

# Similarity

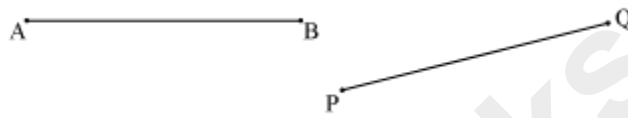
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## Difference Between Similarity and Congruence

### Congruency of line segments:

**“Two line segments are congruent to each other if their lengths are equal”.**

Consider the following line segments.



Here, the line segments AB and PQ will be congruent to each other, if they are of equal length.

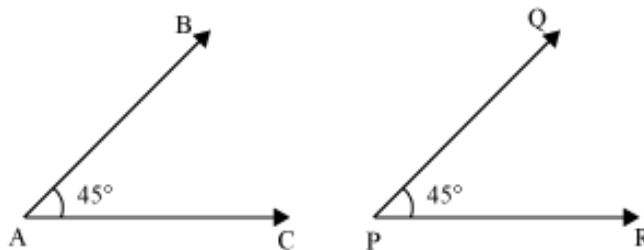
Conversely, we can say that, **“Two line segments are of equal length if they are congruent to each other”.**

i.e. if  $\overline{AB} \cong \overline{PQ}$ , then  $AB = PQ$ .

### Congruency of angles:

**“Two angles are said to be congruent to each other if they have the same measure”.**

The angles shown in the following figures are congruent to each other as both the angles are of the same measure  $45^\circ$ .



Thus, we can write  $\angle BAC \cong \angle QPR$ .

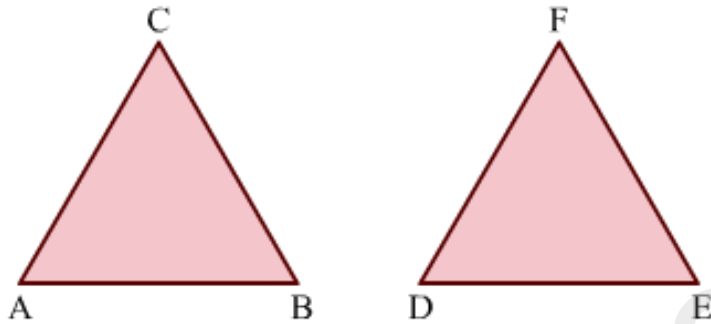
Its converse is also true.

**“If two angles are congruent to each other, then their measures are also equal”.**

There is one special thing about congruent figures that their corresponding parts are always equal.

For example, if two triangles are congruent then their corresponding sides will be equal. Also, their corresponding angles will be equal.

Look at the following triangles.



Here,  $\triangle ABC \cong \triangle DEF$  under the correspondence  $\triangle ABC \leftrightarrow \triangle DEF$ . This correspondence rule represents that in given triangles,  $AB \leftrightarrow DE$  (AB corresponds to DE),  $BC \leftrightarrow EF$ ,  $CA \leftrightarrow FD$ ,  $\angle A \leftrightarrow \angle D$ ,  $\angle B \leftrightarrow \angle E$ ,  $\angle C \leftrightarrow \angle F$ .

These are **corresponding parts of congruent triangles** (CPCT),  $\triangle ABC$  and  $\triangle DEF$ .

Since  $\triangle ABC$  and  $\triangle DEF$  are congruent, their corresponding parts are equal.

Therefore,  $AB = DE$ ,  $BC = EF$ ,  $CA = FD$

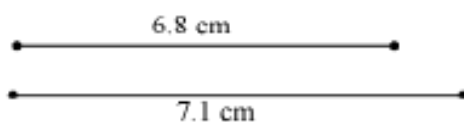
And,  $\angle A = \angle D$ ,  $\angle B = \angle E$ ,  $\angle C = \angle F$

Similarly, we can apply the method of CPCT on other congruent triangles also.

Let us now try and apply what we have just learnt in some examples.

**Example 1:**

**Find which of the pairs of line segments are congruent.**



(i)

(ii)

**Solution:**

(i) Lengths of the two line segments are not same. Therefore, they are not congruent.

(ii) Each of the line segments is of length 3.1 cm, i.e. they are equal. Therefore, they are congruent.

**Example 2:**

If  $\overline{AB} \cong \overline{PQ}$  and  $\overline{PQ} = 9$  cm, then find the length of  $\overline{AB}$ .

**Solution:**

Since  $\overline{AB} \cong \overline{PQ}$ , i.e. line segment AB is congruent to line segment PQ, therefore,  $\overline{AB}$  and  $\overline{PQ}$  are of equal length.

$$\therefore \overline{AB} = 9 \text{ cm}$$

**Example 3:**

If  $\angle ABC \cong \angle PQR$  and  $\angle PQR = 75^\circ$ , then find the measure of  $\angle ABC$ .

**Solution:**

If two angles are congruent, then their measures are equal.

Since  $\angle ABC \cong \angle PQR$ ,

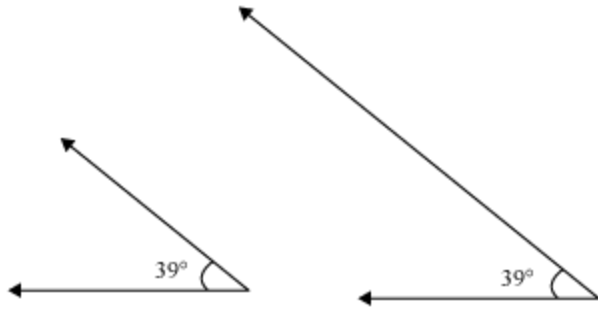
$$\therefore \angle ABC = \angle PQR$$

Therefore,  $\angle ABC = 75^\circ$

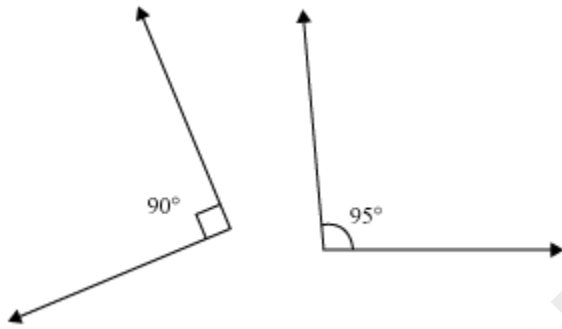
**Example 4:**

**Which of the following pairs of angles are congruent?**

(i)



(ii)



**Solution:**

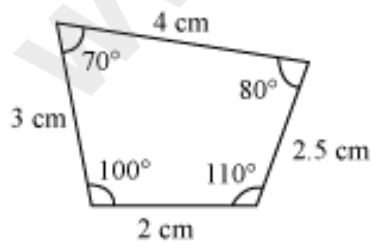
(i) The measure of both the angles is the same. Therefore, they are congruent.

(ii) The measures of the two angles are different. Therefore, they are not congruent.

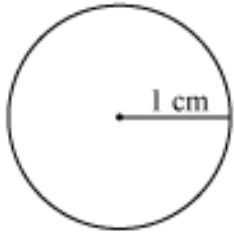
**Example 5:**

**Identify the pairs of similar and congruent figures from the following.**

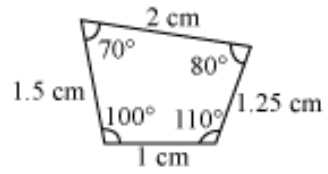
(i)



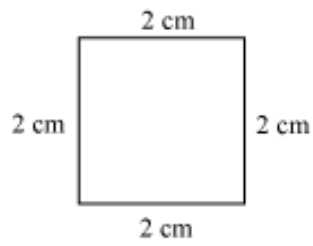
(ii)



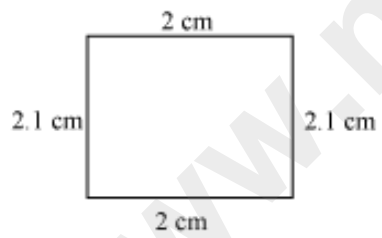
(iii)



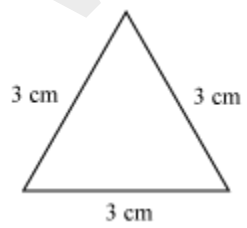
(iv)



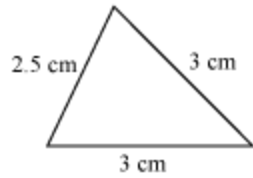
(v)



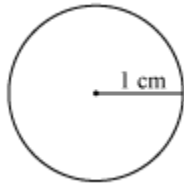
(vi)



(vii)



(viii)



**Solution:**

Figures (i) and (iii) are similar because their corresponding angles are equal and their corresponding sides are in the same ratio. However, these figures are not congruent as they are of different sizes.

Figures (ii) and (viii) are congruent as they are of the same shape and size (circles with radius 1 cm each).

**Example 6:**

**Are the following figures similar or congruent?**

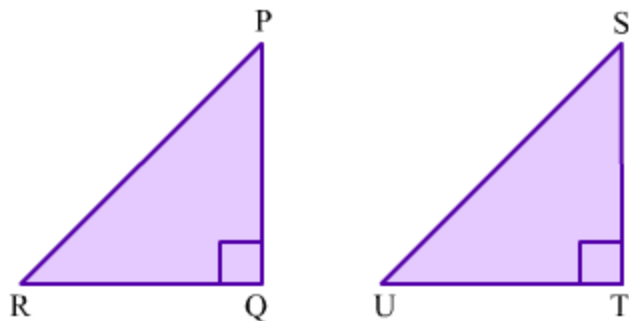


**Solution:**

The two given figures show two one-rupee coins. As both the figures represent the same coin in two different sizes, they are similar to each other. However, the pictures are not congruent because of their different sizes.

**Example 7:**

**In the following figure,  $\Delta PQR$  and  $\Delta STU$  are congruent.**



If  $PQ = 8$  cm,  $QR = 6$  cm then find the perimeter of  $\Delta STU$ .

**Solution:**

In  $\Delta PQR$ , we have

$PQ = 8$  cm,  $QR = 6$  cm and  $\angle Q = 90^\circ$

Applying Pythagoras theorem in  $\Delta PQR$ , we obtain

$$RP^2 = PQ^2 + QR^2$$

$$\Rightarrow RP^2 = 8^2 + 6^2$$

$$\Rightarrow RP^2 = 64 + 36$$

$$\Rightarrow RP^2 = 100$$

$$\Rightarrow RP = 10 \text{ cm}$$

Since  $\Delta PQR$  and  $\Delta STU$  are congruent, their corresponding parts will be equal.

Therefore,

$$PQ = 8 \text{ cm} = ST \quad (\text{CPCT})$$

$$QR = 6 \text{ cm} = TU \text{ and} \quad (\text{CPCT})$$

$$RP = 10 \text{ cm} = US \quad (\text{CPCT})$$

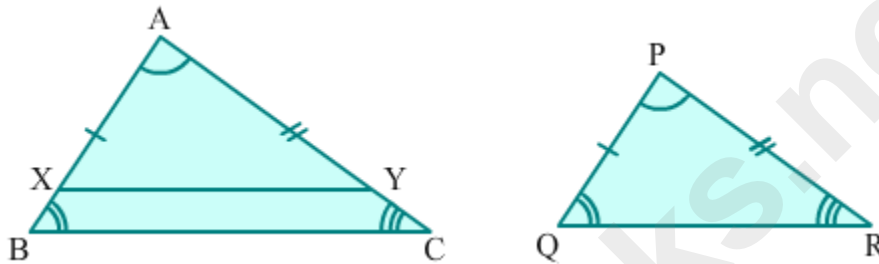
$$\therefore \text{Perimeter of } \Delta STU = ST + TU + US = 8 \text{ cm} + 6 \text{ cm} + 10 \text{ cm} = 24 \text{ cm}$$

**AAA Criterion Of Similarity Of Triangles**

We can check the similarity of any two triangles using AAA criterion of similarity if any two angles of each triangle are given so, AAA criterion is same as AA criterion.

AA criterion "If two triangles are equiangular, then their corresponding sides are proportional." can be proved as below.

**Given:**  $\triangle ABC$  and  $\triangle PQR$  where  $\angle A = \angle P$ ,  $\angle B = \angle Q$  and  $\angle C = \angle R$ .



**To prove:**  $\frac{AB}{PQ} = \frac{BC}{QR} = \frac{CA}{RP}$

**Construction:** Mark X and Y on AB and AC respectively such that  $AX = PQ$  and  $AY = PR$ .

**Proof:**

In  $\triangle AXY$  and  $\triangle PQR$ ,

$AX = PQ$  [By construction]

$\angle A = \angle P$  [Given]

$AY = PR$  [By construction]

So, by SAS postulate,  $\triangle AXY \cong \triangle PQR$ .

[Note: The symbol ' $\cong$ ' stands for congruency]

$\Rightarrow XY = QR$  and  $\angle X = \angle Q$  [CPCT]

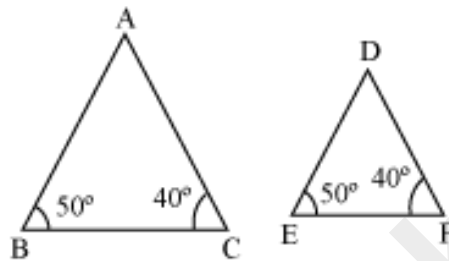
Now,  $\angle X = \angle B$  [ $\angle X = \angle Q = \angle B$ ]

$\therefore XY \parallel BC$  [ $\angle X$  and  $\angle B$  are corresponding angles]

$$\begin{aligned} \therefore \frac{AB}{AX} &= \frac{AC}{AY} = \frac{BC}{XY} \\ \Rightarrow \frac{AB}{PQ} &= \frac{CA}{PR} = \frac{BC}{QR} \end{aligned}$$

Hence, AA criterion is proved.

Now, look at the following triangles.



Here,  $\angle B = \angle E = 50^\circ$

and  $\angle C = \angle F = 40^\circ$

Then, using AAA similarity criterion,  $\triangle ABC$  is similar to  $\triangle DEF$ .

In symbolic form, we can write  $\triangle ABC \sim \triangle DEF$ . In symbolic form, the order of vertices is very important. For the above triangles, we cannot write  $\triangle ABC \sim \triangle EFD$  because  $\angle B = \angle E$  and  $\angle C = \angle F$

Converse of AAA criterion is also true which states that:

If two triangles are similar then their corresponding angles are equal.

For example, if  $\triangle ABC \sim \triangle DEF$  then  $\angle A = \angle D$ ,  $\angle B = \angle E$  and  $\angle C = \angle F$ .

**Note:** In some state boards, the symbol "|||" is used for similarity.

I.e.,  $\triangle ABC \sim \triangle DEF$  may also be written as  $\triangle ABC ||| \triangle DEF$ .

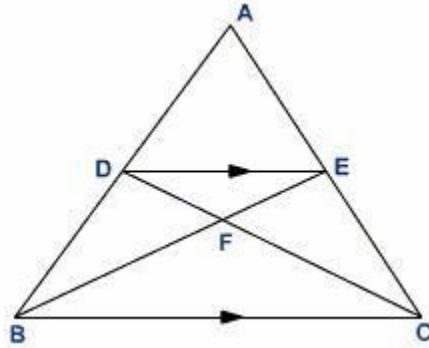
Let us now look at some more problems based on AAA similarity criterion.

**Example 1:**

**In the following figure, if  $DE \parallel BC$ , then prove the following.**

**(a)  $\triangle ABC \sim \triangle ADE$**

(b)  $\triangle DFE \sim \triangle CFB$



**Solution:**

(a) In  $\triangle ABC$  and  $\triangle ADE$ ,

$\angle BAC = \angle DAE$  (Common to both)

$\angle ADE = \angle ABC$  (Since  $DE$  is parallel to  $BC$ ,  $\angle ADE$  and  $\angle ABC$  are corresponding angles)

By AAA similarity criterion,

$\triangle ABC \sim \triangle ADE$

(b) In  $\triangle DFE$  and  $\triangle BFC$ ,

$\angle DFE = \angle BFC$  (Vertically opposite angles)

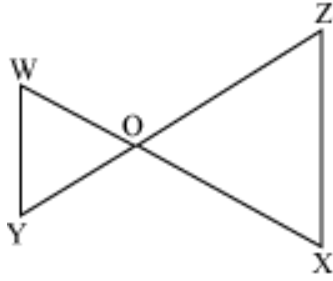
$\angle EDF = \angle BCF$  (Alternate angles)

By AAA similarity criterion,

$\triangle DFE \sim \triangle CFB$

**Example 2:**

In the given figure, if  $WY \parallel ZX$ , then prove that  $\triangle OWY \sim \triangle OXZ$ .



**Solution:**

Here,  $WY \parallel ZX$

Now, in  $\Delta OWY$  and  $\Delta OZX$ ,

$\angle WOY = \angle ZOX$  (Vertically opposite angles)

$\angle OWY = \angle OXZ$  (Alternate angles)

$\angle OYW = \angle OZX$  (Alternate angles)

By AAA similarity criterion of triangles,

$\Delta OWY \sim \Delta OZX$

### SSS Criterion of Similarity of Triangles

Converse of SSS criterion is also true which states that:

If two triangles are similar then their corresponding sides are proportional.

For example, if  $\Delta ABC \sim \Delta PQR$  then  $\frac{AB}{PQ} = \frac{BC}{QR} = \frac{CA}{RP}$ .

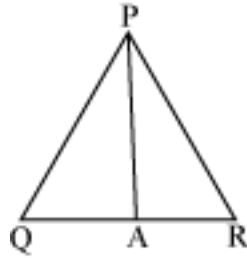
Let us solve some problems to understand this concept better.

**Example 1:**

**If PQR is an isosceles triangle with  $PQ = PR$  and A is the mid-point of side QR, then prove that  $\Delta PAQ$  is similar to  $\Delta PAR$ .**

**Solution:**

It is given that  $\Delta PQR$  is an isosceles triangle and  $PQ = PR$ .



In triangles PAQ and PAR,

$$PQ = PR$$

Also, A is the mid-point of QR, therefore

$$QA = AR$$

And, PA = PA (Common to both triangles)

Therefore, we can say that

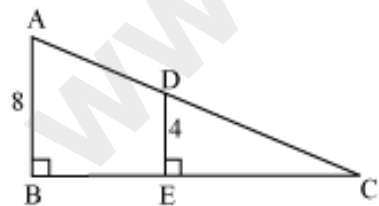
$$\frac{PQ}{PR} = \frac{QA}{AR} = \frac{PA}{PA}$$

∴ Using SSS similarity criterion, we obtain

$$\triangle PAQ \sim \triangle PAR$$

### Example 2:

In the following figure, E and D are the mid-points of the sides BC and AC respectively. Prove that  $\triangle ABC \sim \triangle DEC$ .



### Solution:

It is given that E is the mid-point of BC.

$$\therefore BE = EC$$

Now,  $BC = BE + EC$

$$\Rightarrow BC = 2EC$$

$$\Rightarrow \frac{BC}{EC} = \frac{2}{1}$$

Similarly, D is the mid-point of AC, therefore

$$AC = 2DC$$

$$\Rightarrow \frac{AC}{DC} = \frac{2}{1}$$

Also, from the figure,

$$\frac{AB}{DE} = \frac{8}{4} = \frac{2}{1}$$

$$\therefore \frac{AB}{DE} = \frac{AC}{DC} = \frac{BC}{EC} = \frac{2}{1}$$

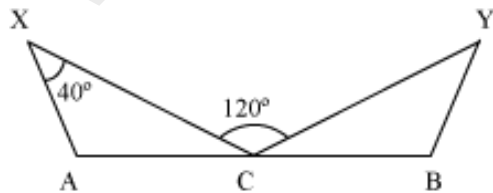
By SSS criterion of similarity of triangles,

$$\triangle ABC \sim \triangle DEC$$

**Example 3:**

In the following figure, the lines XC and YC of same length are drawn such that C is the mid-point of AB. If  $AX = BY$ , then find the measure of the following angles.

1.  $\angle BYC$  (c)  $\angle CAX$
2.  $\angle CBY$  (d)  $\angle ACX$



**Solution:**

In the triangles CAX and CBY,

$$CX = CY \text{ (Given)}$$

$$CA = CB \text{ (C is the mid-point of AB)}$$

$$AX = BY \text{ (Given)}$$

Therefore, by SSS similarity criterion,

$$\triangle CAX \sim \triangle CBY$$

We know that the corresponding angles of similar triangles are equal.

$$\therefore \angle AXC = \angle BYC = 40^\circ$$

$$\Rightarrow \angle BYC = 40^\circ$$

$$\text{Also, } \angle ACX = \angle BCY$$

$$\text{Let } \angle ACX = \angle BCY = x$$

Therefore,  $x + x + 120^\circ = 180^\circ$  ( $\angle ACX$ ,  $\angle BCY$ , and  $\angle XCY$  form a linear pair)

$$\Rightarrow 2x = 180^\circ - 120^\circ = 60^\circ$$

$$\Rightarrow x = 30^\circ$$

$$\therefore \angle ACX = \angle BCY = 30^\circ$$

Now, by angle sum property in  $\triangle ACX$ , we obtain

$$30^\circ + \angle CAX + 40^\circ = 180^\circ$$

$$\Rightarrow \angle CAX = 180^\circ - 70^\circ = 110^\circ$$

$$\therefore \angle CBY = \angle CAX = 110^\circ$$

Thus, we obtain

1.  $\angle BYC = 40^\circ$
2.  $\angle CBY = 110^\circ$

3.  $\angle CAX = 110^\circ$
4.  $\angle ACX = 30^\circ$

**Example 4:**

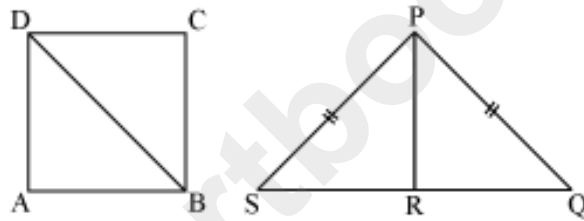
**ABCD is a square and PQS is an isosceles triangle with  $PQ = PS$  and R is the mid-point of QS. If  $\triangle ABD \sim \triangle RPQ$ , then prove that  $\triangle CBD \sim \triangle RPS$ .**

**Solution:**

ABCD is a square and PQS is an isosceles triangle.

Therefore,  $AB = BC = CD = DA$

And,  $PQ = PS$



It is also given that  $\triangle ABD \sim \triangle QRP$ .

In  $\triangle ABD$  and  $\triangle CBD$ ,

$AB = CB$  (Sides of a square)

$BD = BD$  (Common side)

$DA = DC$  (Sides of a square)

By SSS similarity criterion,

$\triangle ABD \sim \triangle CBD \dots (2)$

Now, in  $\triangle RPQ$  and  $\triangle RPS$ ,

$RP = RP$  (Common side)

$PQ = PS$  (Equal sides of an isosceles triangle)

QR = SR (R is the mid-point of QS)

Therefore,  $\triangle RPQ \sim \triangle RPS$  ... (3)

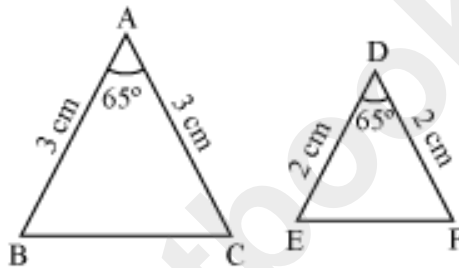
However,  $\triangle ABD \sim \triangle RPQ$

Therefore, from (2) and (3), we obtain

$\triangle CBD \sim \triangle RPS$

## SAS Criterion Of Similarity Of Triangles

Look at the following figures.



**Is there any similarity between them?**

We can see that in both the triangles, the lengths of two sides are given and also the measure of the included angle is given. Now, let us compare the sides of the triangles and observe the result we obtain.

On taking the ratio of the sides, we obtain

$$\frac{AB}{DE} = \frac{AC}{DF} = \frac{3}{2}$$

Therefore, we observe that the sides of the triangles are in the same ratio i.e., we can say that the sides of the triangles are proportional.

**Using the above fact, can we say that the given triangles are similar?**

To know the answer, let us first know about a similarity criterion known as SAS similarity criterion.

**SAS similarity criterion can be stated as follows.**

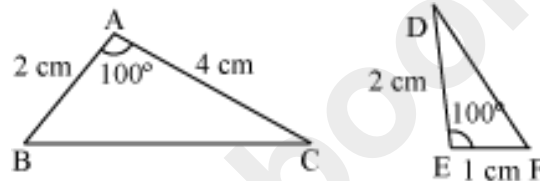
**“If one angle of a triangle is equal to one angle of the other triangle and the sides including these angles are proportional, then the two triangles are similar”.**

Using this criterion, we can check the similarity of any two triangles, if the two sides and the included angle between them are given.

In the above example,  $\angle A = \angle D = 65^\circ$  and the sides including these angles are in the same proportion i.e.,  $3/2$ . Thus, we can say that  $\Delta ABC$  is similar to  $\Delta DEF$ .

In symbolic form, we can write  $\Delta ABC \sim \Delta DEF$ . For writing the symbolic form, the order of the vertices is very important.

For example, consider the following figure.



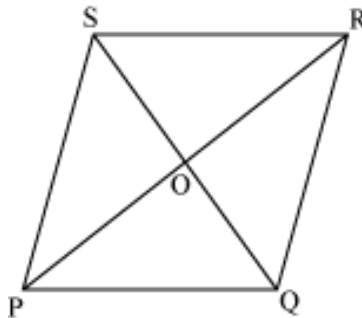
Here,  $\Delta ABC$  and  $\Delta DEF$  are similar triangles as two sides of both the triangles are proportional and the angles included between them are also equal.

Therefore, we can write  $\Delta ABC \sim \Delta EFD$ .

Let us now look at some more examples to understand this concept better.

**Example1:**

**If PQRS is a parallelogram, then prove that  $\Delta SOR$  is similar to  $\Delta POQ$ .**



**Solution:**

Consider  $\Delta SOR$  and  $\Delta POQ$ .

Since PQRS is a parallelogram, the diagonals bisect each other.

$\therefore SO = OQ$  and  $PO = OR$

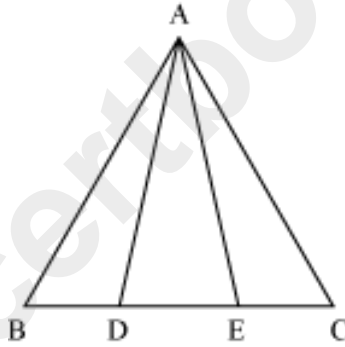
and  $\angle POQ = \angle SOR$  (Vertically opposite angles)

By SAS similarity criterion, we obtain

$\Delta SOR \sim \Delta QOP$

**Example2:**

$\Delta ABC$  is an isosceles triangle with  $AB$  and  $AC$  as the equal sides. The points  $D$  and  $E$  divide the side  $BC$  into three equal parts as shown in the figure. Prove that  $\Delta ABD \sim \Delta ACE$ .



**Solution:**

Since  $ABC$  is an isosceles triangle,

$AB = AC$

$\angle ABC = \angle ACB$  (Angles opposite to equal sides are equal in an isosceles triangle)

It is given that the points  $D$  and  $E$  divide the side  $BC$  in three equal parts. Therefore,

$BD = DE = EC$

In  $\Delta ABD$  and  $\Delta AEC$ ,

$AB = AC$

$$BD = EC$$

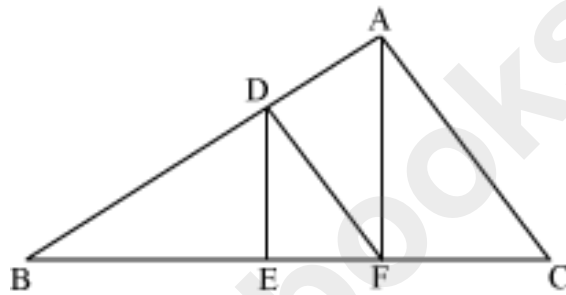
$$\angle ABD = \angle ACE$$

By SAS similarity criterion,

$$\triangle ABD \sim \triangle ACE$$

## Basic Proportionality Theorem and Its Converse

Consider the following figure.



In the above figure, DE is parallel to AC and DF is parallel to AC. Can we say that point E divides BF in the same ratio in which point F divides BC?

$$\left( \frac{BE}{EF} = \frac{BF}{FC} \right)$$

For this, we have to prove that

To prove it, we should have the knowledge of basic proportionality theorem (Thales theorem).

Now, let us solve the problem discussed in the beginning with the help of BPT.

In  $\triangle ABF$ , we know that AF is parallel to DE.

Thus, using BPT,

$$\frac{BD}{DA} = \frac{BE}{EF} \dots (1)$$

Similarly, in  $\triangle ABC$ , DF is parallel to AC.

Thus, using BPT,

$$\frac{BD}{DA} = \frac{BF}{FC} \dots (2)$$

From equations (1) and (2), we obtain

$$\frac{BE}{EF} = \frac{BF}{FC}$$

Thus, we can say that point E divides BF in the same ratio in which point F divides BC.

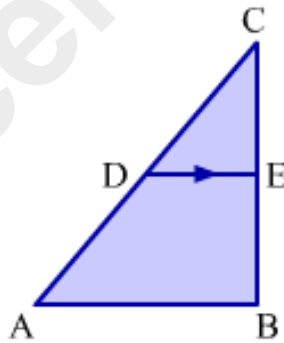
The **converse of BPT** is also true, which can be stated as follows.

**“If a line divides any two sides of a triangle in the same ratio, then the line is parallel to the third side”.**

### Corollary of BPT:

If a line is drawn parallel to a side of a triangle, then the sides of the new triangle formed are proportional to the sides of the given triangle.

I.e, In the given figure, if  $DE \parallel AB$ , then  $\frac{CD}{CA} = \frac{DE}{AB} = \frac{CE}{CB}$



### Applications of Basic Proportionality Theorem:

There are two very important properties based on BPT which are as follows:

1. Property of intercepts made by three parallel lines on a transversal.
2. Property of angle bisector of a triangle.

Let us discuss these properties in detail along with their proofs.

### Property 1: Intercept Theorem

The lengths of the intercepts made by three parallel lines on one transversal are in the same ratio as the lengths of the corresponding intercepts made by the same lines on any other transversal.

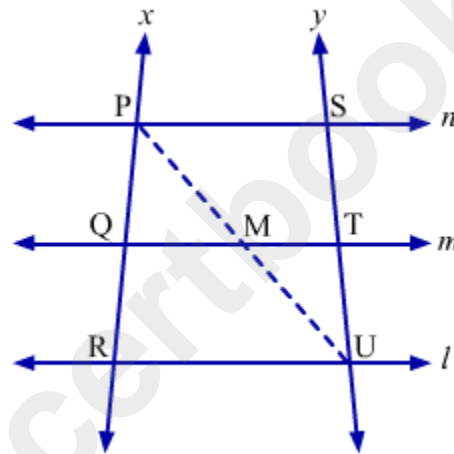
Let us prove this property.

**Given:** line  $l \parallel$  line  $m \parallel$  line  $n$

Transversal  $x$  intersects these lines at points P, Q and R while transversal  $y$  intersects these lines at points S, T and U.

**To prove:**  $\frac{PQ}{QR} = \frac{ST}{TU}$

**Construction:** Draw a line segment PU intersecting line  $m$  at point M.



**Proof:**

In  $\Delta PRU$ , we have  
 $QM \parallel RU$

$$\therefore \frac{PQ}{QR} = \frac{PM}{MU} \quad \dots(1) \quad \dots(\text{By BPT})$$

Similarly, in  $\Delta USP$ , we have  
 $TM \parallel SP$

$$\therefore \frac{UM}{MP} = \frac{UT}{TS} \quad \dots(\text{By BPT})$$

$$\Rightarrow \frac{PM}{MU} = \frac{ST}{TU}$$

$$\Rightarrow \frac{PQ}{QR} = \frac{ST}{TU} \quad [\text{Using (1)}]$$

Hence proved.

## Property 2: Angle Bisector Theorem

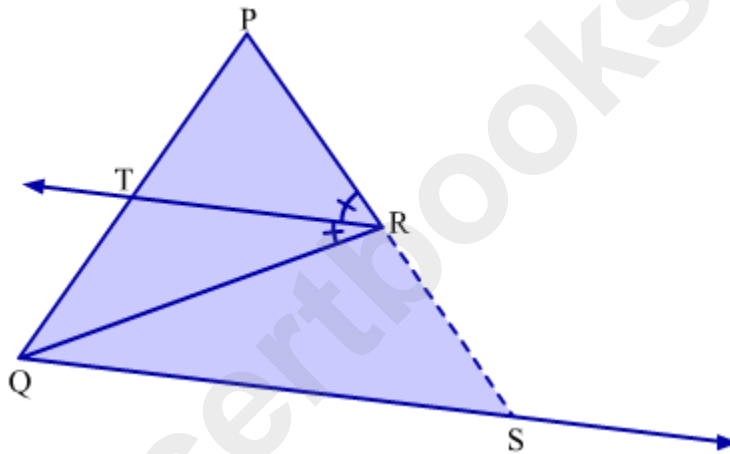
In a triangle, the angle bisector divides the side opposite to the angle in the ratio same as the ratio of remaining sides.

Let us prove this property.

**Given:** In  $\triangle PQR$ , ray  $RT$  bisects  $\angle PRQ$ .

**To prove:**  $\frac{PT}{TQ} = \frac{PR}{RQ}$

**Construction:** Draw a ray from  $Q$  parallel to ray  $RT$  such that it intersects extended  $PR$  at  $S$ .



### Proof:

We have,  
 $RT \parallel QS$  and  $PS$  is transversal

$$\therefore \angle PRT = \angle RSQ \quad \dots(1) \quad (\text{Corresponding angles})$$

Considering other transversal  $RQ$ , we obtain

$$\angle TRQ = \angle RQS \quad \dots(2) \quad (\text{Alternate angles})$$

$$\text{But } \angle PRT = \angle TRQ \quad (\text{RT bisects } \angle PRQ)$$

$$\therefore \angle RSQ = \angle RQS \quad [\text{Using (1) and (2)}]$$

Thus, in  $\triangle RQS$ ,

$$RS = RQ \quad \dots(3) \quad (\text{Side opposite to equal angles are equal})$$

Now, in  $\triangle PQS$ , we have

$$RT \parallel QS$$

$$\therefore \frac{PT}{TQ} = \frac{PR}{RS} \quad (\text{By BPT})$$

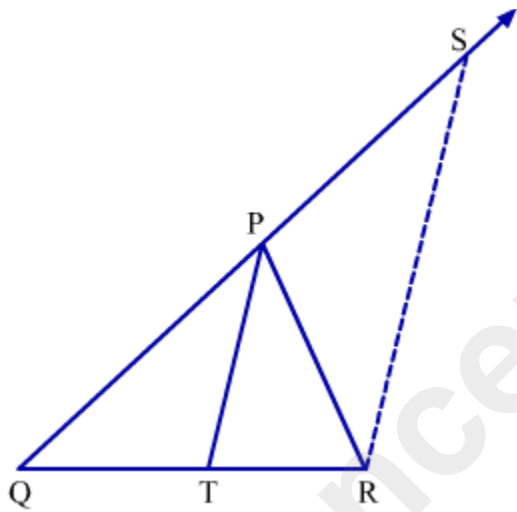
$$\Rightarrow \frac{PT}{TQ} = \frac{PR}{RQ} \quad [\text{Using (3)}]$$

Hence proved.

### Property 3: Converse of Angle Bisector Theorem

**If a straight line through one vertex of a triangle divides the opposite side in the ratio of the other two sides, then the line bisects the angle at the vertex.**

Let us prove this property.



**Given:** In  $\Delta PQR$ , line  $PT$  divides the opposite side  $BC$  internally such that.

$$\frac{QT}{TR} = \frac{PQ}{PR}$$

**To prove:**  $PT$  bisects  $\angle QPR$ . i.e.  $\angle QPT = \angle RPT$ .

**Construction:** Draw a ray from  $R$  parallel to ray  $PT$  such that it intersects extended  $QP$  at  $S$ .

**Proof:**

Since  $PT \parallel SR$ , then

$$\frac{QT}{TR} = \frac{QP}{PS} \dots(1) \quad (\text{Basic Proportionality Theorem})$$

And we have,

$$\frac{QT}{TR} = \frac{QP}{PR} \dots(2) \quad (\text{Given})$$

From (1) and (2) we have,

$$\frac{QP}{PR} = \frac{QP}{PS}$$

$$\Rightarrow PS = PR$$

Now in  $\triangle PSR$ ,  $\angle PSR = \angle PRS \dots(3)$

If  $PT \parallel SR$ , then

$$\angle TPR = \angle PRS \dots(4) \quad (\text{Alternate Interior Angles})$$

$$\angle QPT = \angle PSR \dots(5) \quad (\text{Corresponding Angles})$$

From (3), (4) and (5) we get

$$\angle QPT = \angle TPR$$

$\therefore$   $PT$  bisect  $\angle QPR$ .

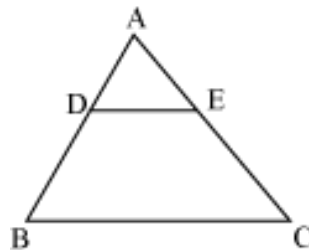
Hence proved.

These properties are very useful sometimes.

Let us now solve some examples based on BPT, its converse and properties related to BPT.

**Example 1:**

In triangle  $ABC$ ,  $D$  and  $E$  are points on the sides  $AB$  and  $AC$ , such that  $AB = 11.2$  cm,  $AD = 2.8$  cm,  $AC = 14.4$  cm, and  $AE = 3.6$  cm. Show that  $DE$  is parallel to  $BC$ .



**Solution:**

It is given that,

$AB = 11.2$  cm,  $AD = 2.8$  cm,  $AC = 14.4$  cm, and  $AE = 3.6$  cm

Therefore,  $BD = AB - AD = 11.2 - 2.8 = 8.4$  cm

And,

$$EC = AC - AE = 14.4 - 3.6 = 10.8 \text{ cm}$$

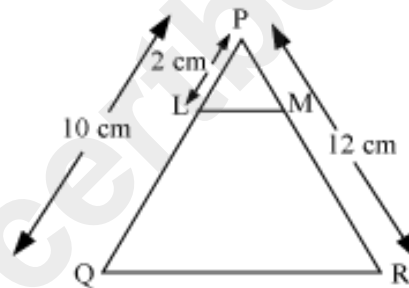
Now,

$$\frac{AD}{DB} = \frac{2.8}{8.4} = \frac{1}{3} \text{ and } \frac{AE}{EC} = \frac{3.6}{10.8} = \frac{1}{3}$$
$$\Rightarrow \frac{AD}{DB} = \frac{AE}{EC}$$

Thus, DE divides sides AB and AC of triangle ABC in the same ratio. Therefore, by the **converse of BPT**, we obtain that DE is parallel to BC.

### Example 2:

In the figure shown below, find the length of PM, if it is given that  $LM \parallel QR$ . The corresponding measures are shown in the figure.



### Solution:

Here,  $LM \parallel QR$

Then, using basic proportionality theorem, we obtain

$$\frac{PL}{LQ} = \frac{PM}{MR} \quad \dots(i)$$

Let  $PM = x \text{ cm}$

Then,  $MR = 12 - x \text{ cm}$

And,  $PL = 2 \text{ cm}$

$LQ = 10 \text{ cm} - 2 \text{ cm} = 8 \text{ cm}$

On putting these values in equation (i), we obtain

$$\frac{2}{8} = \frac{x}{12-x}$$

$$2(12-x) = 8x$$

$$24 - 2x = 8x$$

$$24 = 8x + 2x$$

$$24 = 10x$$

$$x = 2.4 \text{ cm}$$

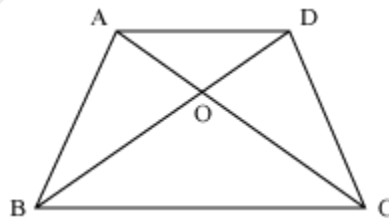
Thus, PM = 2.4 cm

**Example 3:**

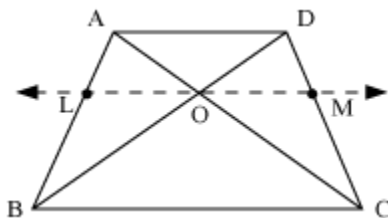
If ABCD is a trapezium with  $AD \parallel BC$ , then prove that  $\frac{AO}{CO} = \frac{DO}{BO}$ , where O is the point of intersection of diagonals AC and BD.

**Solution:**

A trapezium has been shown in the following figure.



A line LM is drawn parallel to AD and BC and passing through O.



Here,  $LO \parallel BC$ .

Using BPT in  $\triangle ABC$ ,

$$\frac{AL}{LB} = \frac{AO}{CO} \quad \dots(i)$$

Similarly, using BPT in  $\triangle ABD$  as  $LO \parallel AD$ , we obtain

$$\frac{AL}{LB} = \frac{DO}{BO} \quad \dots(ii)$$

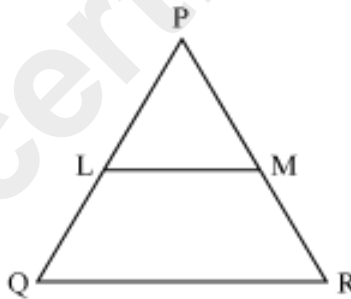
From equations (i) and (ii), we obtain

$$\frac{AO}{CO} = \frac{DO}{BO}$$

Hence, proved

**Example 4:**

In  $\triangle PQR$ ,  $LM \parallel QR$  and  $L$  is the mid-point of side  $PQ$ . Show that  $PM = MR$ .



**Solution:**

Here,  $LM \parallel QR$

Using basic proportionality theorem (BPT),

$$\frac{PL}{LQ} = \frac{PM}{MR} \quad \dots(i)$$

Now,  $L$  is the mid-point of  $PQ$ .

$$\therefore PL = LQ$$

Using this in equation (i), we obtain

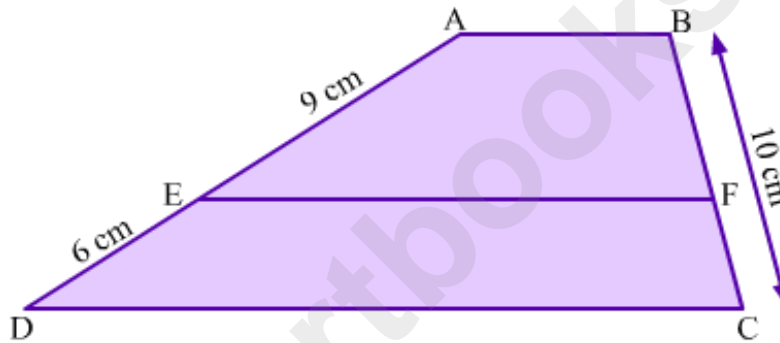
$$\frac{LQ}{LQ} = \frac{PM}{MR}$$
$$\frac{PM}{MR} = 1$$

$$\therefore PM = MR$$

Hence, proved

**Example 5:**

In trapezium ABCD,  $AB \parallel EF \parallel DC$ . Find the length of BF and FC.



**Solution:**

In trapezium ABCD,  $AB \parallel EF \parallel DC$ .

Here, AD and BC are transversals to parallel segments AB, EF and DC.

Intercepts made by AD are AE and ED while intercepts made by BC are BF and FC.

Using property of intercepts made by three parallel lines on a transversal, we obtain

$$\frac{AE}{ED} = \frac{BF}{FC}$$

$$\Rightarrow \frac{9}{6} = \frac{BF}{FC}$$

$$\Rightarrow FC = \frac{6}{9} BF \quad \dots(1)$$

Now,

$$BF + FC = 10$$

$$BF + \frac{6}{9}BF = 10$$

$$\frac{15}{9}BF = 10$$

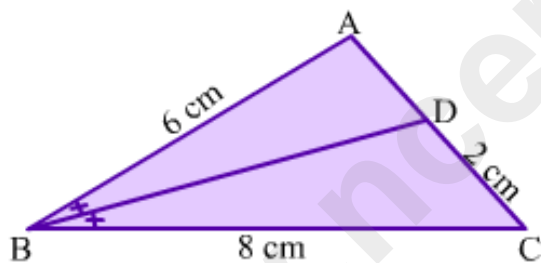
$$BF = 6$$

$$\therefore FC = \frac{6}{9} \times 6 = 4$$

Thus,  $BF = 6$  cm and  $FC = 4$  cm.

**Example 6:**

In  $\triangle ABC$ ,  $BD$  bisects  $\angle ABC$ . Find the length of  $AD$ .



**Solution:**

In  $\triangle ABC$ ,  $BD$  bisects  $\angle ABC$

Thus, by using the property of angle bisector of a triangle, we obtain

$$\frac{AB}{BC} = \frac{AD}{CD}$$

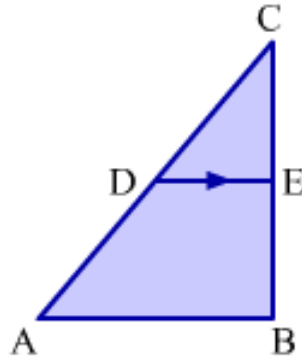
$$\Rightarrow \frac{6}{8} = \frac{AD}{2}$$

$$\Rightarrow AD = 1.5$$

Hence, the length of  $AD$  is 1.5 cm.

**Example 7.**

In the given figure,  $DE \parallel AB$ . If perimeter of  $\Delta ABC$  : perimeter of  $\Delta CDE = 4:5$  and  $DE = 1.2$  cm, then find the length of  $AB$ .



**Answer:**

It is given that, perimeter of  $\Delta ABC$  : perimeter of  $\Delta CDE = 4:5$  and  $DE = 1.2$ .  
In  $\Delta ABC$ ,  $DE \parallel AB$ .

By applying the corollary of basic proportionality theorem, we get

$$\frac{CD}{CA} = \frac{CE}{CB} = \frac{DE}{AB} = k (= \text{say})$$

$$CD = kCA, CE = kCB, DE = kAB$$

$$CD + CE + DE = k(CA + CB + AB)$$

$$\text{Perimeter of } \Delta CDE = k \text{Perimeter of } \Delta ABC$$

$$\frac{\text{Perimeter of } \Delta CDE}{\text{Perimeter of } \Delta ABC} = k$$

$$\therefore \frac{CD}{CA} = \frac{CE}{CB} = \frac{DE}{AB} = \frac{\text{Perimeter of } \Delta CDE}{\text{Perimeter of } \Delta ABC}$$

$$\Rightarrow \frac{1.2}{AB} = \frac{5}{4}$$

$$\Rightarrow AB = 1.2 \times \frac{5}{4} = 1.5 \text{ cm}$$

## Areas Of Similar Triangles

We know what similar triangles are. Now, let us learn about an interesting theorem related to areas of similar triangles.

The theorem states that:

**The ratio of areas of two similar triangles is equal to the ratio of squares of their corresponding sides.**

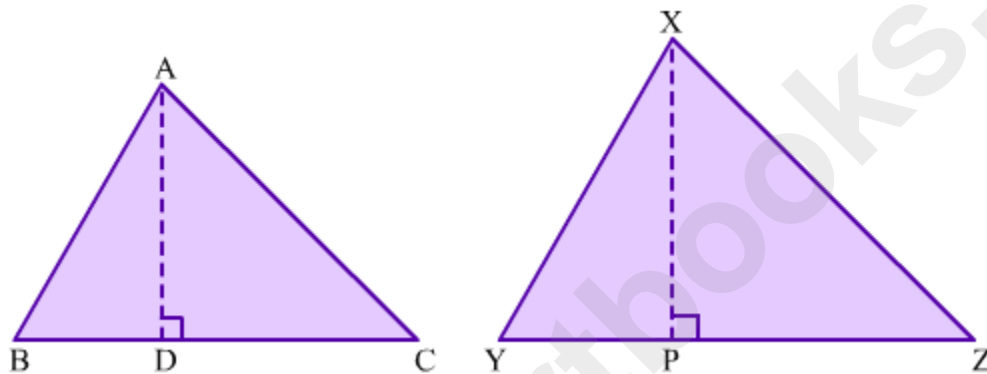
Let us prove this theorem.

**Given:**  $\triangle ABC \sim \triangle XYZ$

**To prove:**  $\frac{A(\triangle ABC)}{A(\triangle XYZ)} = \frac{AB^2}{XY^2} = \frac{BC^2}{YZ^2} = \frac{CA^2}{ZX^2}$

**Construction:** Draw segment AD perpendicular to BC and segment XP perpendicular to YZ.

**Proof:**



From the figure, we have

$$A(\triangle ABC) = \frac{1}{2} \times BC \times AD$$

$$\text{And, } A(\triangle XYZ) = \frac{1}{2} \times YZ \times XP$$

$$\therefore \frac{A(\triangle ABC)}{A(\triangle XYZ)} = \frac{BC \times AD}{YZ \times XP} \quad \dots(1)$$

Since  $\triangle ABC \sim \triangle XYZ$ , we have

$$\angle B = \angle Y, \frac{AB}{XY} = \frac{BC}{YZ} = \frac{CA}{ZX} \quad \dots(2)$$

In  $\triangle ADB$  and  $\triangle XPY$ , we have

$$\angle B = \angle Y$$

$$\angle ADB = \angle XPY \quad (\text{Both are right angles})$$

$$\therefore \triangle ADB \sim \triangle XPY \quad (\text{Using AA similarity test})$$

$$\therefore \frac{AB}{XY} = \frac{AD}{XP} \quad \dots(3)$$

$$\therefore \frac{A(\triangle ABC)}{A(\triangle XYZ)} = \frac{BC}{YZ} \times \frac{AB}{XY} \quad [\text{Using (1) and (3)}]$$

$$\Rightarrow \frac{A(\triangle ABC)}{A(\triangle XYZ)} = \frac{AB}{XY} \times \frac{AB}{XY} \quad [\text{Using (2)}]$$

$$\Rightarrow \frac{A(\triangle ABC)}{A(\triangle XYZ)} = \frac{AB^2}{XY^2}$$

Similarly, it can be shown that

$$\frac{A(\triangle ABC)}{A(\triangle XYZ)} = \frac{BC^2}{YZ^2} \quad \text{and} \quad \frac{A(\triangle ABC)}{A(\triangle XYZ)} = \frac{CA^2}{ZX^2}$$

$$\therefore \frac{A(\triangle ABC)}{A(\triangle XYZ)} = \frac{AB^2}{XY^2} = \frac{BC^2}{YZ^2} = \frac{CA^2}{ZX^2}$$

Thus, the ratio of areas of similar triangles is equal to the ratio of squares of their corresponding sides.

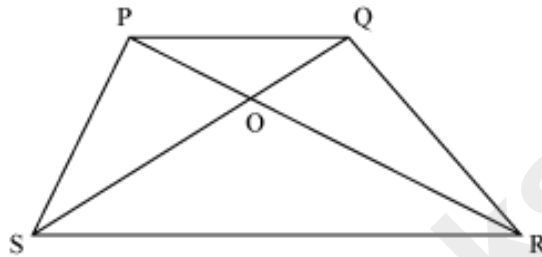
Let  $A_1$  and  $A_2$  be the areas of similar triangles and  $s_1$  and  $s_2$  be their corresponding sides.

Then

$$\frac{A_1}{A_2} = \frac{(s_1)^2}{(s_2)^2} = \left(\frac{s_1}{s_2}\right)^2$$

Now, let us learn to apply this formula with the help of an example.

Consider a trapezium PQRS in which  $SR = 3 PQ$ . The diagonals PR and QS intersect each other at O.



**If the area of  $\Delta POQ$  is 9 square cm, then what will be the area of  $\Delta SOR$ ?**

**Relation between areas, heights, medians and perimeters of similar triangles:**

Let  $A_1$  and  $A_2$  be the areas of two similar triangles such that  $s_1$  and  $s_2$  are their corresponding sides,  $h_1$  and  $h_2$  are their corresponding heights,  $m_1$  and  $m_2$  are their corresponding medians and  $P_1$  and  $P_2$  are their respective perimeters.

Then,

$$\frac{A_1}{A_2} = \frac{(s_1)^2}{(s_2)^2} = \frac{(h_1)^2}{(h_2)^2} = \frac{(m_1)^2}{(m_2)^2} = \frac{(P_1)^2}{(P_2)^2}$$

Let us go through some examples based on the areas of similar triangles.

**Example 1:**

**The ratio of areas of two similar triangles is 16:25. Find the ratio of their corresponding sides.**

**Solution:**

We know that,

Ratio of areas of similar triangles = (Ratio of corresponding sides)<sup>2</sup>

$$\Rightarrow \frac{16}{25} = (\text{Ratio of corresponding sides})^2$$

$$\text{Ratio of corresponding sides} = \sqrt{\frac{16}{25}} = \frac{4}{5}$$

$$= 4:5$$

**Example 2:**

The areas of two similar triangles are  $25 \text{ cm}^2$  and  $100 \text{ cm}^2$ . If one side of the first triangle is  $4 \text{ cm}$ , then find the corresponding side of the other triangle.

**Solution:**

Let ABC and DEF be two triangles whose areas are  $25 \text{ cm}^2$  and  $100 \text{ cm}^2$  respectively.

Let  $AB = 4 \text{ cm}$

Then, we have to find DE.

Since the two triangles ABC and DEF are similar,

$$\therefore \frac{\text{Area of } \triangle ABC}{\text{Area of } \triangle DEF} = \frac{(AB)^2}{(DE)^2}$$

$$\frac{25}{100} = \frac{(4)^2}{(DE)^2}$$

$$\frac{1}{4} = \frac{16}{(DE)^2}$$

$$(DE)^2 = 16 \times 4$$

$$(DE)^2 = 64$$

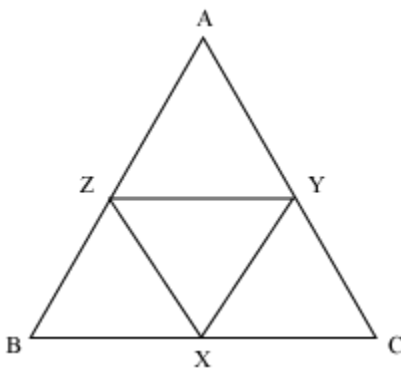
$$DE = 8 \text{ cm}$$

Thus, the corresponding side of the other triangle is  $8 \text{ cm}$ .

**Example 3:**

In a triangle ABC, X, Y, and Z are the mid-points of the sides BC, AC, and AB respectively. Find the ratios of the areas of  $\triangle ABC$  and  $\triangle XYZ$ .

**Solution:**



Here, X, Y, and Z are the mid-points of sides BC, AC, and AB respectively.

We know that the line joining the mid-points of two sides is parallel to the third side and its length is half of the third side.

$$\therefore XY \parallel AB \text{ and } XY = \frac{AB}{2}$$

$$YZ \parallel BC \text{ and } YZ = \frac{BC}{2}$$

$$\text{Again, } XZ \parallel AC \text{ and } XZ = \frac{AC}{2}$$

As,  $XY \parallel AB$ ,  $YZ \parallel BC$ , and  $XZ \parallel AC$ ,

$\therefore$  Quadrilaterals AYXZ, BXYZ, and CXZY are parallelograms.

$$\therefore \angle BAC = \angle ZXY, \angle ABC = \angle ZYX, \text{ and } \angle ACB = \angle XZY$$

Using AAA similarity criterion, we obtain

$$\triangle ABC \sim \triangle XYZ$$

$$\therefore \frac{\text{Area of } \triangle ABC}{\text{Area of } \triangle XYZ} = \left(\frac{AB}{XY}\right)^2$$

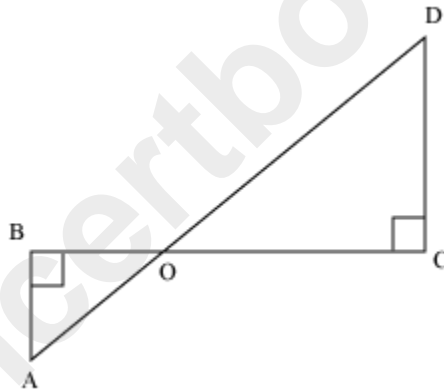
$$\frac{\text{Area of } \triangle ABC}{\text{Area of } \triangle XYZ} = \left(\frac{AB}{\left(\frac{AB}{2}\right)}\right)^2$$

$$\frac{\text{Area of } \triangle ABC}{\text{Area of } \triangle XYZ} = \frac{4}{1}$$

Area of  $\triangle ABC$ : Area of  $\triangle XYZ = 4:1$

#### Example 4:

In the given figure,  $AB$  and  $CD$  are perpendiculars to the line segment  $BC$ . Also,  $AB = 5$  cm,  $CD = 8$  cm, and area of  $\triangle AOB$  is  $175$  cm<sup>2</sup>. Find the area of  $\triangle COD$ .



#### Solution:

Here,  $\triangle AOB$  and  $\triangle DOC$  are similar triangles because

$$\angle ABO = \angle DCO \text{ (Each } 90^\circ)$$

$$\angle AOB = \angle COD \text{ (Vertically opposite angles)}$$

Therefore, by AAA similarity criterion,

$$\triangle AOB \sim \triangle DOC$$

$$\therefore \frac{\text{Area of } \triangle AOB}{\text{Area of } \triangle DOC} = \frac{(AB)^2}{(CD)^2}$$

$$\frac{175}{\text{Area of } \triangle DOC} = \frac{(5)^2}{(8)^2}$$

$$\begin{aligned}\text{Area of } \triangle DOC &= \frac{175 \times 64}{25} \\ &= 7 \times 64 \\ &= 448 \text{ cm}^2\end{aligned}$$

Thus, the area of  $\triangle COD$  is  $448 \text{ cm}^2$ .

## Maps and Models

The concept of similarity has a lot of applications in real life.

Let us see how this concept is used in maps and models.

In maps, the distance between any two objects is proportional to the actual distance between the two objects. Thus, the map and the object are similar to each other.

Maps are always drawn by taking a suitable scale.

For example, the distance between Anshika's and Nakul's houses is 500 m.

If we draw the map of their locality, then we cannot mark their houses 500 m apart. This is because this distance is very large. So, we need to choose a suitable scale.

Let us choose the scale as  $100 \text{ m} = 1 \text{ cm}$

Then, the distance between their houses on the map = 5 cm

The scale of a map can also be written in the form of a ratio.

**“The scale of a map can be defined as the ratio of the distance between two points on the map to the actual distance of these two points on the ground.”**

The scale given in the above example can be written as  $1 : 100$ .

This ratio is known as the **scale factor**, and is denoted by the letter  $k$ .

$$\therefore k = \frac{1}{100}$$

The lengths in the model of an object are proportional to the actual lengths of the object.

In the case of models:

$$k = \frac{\text{Length of the model}}{\text{Length of the object}} = \frac{\text{Height of the model}}{\text{Height of the object}}$$

Let us learn some facts about the scale factor.

(1) If the scale factor is  $k$ , then each side of the model is  $k$  times the corresponding side of the object.

(2)

Scale factor	Transformation	Size
$k = 1$	Identify transformation	Size of the model = Size of the object
$k > 1$	Enlargement	Size of the model > Size of the object
$k < 1$	Reduction	Size of the model < Size of the object

Let us solve some examples based on maps and models.

**Example 1:**

**An architect makes the model of a resort. There is a swimming pool in the resort. The dimensions of the swimming pool in the model are 8 cm × 5 cm × 2 cm.**

**What is the capacity of the pool in the resort? The scale factor is 1/100.**

**Solution:**

In the case of the model:

Length of the pool = 8 cm

Breadth of the pool = 5 cm

Depth of the pool = 2 cm

$$\text{Length of the actual pool} = \frac{1}{k} \times \text{Length of the model}$$

$$= \frac{1}{100} \times 8 \text{ cm}$$

$$= 800 \text{ cm} = 8 \text{ m}$$

$$\text{Breadth of the actual pool} = \frac{1}{k} \times \text{Breadth of the model}$$

$$\frac{1}{100} \times 5 \text{ cm} = 500 \text{ cm} = 5 \text{ m}$$

$$\text{Depth of the actual pool} = \frac{1}{k} \times \text{Depth of the model}$$

$$= \frac{1}{100} \times 2 \text{ cm} = 200 \text{ cm} = 2 \text{ m}$$

$$\text{Volume of the actual pool} = 8 \text{ m} \times 5 \text{ m} \times 2 \text{ m}$$

$$= 80 \text{ sq. m}$$

Thus, the capacity of the pool in the resort is 80 sq. m.