230^2/R \quad \therefore \ R = 529\ \Omega$

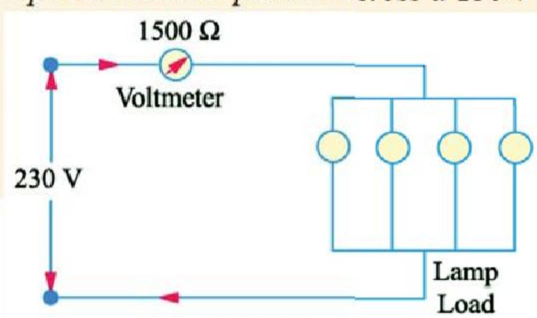


Fig.1.18

Resistance of each lamp under stated condition is = 6 × 529 = 3174 Ω

Equivalent resistance of these four lamps connected in parallel = 3174/4 = 793.5 Ω

This resistance is connected in series with the voltmeter of 1500 Ω resistance.

$\therefore$total circuit resistance = 1500 + 793.5 = 2293.5 Ω

$\therefore$ circuit current = 230/2293.5 A

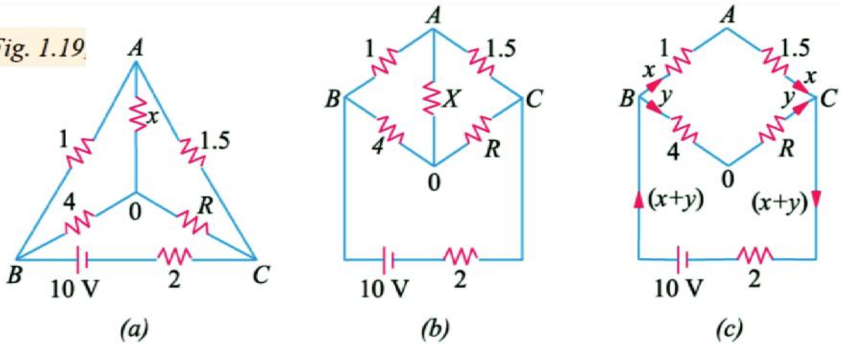
According to Ohm's law, voltage drop across the voltmeter = 1500 × 230/2293.5 = **150 V (approx)**

Example-10 *Determine the value of R and current through it in Fig. 1.19, if current through branch AO is zero.*

Solution. The given circuit can be redrawn as shown in Fig. 1.19 (b). As seen, it is nothing else but Wheatstone bridge circuit. As is well-known, when current through branch AO becomes zero, the bridge is said to be balanced. In that case, products of the resistances of opposite arms of the bridge become equal.

$$\therefore \quad 4 \times 1.5 = R \times 1; R = 6\,\Omega$$

Fig. 1.19



Under condition of balance, it makes no difference if resistance X is removed thereby giving us the circuit of Fig. 1.19 (c).
Now, there are two parallel paths between points B and C of resistances
(1+1.5) = 2.5Ω and (4+6)= 10Ω.
R_{BC}= 10 || 2.5 = 2 Ω.
Total circuit resistance = 2+2=4Ω.
Total circuit current = 10/4=2.5A
This current gets divided into two parts at point B.
Current through R
y=2.5×2.5/12.5=**0.5A**
Current through the second branch
x=2.5-0.5=**2.0A**

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Example-11 *In the unbalanced bridge circuit of Fig. 1.20 (a), find the potential difference that exists across the open switch S. Also, find the current which will flow through the switch when it is closed.*

Solution. With switch open, there are two parallel branches across the 15-V supply. Branch ABC has a resistance of (3 + 12) = 15 Ω and branch ADC has a resistance of (6 + 4) = 10 Ω. Obviously, each branch has 15 V applied across it.

$$V_B = 12 \times 15/(3+12) = 12\text{ V}; \qquad V_D = 4 \times 15/(6+4) = 6\text{ V}$$

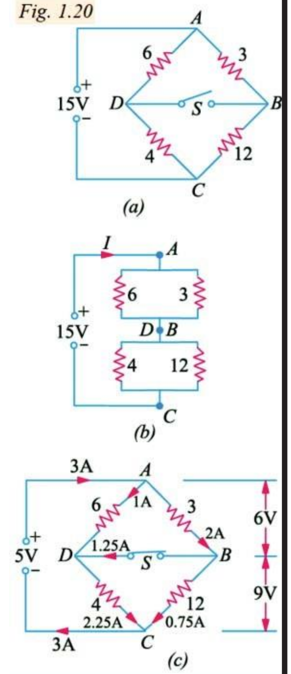
$$\therefore \quad \text{p.d. across points } B \text{ and } D = V_B - V_D = 12 - 6 = 6\text{ V}$$

When S is closed, the circuit becomes as shown in Fig. 1.20 (b) where points B and D become electrically connected together.

$$R_{AB} = 3 \,||\, 6 = 2\,\Omega \quad \text{and} \quad R_{BC} = 4 \,||\, 12 = 3\,\Omega$$

$$R_{AC} = 2 + 3 = 5\,\Omega \quad ; \qquad I = 15/5 = 3\text{ A}$$

Fig. 1.20



Current through arm AB =3×6/9=2A. The voltage drop over arm AB =3×2=6V.
Hence, drop over arm BC =15−6=9V. Current through BC =9/12=0.75A.
It is obvious that at point B, the incoming current is 2A, out of which 0.75A flows along BC, whereas remaining 2−0.75 =1.25A passes through the switch.

As a check, it may be noted that current through AD =6/6=1A.
At point D, this current is joined by 1.25A coming through the switch. Hence, current through DC=1.25+1=2.25A.
This fact can be further verified by the fact that there is a voltage drop of 9V across 4Ω resistor thereby giving a current of 9/4=2.25A.

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Example-12 *Find the values of R and V_s in Fig. 1.22. Also find the power supplied by the source.*

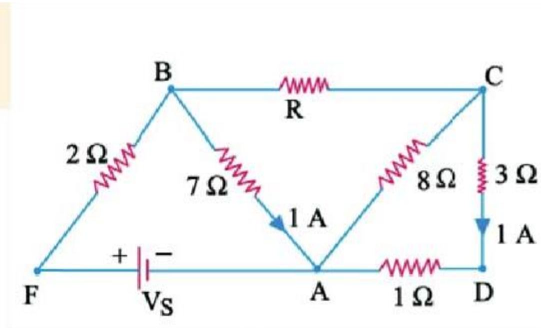


Fig. 1.22

Solution. Name the nodes as marked on Fig. 1.22. Treat node A as the reference node, so that $V_A = 0$. Since path ADC carries 1 A with a total of 4 ohms resistance, $V_C = +4$ V.

Since $V_{CA} = +4$ V, $I_{CA} = 4/8 = 0.5$ amp from C to A.

Applying KCL at node C, $I_{BC} = 1.5$ A from B to C.

Along the path BA, 1 A flows through 7–ohm resistor.

$V_B = +7$ Volts. $V_{BC} = 7 - 4 = +3$V.

This drives a current of 1.5 amp, through R ohms. Thus $R = 3/1.5 = 2$ ohms.

Applying KCL at node B, $I_{FB} = 2.5$ A from F to B.

$V_{FB} = 2 \times 2.5 = 5$ volts, F being higher than B from the view-point of Potential. Since V_B has already been evaluated as + 7 volts, V + 12 volts (w.r. to A). Thus, the source voltage $V_s = 12$ volts.

The overall resistance between F and A will be as follows:

R_{CA}=(1+3)||8= 2.667 Ω, R_{BA}=(2.667+2)||7= 2.8 Ω, R_{FA}=(2.8+2)= 4.8 Ω

Delta/Star & Star/Delta Transformation

Take the resistance between terminals 1 and 2,

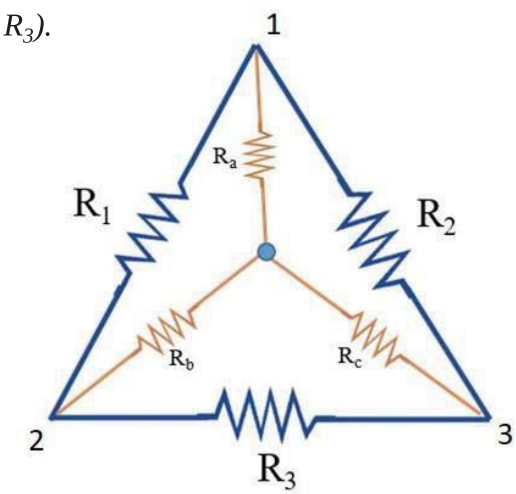
- *In Delta connection, R_1 in parallel with ($R_2 + R_3$).*
- *In Star connection R_a in series with R_b , So:*

$$R_a + R_b = \frac{R_1 \times (R_2 + R_3)}{R_1 + R_2 + R_3}$$

Similarly, for terminals 2 and 3 and terminals 3 and 1, we get

$$R_b + R_c = \frac{R_3 \times (R_1 + R_2)}{R_1 + R_2 + R_3}$$

$$R_a + R_c = \frac{R_2 \times (R_1 + R_3)}{R_1 + R_2 + R_3}$$



Delta $\Rightarrow$ Star

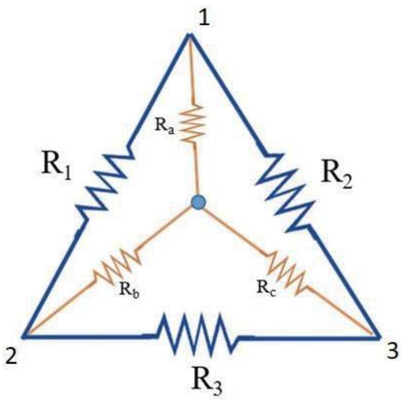
$$R_a = \frac{R_1 \times R_2}{R_1 + R_2 + R_3} \quad , \quad R_b = \frac{R_1 \times R_3}{R_1 + R_2 + R_3} \quad , \quad R_c = \frac{R_2 \times R_3}{R_1 + R_2 + R_3}$$

Star $\Rightarrow$ Delta

$$R_1 = \frac{R_a \times R_b + R_a \times R_c + R_b \times R_c}{R_c} = R_a + R_b + \frac{R_a \times R_b}{R_c}$$

$$R_2 = \frac{R_a \times R_b + R_a \times R_c + R_b \times R_c}{R_b} = R_a + R_c + \frac{R_a \times R_c}{R_b}$$

$$R_2 = \frac{R_a \times R_b + R_a \times R_c + R_b \times R_c}{R_a} = R_b + R_c + \frac{R_b \times R_c}{R_a}$$



Example-13 *Find the input resistance of the circuit between the points A and B of Fig 2.186(a).*

Solution. For finding R_{AB}, we will convert the delta *CDE* of Fig. 2.186 (*a*) into its equivalent star as shown in Fig. 2.186 (*b*).

$R_{CS} = 8 \times 4/18 = 16/9\ \Omega$; $R_{ES'} = 8 \times 6/18 = 24/9\ \Omega$; $R_{DS} = 6 \times 4/18 = 12/9\ \Omega$

The two parallel resistances between *S* and *B* can be reduced to a single resistance of 35/9 Ω

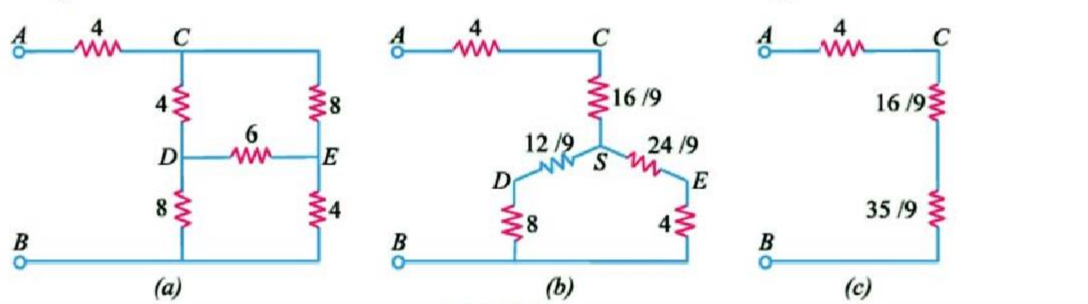


Fig 2.186

As seen from Fig. 2.186 (*c*), $R_{AB} = 4 + (16/9) + (35/9) = 87/9\ \Omega$

Example-14 *Calculate the equivalent resistance between the terminals A and B in the network shown in Fig. 2.187 (a).* **(F.Y. Engg. Pune Univ.)**

Solution. The given circuit can be redrawn as shown in Fig. 2.187 (*b*). When the delta *BCD* is converted to its equivalent star, the circuit becomes as shown in Fig. 2.187 (*c*).

Each arm of the delta has a resistance of 10 Ω Hence, each arm of the equivalent star has a resistance = 10 × 10/30 = 10/3 Ω As seen, there are two parallel paths between points *A* and *N*, each having a resistance of (10 + 10/3) = 40/3 Ω Their combined resistance is 20/3 Ω Hence, R_{AB} = (20/3) + 10/3 = 10 Ω

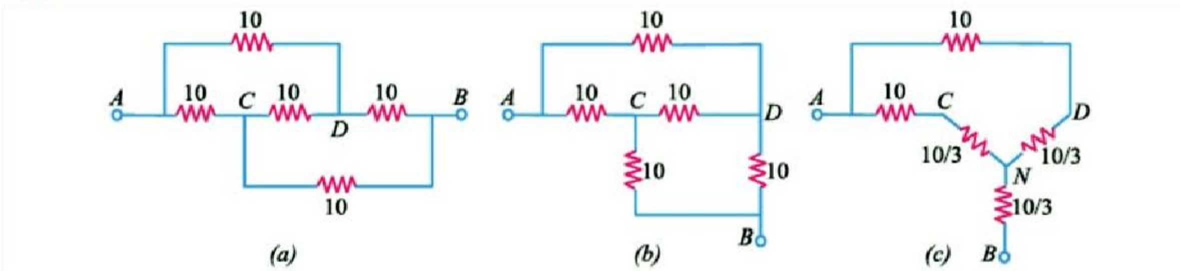


Fig. 2.187

Example-15 *Calculate the current flowing through the 10 Ω resistor of Fig. 2.188 (a) by using any method.* **(Network Theory, Nagpur Univ. 1993)**

Solution. It will be seen that there are two deltas in the circuit *i.e. ABC* and *DEF*. They have been converted into their equivalent stars as shown in Fig. 2.188 (*b*). Each arm of the delta *ABC* has a resistance of 12 Ω and each arm of the equivalent star has a resistance of 4 Ω Similarly, each arm of the delta *DEF* has a resistance of 30 Ω and the equivalent star has a resistance of 10 Ω per arm.

The total circuit resistance between *A* and *F* = 4 + 48 || 24 + 10 = 30 Ω Hence *I* = 180/30 = 6 A.

Current through 10 Ω resistor as given by current-divider rule = 6 × 48/(48 + 24) = **4 A.**

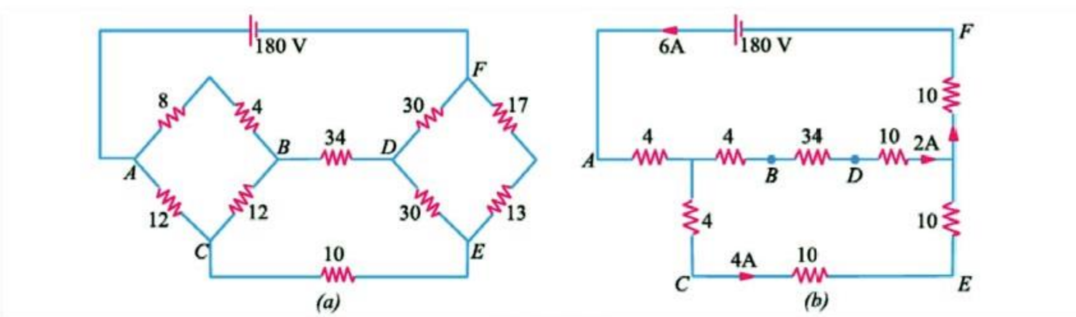


Fig. 2.188

Home Work

1. Find the current in the 17 Ω resistor in the network shown in Fig. 2.194 (*a*) by using (*a*) star/delta conversion and (*b*) Thevenin's theorem. The numbers indicate the resistance of each member in ohms. **[10/3A]**
2. Convert the star circuit of Fig. 2.194 (*b*) into its equivalent delta circuit. Values shown are in ohms. Derive the formula used. ***(Elect. Technology, Indor Univ.)***

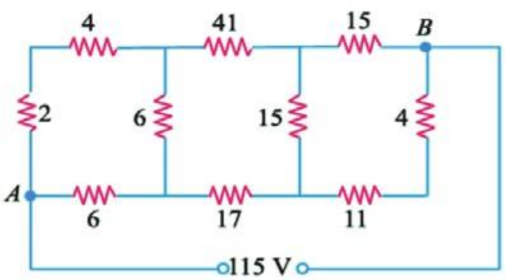


Fig. 2.194 (*a*)

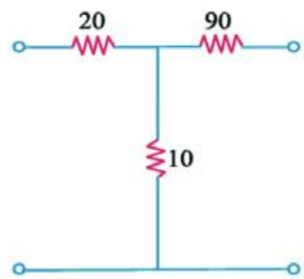


Fig. 2.194 (*b*)

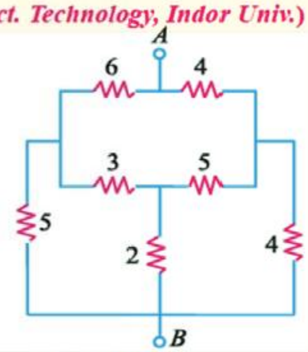


Fig. 2.195

3. Determine the resistance between points *A* and *B* in the network of Fig. 2.195. **[4.23 Ω]** ***(Elect. Technology, Indor Univ.)***

Types of Resistors

1- Carbon Composition: It is a combination of carbon particles and a binding resin with different proportions for providing desired resistance.

2- Deposited Carbon: Deposited carbon resistors consist of ceramic rods which have a carbon film deposited on them.

3- High-Voltage Ink Film: These resistors consist of a ceramic base on which a special resistive ink is laid down in a helical band.

4- Metal Film: Metal film resistors are made by depositing vaporized metal in vacuum on a ceramic-core rod.

5- Metal Glaze: A metal glaze resistor consists of a metal glass mixture which is applied as a thick film to a ceramic substrate and then fired to form a film.

6- Wire-wound: Wire-wound resistors are different from all other types in the sense that no film or resistive coating is used in their construction.

7- Cermet (Ceramic Metal): The cermet resistors are made by firing certain metals blended with ceramics on a ceramic substrate.