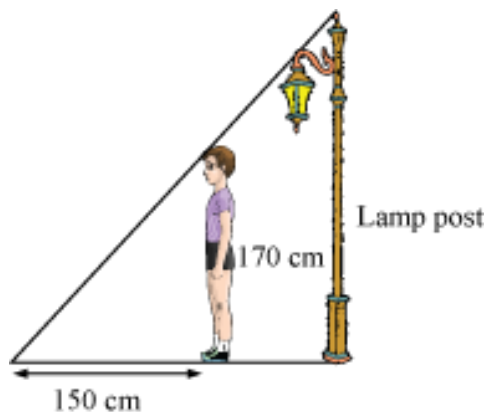


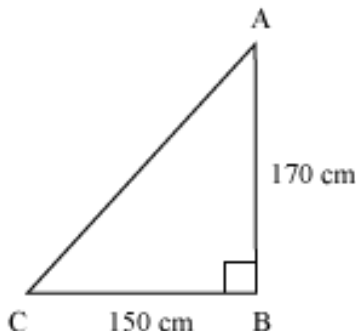
# Trigonometrical Identities

## Trigonometric Ratios

Suppose a boy is standing in front of a lamp post at a certain distance. The height of the boy is 170 cm and the length of his shadow is 150 cm.



You can see from the above figure that the boy and his shadow form a right-angled triangle as shown in the figure below.



The ratio of the height of the boy to his shadow is 170:150 i.e., 17:15.

**Is this ratio related to either of the angles of  $\triangle ABC$ ?**

We can also conclude the following:

$$\cos A = \frac{1}{\sec A}, \tan A = \frac{1}{\cot A}$$

Also, note that

$$\tan A = \frac{\sin A}{\cos A} \text{ and } \cot A = \frac{\cos A}{\sin A}$$

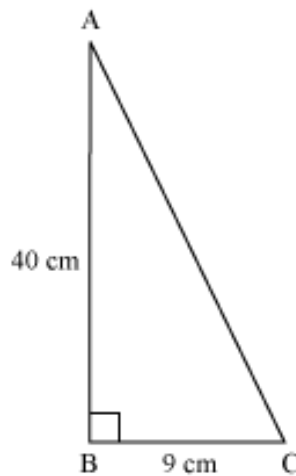
Let us now solve some more examples based on trigonometric ratios.

**Example 1:**

**In a triangle ABC, right-angled at B, side AB = 40 cm and BC = 9 cm. Find the value of sin A, cos A, and tan A.**

**Solution:**

It is given that AB = 40 cm and BC = 9 cm



Using Pythagoras theorem in  $\triangle ABC$ , we obtain

$$(AC)^2 = (AB)^2 + (BC)^2$$

$$(AC)^2 = (40)^2 + (9)^2$$

$$(AC)^2 = 1600 + 81$$

$$(AC)^2 = 1681$$

$$(AC)^2 = (41)^2$$

$$AC = 41 \text{ cm}$$

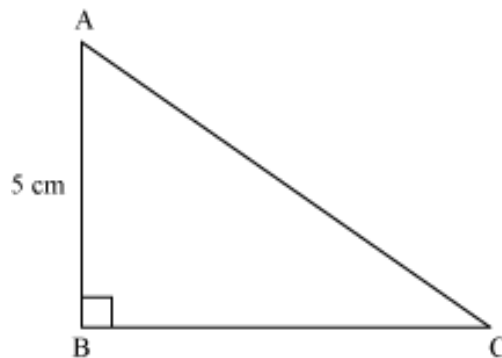
$$\text{Now, } \sin A = \frac{BC}{AC} = \frac{9}{41}$$

$$\cos A = \frac{AB}{AC} = \frac{40}{41}$$

$$\tan A = \frac{BC}{AB} = \frac{9}{40}$$

**Example 2:**

From the given figure, find the values of cosec C and cot C, if  $AC = BC + 1$ .



**Solution:**

Now, it is given that  $AB = 5$  cm and

$$AC = BC + 1 \dots (1)$$

By Pythagoras theorem, we obtain

$$(AB)^2 + (BC)^2 = (AC)^2$$

$$\Rightarrow (AC)^2 - (BC)^2 = (AB)^2$$

$$\Rightarrow (BC + 1)^2 - (BC)^2 = (5)^2 \text{ [Using (1)]}$$

$$\Rightarrow (BC)^2 + 1 + 2BC - (BC)^2 = 25$$

$$\Rightarrow 2BC = 25 - 1$$

$$\Rightarrow 2BC = 24$$

$$\Rightarrow BC = 12 \text{ cm}$$

$$\therefore AC = 12 + 1 = 13 \text{ cm}$$

Thus,  $\operatorname{cosec} C = AC/AB$

$$= 13/5$$

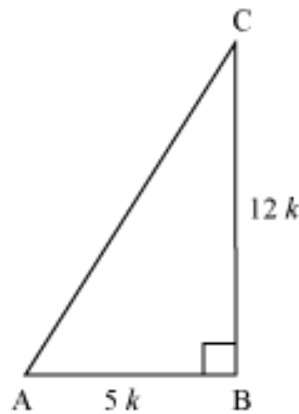
And,  $\cot C = BC/AB$

$$= 12/5$$

**Example 3:**

**In a right-angled triangle ABC, which is right-angled at B,  $\tan A = 12/5$ . Find the value of  $\cos A$  and  $\sec A$ .**

**Solution:**



It is given that  $\tan A = 12/5$

We know that  $\tan A = BC/AB$

$$\Rightarrow \frac{BC}{AB} = \frac{12}{5}$$

Let  $BC = 12k$  and  $AB = 5k$

Using Pythagoras theorem in  $\triangle ABC$ , we obtain

$$(AC)^2 = (AB)^2 + (BC)^2$$

$$= (5k)^2 + (12k)^2$$

$$= 25k^2 + 144k^2$$

$$(AC)^2 = 169k^2$$

$$AC = 13k$$

$$\text{Now, } \cos A = \frac{\text{Side adjacent to } \angle A}{\text{Hypotenuse}}$$

$$= \frac{5k}{13k}$$

$$= \frac{5}{13}$$

$$\text{Sec } A = \frac{1}{\cos A}$$

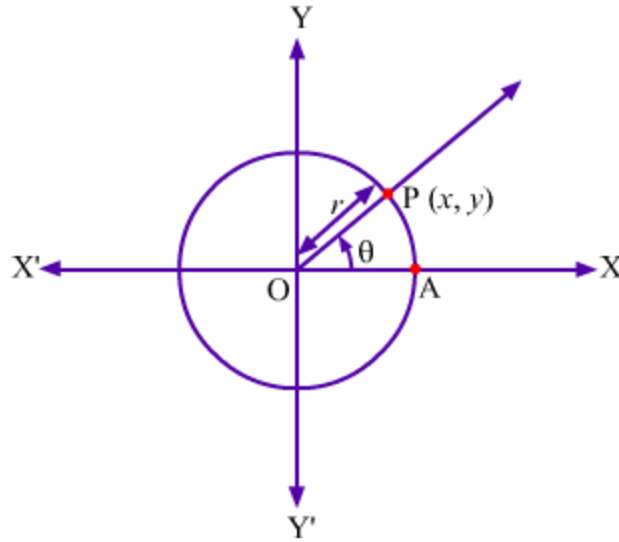
$$= \frac{1}{\frac{5}{13}}$$

$$= \frac{13}{5}$$

## Trigonometric Identities

Now, let us prove these identities.

Let us take a standard circle with radius  $r$  such that it intersects the X-axis at point A. Also, let the initial arm OA is rotated in anti-clockwise direction by an angle ?



In the figure, the terminal arm intersects the circle at point P (x, y) where  $x, y \neq 0$  and  $OP = r$ .

By the definition of trigonometric ratios, we have

$$\sin \theta = \frac{y}{r}, \quad \operatorname{cosec} \theta = \frac{r}{y}$$

$$\cos \theta = \frac{x}{r}, \quad \sec \theta = \frac{r}{x}$$

$$\tan \theta = \frac{y}{x}, \quad \cot \theta = \frac{x}{y}$$

Now, OP is a distance between origin O (0, 0) and point P (x, y) which can be obtained by distance formula as follows:

$$OP = \sqrt{(x-0)^2 + (y-0)^2}$$

$$\Rightarrow r = \sqrt{x^2 + y^2}$$

$$\Rightarrow r^2 = x^2 + y^2 \quad \dots(i)$$

(1) On dividing both sides of the equation (i) by  $r^2$ , we get

$$\frac{r^2}{r^2} = \frac{x^2}{r^2} + \frac{y^2}{r^2}$$

$$\Rightarrow 1 = \left(\frac{x}{r}\right)^2 + \left(\frac{y}{r}\right)^2$$

$$\Rightarrow 1 = \cos^2 \theta + \sin^2 \theta$$

$$\Rightarrow \sin^2 \theta + \cos^2 \theta = 1$$

From this identity, we get two results

$$\text{I. } \sin^2 \theta = 1 - \cos^2 \theta$$

$$\text{II. } \cos^2 \theta = 1 - \sin^2 \theta$$

(2) On dividing both sides of the equation (i) by  $x^2$  ( $x \neq 0$ ), we get

$$\frac{r^2}{x^2} = \frac{x^2}{x^2} + \frac{y^2}{x^2}$$

$$\Rightarrow \left(\frac{r}{x}\right)^2 = 1 + \left(\frac{y}{x}\right)^2$$

$$\Rightarrow \sec^2 \theta = 1 + \tan^2 \theta$$

$$\Rightarrow 1 + \tan^2 \theta = \sec^2 \theta$$

From this identity, we get two results

$$\text{I. } \tan^2 \theta = \sec^2 \theta - 1$$

$$\text{II. } \sec^2 \theta - \tan^2 \theta = 1$$

(3) On dividing both sides of the equation (i) by  $y^2$  ( $y \neq 0$ ), we get

$$\frac{r^2}{y^2} = \frac{x^2}{y^2} + \frac{y^2}{y^2}$$

$$\Rightarrow \left(\frac{r}{y}\right)^2 = \left(\frac{x}{y}\right)^2 + 1$$

$$\Rightarrow \operatorname{cosec}^2 \theta = \cot^2 \theta + 1$$

$$\Rightarrow 1 + \cot^2 \theta = \operatorname{cosec}^2 \theta$$

From this identity, we get two results

$$\text{I. } \cot^2 \theta = \operatorname{cosec}^2 \theta - 1$$

$$\text{II. } \operatorname{cosec}^2 \theta - \cot^2 \theta = 1$$

### Corollary:

(i) When  $x = 0$  then we have

$$\begin{aligned} \sin \theta &= \frac{y}{r}, & \operatorname{cosec} \theta &= \frac{r}{y} \\ \cos \theta &= \frac{x}{r} = \frac{0}{r} = 0, & \sec \theta &= \frac{r}{x} = \frac{r}{0} (\text{Undefined}) \\ \tan \theta &= \frac{y}{x} = \frac{y}{0} (\text{Undefined}), & \cot \theta &= \frac{x}{y} = \frac{0}{y} = 0 \end{aligned}$$

In this case, the identities  $\sin^2 \theta + \cos^2 \theta = 1$  and  $1 + \cot^2 \theta = \operatorname{cosec}^2 \theta$  exist but the identity  $1 + \tan^2 \theta = \sec^2 \theta$  does not exist.

(ii) When  $y = 0$  then we have

$$\begin{aligned} \sin \theta &= \frac{y}{r} = \frac{0}{r} = 0, & \operatorname{cosec} \theta &= \frac{r}{y} = \frac{r}{0} (\text{Undefined}) \\ \cos \theta &= \frac{x}{r}, & \sec \theta &= \frac{r}{x} \\ \tan \theta &= \frac{y}{x} = \frac{0}{x} = 0, & \cot \theta &= \frac{x}{y} = \frac{x}{0} (\text{Undefined}) \end{aligned}$$

In this case, the identities  $\sin^2 \theta + \cos^2 \theta = 1$  and  $1 + \tan^2 \theta = \sec^2 \theta$  exist but the identity  $1 + \cot^2 \theta = \operatorname{cosec}^2 \theta$  does not exist.

Let us now solve some more problems using trigonometric identities.

### Example 1:



**Find the value of the expression ( $\sec^2 27^\circ - \tan 27^\circ \cdot \cot 63^\circ$ ).**

**Solution:**

$$\sec^2 27^\circ - \tan 27^\circ \cdot \cot 63^\circ = \sec^2 27^\circ - \tan 27^\circ \cdot \cot (90^\circ - 27^\circ)$$

[ $27^\circ$  and  $63^\circ$  are complementary angles]

$$= \sec^2 27^\circ - \tan 27^\circ \cdot \tan 27^\circ [\cot (90^\circ - ?) = \tan ?]$$

$$= \sec^2 27^\circ - \tan^2 27^\circ$$

$$= 1 + \tan^2 27^\circ - \tan^2 27^\circ [\text{Using the identity } 1 + \tan^2 \theta = \sec^2 \theta]$$

$$= 1$$

Thus, the value of the given expression is 1.

**Example 2:**

**Write all the trigonometric ratios in terms of  $\sin A$ .**

**Solution:**

Using the identity

$$\sin^2 A + \cos^2 A = 1,$$

$$\text{we can write, } \cos^2 A = 1 - \sin^2 A$$

Taking square root on both sides,

$$\cos A = \sqrt{1 - \sin^2 A} \quad \dots(i)$$

$$\text{Now, } \tan A = \frac{\sin A}{\cos A}$$

$$= \frac{\sin A}{\sqrt{1 - \sin^2 A}} \quad [\text{Using (i)}]$$

$$\Rightarrow \tan A = \frac{\sin A}{\sqrt{1 - \sin^2 A}} \quad \dots(ii)$$

$$\cot A = \frac{1}{\tan A}$$

$$\Rightarrow \cot A = \frac{\sqrt{1 - \sin^2 A}}{\sin A} \quad \dots(\text{iii})$$

$$\sec A = \frac{1}{\cos A}$$

$$\Rightarrow \sec A = \frac{1}{\sqrt{1 - \sin^2 A}} \quad \dots(\text{iv})$$

[Using (i)]

$$\text{and, cosec } A = \frac{1}{\sin A} \quad \dots(\text{v})$$

The trigonometric ratios in terms of  $\sin A$  are given by (i), (ii), (iii), (iv), and (v).

### Example 3:

Simplify the following expression.

$$[(1 + \cot A - \text{cosec } A)(1 + \tan A + \sec A)]$$

**Solution:**

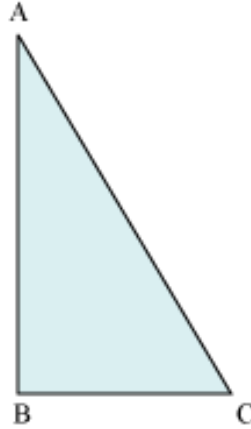
$$(1 + \cot A - \text{cosec } A)(1 + \tan A + \sec A)$$

$$\begin{aligned} &= \left(1 + \frac{\cos A}{\sin A} - \frac{1}{\sin A}\right) \left(1 + \frac{\sin A}{\cos A} + \frac{1}{\cos A}\right) \\ &= \left(\frac{\sin A + \cos A - 1}{\sin A}\right) \left(\frac{\cos A + \sin A + 1}{\cos A}\right) \\ &= \frac{(\sin A + \cos A)^2 - 1^2}{\sin A \cdot \cos A} \\ &= \frac{\sin^2 A + \cos^2 A + 2 \cdot \sin A \cdot \cos A - 1}{\sin A \cdot \cos A} \\ &= \frac{1 + 2 \cdot \sin A \cdot \cos A - 1}{\sin A \cdot \cos A} = \frac{2 \cdot \sin A \cdot \cos A}{\sin A \cdot \cos A} = 2 \end{aligned}$$

Thus, the value of the given expression is 2.

## Trigonometric Ratios Of Complementary Angles

Consider the following figure.



Here, a right-angled triangle ABC has been shown. In this triangle, suppose that the value of  $\sin C$  is  $12/13$ .

**Can we find the value of  $\cos A$ ?**

We can use these relations for simplifying the given expression.

For example: Let us express  **$\sec 55^\circ - \operatorname{cosec} 89^\circ$**  in terms of trigonometric ratios of angles between  $0^\circ$  and  $45^\circ$ .

Now, how can we do so? Let us see.

Since  $55^\circ$  and  $35^\circ$  are complementary angles and also  $89^\circ$  and  $1^\circ$  are complementary angles, we can write  $55^\circ$  as  $(90^\circ - 35^\circ)$  and  $89^\circ$  as  $(90^\circ - 1^\circ)$ .

Therefore,

$$\sec 55^\circ - \operatorname{cosec} 89^\circ = \sec (90^\circ - 35^\circ) - \operatorname{cosec} (90^\circ - 1^\circ)$$

$$= \operatorname{cosec} 35^\circ - \sec 1^\circ$$

$$[\because \sec (90^\circ - A) = \operatorname{cosec} A \text{ and } \operatorname{cosec} (90^\circ - A) = \sec A]$$

$$\therefore \sec 55^\circ - \operatorname{cosec} 89^\circ = \operatorname{cosec} 35^\circ - \sec 1^\circ$$

Let us now solve some more examples involving trigonometric ratios of complementary angles.

**Example 1:**

Find the value of  $\sin 53^\circ - \cos 37^\circ$ .

**Solution:**

We know that  $53^\circ$  and  $37^\circ$  are complementary angles as

$$53^\circ + 37^\circ = 90^\circ$$

$\therefore$  We can write  $37^\circ$  as  $(90^\circ - 53^\circ)$ .

$$\therefore \sin 53^\circ - \cos 37^\circ = \sin 53^\circ - \cos (90^\circ - 53^\circ)$$

$$= \sin 53^\circ - \sin 53^\circ$$

$$[\because \cos (90^\circ - A) = \sin A]$$

$$= 0$$

Thus, the value of  $(\sin 53^\circ - \cos 37^\circ)$  is 0.

**Example 2:**

Evaluate  $\frac{\operatorname{cosec} 27^\circ}{\sec 63^\circ}$

**Solution:**

Here,  $27^\circ$  and  $63^\circ$  are complementary angles as  $27^\circ + 63^\circ = 90^\circ$

$\therefore$  We can write  $27^\circ = 90^\circ - 63^\circ$

Now,

$$\begin{aligned} \frac{\operatorname{cosec} 27^\circ}{\sec 63^\circ} &= \frac{\operatorname{cosec} (90^\circ - 63^\circ)}{\sec 63^\circ} \\ &= \frac{\sec 63^\circ}{\sec 63^\circ} & [\because \operatorname{cosec} (90^\circ - A) = \sec A] \\ &= 1 \end{aligned}$$

**Example 3:**

**Prove that  $\tan 2A = \cot 3A$ , when  $A = 18^\circ$ .**

**Solution:**

When  $A = 18^\circ$ ,

$$\text{L.H.S} = \tan 2A = \tan (2 \times 18^\circ)$$

$$= \tan 36^\circ$$

$$\text{R.H.S} = \cot 3A = \cot (3 \times 18)$$

$$= \cot 54^\circ$$

$54^\circ$  and  $36^\circ$  are complementary angles.

$\therefore$  We can write  $54^\circ$  as  $90^\circ - 36^\circ$ .

Therefore,  $\cot 3A = \cot 54^\circ$

$$= \cot (90^\circ - 36^\circ)$$

$$= \tan 36^\circ \quad [\because \cot (90^\circ - A) = \tan A]$$

$$\therefore \text{L.H.S} = \text{R.H.S} = \tan 36^\circ$$

$$\therefore \tan 2A = \cot 3A$$

**Example 4:**

**If  $\sin A = \cos A$ , then prove that  $A = 45^\circ$ .**

**Solution:**

It is given that  $\sin A = \cos A$

$$\Rightarrow \sin A = \sin (90^\circ - A)$$

$$[\because \sin (90^\circ - A) = \cos A]$$

$$\Rightarrow A = 90^\circ - A$$

$$\Rightarrow 2A = 90^\circ$$

$$\Rightarrow A = \frac{90^\circ}{2}$$

$$\Rightarrow A = 45^\circ$$

Hence, proved

### Example 5:

If P, Q, and R are interior angles of a triangle PQR, which is right-angled at Q, then show that

$$\cot\left(\frac{P+R}{2}\right) = \tan \frac{Q}{2}$$

### Solution:

Now, P, Q, and R are the interior angles of the triangle PQR. Therefore, their sum should be  $180^\circ$ .

$$\therefore P + R = 180 - Q$$

$$\text{Now, consider the L.H.S.} = \cot\left(\frac{P+R}{2}\right)$$

$$= \cot\left(\frac{180^\circ - Q}{2}\right)$$

$$= \cot\left(90^\circ - \frac{Q}{2}\right)$$

$$= \tan \frac{Q}{2} \quad [\because \cot(90^\circ - A) = \tan A]$$

$$= \text{R.H.S.}$$

$$\therefore \cot\left(\frac{P+R}{2}\right) = \tan \frac{Q}{2}$$

Hence, proved

### Example 6:

**Prove that**

$$\tan 1^\circ \times \tan 2^\circ \times \tan 3^\circ \dots \tan 87^\circ \times \tan 88^\circ \times \tan 89^\circ = 1$$

**Solution:**

Here,  $1^\circ$  and  $89^\circ$  are complementary angles as  $1^\circ + 89^\circ = 90^\circ$

Therefore, we can write  $89^\circ = 90^\circ - 1^\circ$

Similarly,  $88^\circ = 90^\circ - 2^\circ$

$87^\circ = 90^\circ - 3^\circ$

$46^\circ = 90^\circ - 44^\circ$  and so on

Now, the L.H.S is

$$\tan 1^\circ \times \tan 2^\circ \times \tan 3^\circ \dots \tan 44^\circ \times \tan 45^\circ \times \tan 46^\circ \dots \tan 87^\circ \times \tan 88^\circ \times \tan 89^\circ$$

$$= \tan 1^\circ \times \tan 2^\circ \times \tan 3^\circ \dots \tan 44^\circ \times \tan 45^\circ \times \tan (90^\circ - 44^\circ) \dots \tan (90^\circ - 3^\circ) \tan (90^\circ - 2^\circ) \tan (90^\circ - 1^\circ)$$

$$= \tan 1^\circ \times \tan 2^\circ \times \tan 3^\circ \dots \tan 44^\circ \times \tan 45^\circ \times \cot 44^\circ \dots \cot 3^\circ \times \cot 2^\circ \times \cot 1^\circ$$

$$[\because \tan (90^\circ - A) = \cot A]$$

$$= \tan 1^\circ \times \tan 2^\circ \times \tan 3^\circ \dots \tan 44^\circ \times \tan 45^\circ \times \frac{1}{\tan 44^\circ} \dots \frac{1}{\tan 3^\circ} \times \frac{1}{\tan 2^\circ} \times \frac{1}{\tan 1^\circ}$$
$$\left[ \because \cot A = \frac{1}{\tan A} \right]$$

$$= \tan 45^\circ$$

$$= 1$$

$$= \text{R.H.S}$$

$$\therefore \tan 1^\circ \times \tan 2^\circ \times \tan 3^\circ \dots \tan 87^\circ \times \tan 88^\circ \times \tan 89^\circ = 1$$

Hence, proved

## Trigonometric Tables

We know the sine, cosine, and tangent values of angles such as  $0^\circ$ ,  $30^\circ$ ,  $45^\circ$ ,  $60^\circ$ , and  $90^\circ$ .

However, what about angles such as  $1^\circ$ ,  $31^\circ$ ,  $44^\circ$ ,  $66^\circ$ , and so on?

Do sine, cosine, and tangent values exist for these angles?

If yes, then how do we find these values?

Well, sine, cosine, and tangent values exist for all angles  $\theta$ , where  $\theta \in R$

If we know the sine, cosine, and tangent values for  $\theta$  lying between  $0^\circ$  and  $90^\circ$ , then we can find the trigonometric ratio values for all other angles using trigonometric identities and complementary angle identities.

To find the sine, cosine, and tangent values of all angles between  $0^\circ$  and  $90^\circ$ , we use the trigonometric tables.

Let us discuss some more examples based on trigonometric tables.

**Example 1:**

What is the value of  $\sin 29^\circ 44'$ ?

**Solution:**

We read the table of natural sines in the horizontal line, which begins with  $29^\circ$ , and in the vertical column headed by  $42'$ .

$$\sin 29^\circ 42' = 0.4955$$

Now, we read, in the same horizontal line, the value written in the mean difference column headed by  $2' (44' = 42' + 2')$ .

It is found to be 5.

As  $\theta$  increases, sine value increases.

$\therefore$  The mean difference value is to be added.

$$\begin{aligned}\therefore \sin 29^\circ 44' &= \sin (29^\circ 42' + 2') \\ &= 0.4955 + 0.0005 = 0.4960\end{aligned}$$



**Example 2:**

Using trigonometric tables, find the measure of angle  $\theta$  when  $\cos \theta = 0.2473$ .

**Solution:**

Given:  $\cos \theta = 0.2473$

$$\cos 75^\circ 42' = 0.2470$$

$$\therefore \text{Difference} = 0.0003$$

Mean difference for  $1' = 0.0003$

$$\begin{aligned}\therefore \theta &= 75^\circ 42' - 1' \\ &= 75^\circ 41'\end{aligned}$$

Therefore, the required angle is  $75^\circ 41'$ .

**Example 3:**

Using trigonometric tables, find the value of  $\cos \theta - \sin \theta$  when  $\tan \theta = 0.8977$

**Solution:**

$$\tan \theta = 0.8977$$

$$\tan 41^\circ 54' = 0.8972$$

$$\therefore \text{Difference} = 0.0005$$

Mean difference for  $1' = 0.0005$

$$\theta = 41^\circ 54' + 1' = 41^\circ 55'$$

To find the value of  $\cos \theta - \sin \theta$ , we first find the value of  $\cos 41^\circ 55'$  and  $\sin 41^\circ 55'$ .

$$\cos 41^\circ 54' = 0.7443$$

$$\therefore \text{Difference} = 1'$$

Mean difference for  $1' = 0.0002$

$$\therefore \cos 41^{\circ}55' = 0.7441$$

$$\sin 41^{\circ}54' = 0.6678$$

$$\therefore \text{Difference} = 1'$$

$$\text{Mean difference of } 1' = 0.0002$$

$$\therefore \sin 41^{\circ}55' = 0.6680$$

$$\cos 41^{\circ}55' - \sin 41^{\circ}55' = 0.7441 - 0.6680 = 0.0761$$