

Section 2: Trigonometric equations

Notes and Examples

In this section you learn how to solve trigonometric equations.

These notes contain subsections on

- [Principal values](#)
- [Solving simple trigonometric equations](#)
- [More complicated examples of trigonometric equations.](#)

Principal values

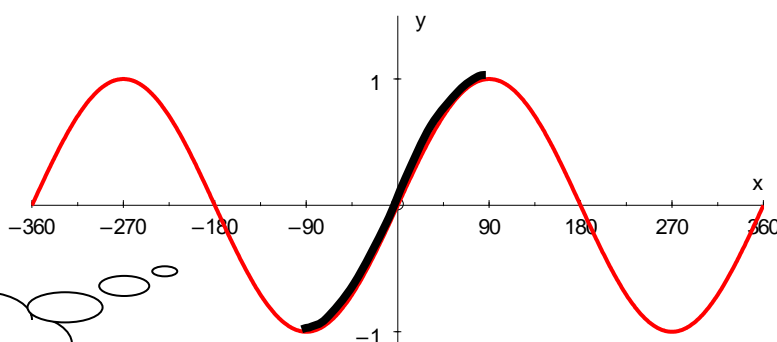
There are infinitely many roots to an equation like $\sin \theta = \frac{1}{2}$.

Your calculator will only give one root – the **principal value**.

You find this by pressing the calculator keys for $\arcsin 0.5$ (or $\sin^{-1} 0.5$ or $\text{invsin } 0.5$). Check that you can get the answer of 30° .

You can find other roots by looking at the symmetry of the appropriate graph.

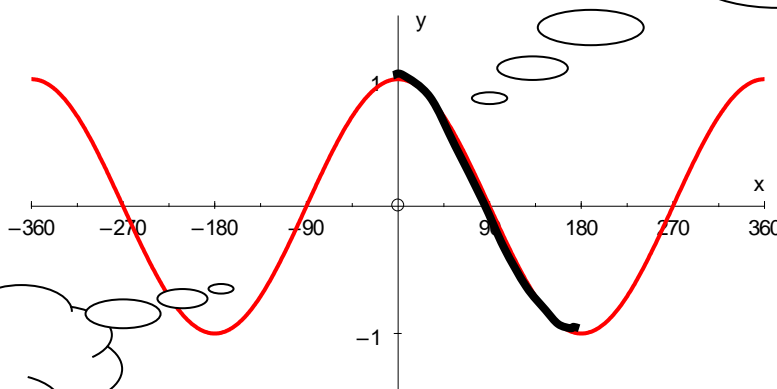
$$y = \sin \theta$$



A second root in a 360° cycle can be found by $180^\circ - \theta$

When you use the inverse cosine function, your calculator will always give you an answer from 0° to 180° .

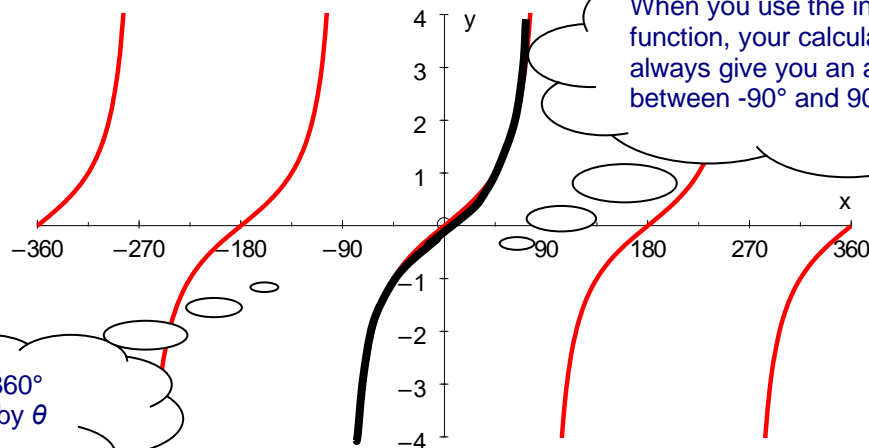
$$y = \cos \theta$$



A second root in a 360° cycle can be found by $360^\circ - \theta$

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$$y = \tan \theta$$



Alternatively, you can use the quadrant diagram to find other roots, by thinking about which quadrants the roots will be in.

Solving simple trigonometric equations

Because there are infinitely many roots to a trigonometric equation you are only ever asked to find a few of them! Any question at this level asking you to solve a trigonometric equation will also give you the interval or range of values in which the roots must lie, e.g. you might be asked to solve $\tan \theta = 2$ for $0^\circ \leq \theta \leq 360^\circ$.

You can only directly solve trigonometric equations like $\sin \theta = \frac{1}{2}$ or $\cos \theta = \frac{1}{4}$ or $\tan \theta = -2$. Here is an example.



Example 1

Solve $\sin \theta = \frac{\sqrt{3}}{2}$ for $-360^\circ \leq \theta \leq 360^\circ$.

Solution

$$\sin \theta = \frac{\sqrt{3}}{2} \Rightarrow \theta = 60^\circ$$

There will be a second root in the second quadrant.

$180^\circ - 60^\circ = 120^\circ$ is also a root.

Since $y = \sin \theta$ has a period of 360° any other roots can be found by adding/subtracting 360° to these two roots.

So the other roots are:

$$60^\circ - 360^\circ = -300^\circ$$

and $120^\circ - 360^\circ = -240^\circ$

So the values of θ for which $\sin \theta = \frac{\sqrt{3}}{2}$ are $-300^\circ, -240^\circ, 60^\circ, 120^\circ$.



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Almost all equations of the type in Example 1 have two roots in the range $0^\circ \leq x < 360^\circ$.

However, this is not true of all trigonometric equations. Suppose, for example, that you want to solve the equation $\sin 2x = 0.5$ in the range $0^\circ \leq x < 360^\circ$. You can find that $2x = 30^\circ$ or 150° , which means that $x = 15^\circ$ or 75° . However, there are two further roots in the range $0^\circ \leq x < 360^\circ$, given by $2x = 30^\circ + 360^\circ = 390^\circ \Rightarrow x = 195^\circ$, and $2x = 150^\circ + 360^\circ = 510^\circ \Rightarrow x = 255^\circ$. So there are four roots: $x = 15^\circ, 75^\circ, 195^\circ, 255^\circ$.

This means that if you are solving an equation of the form $\sin nx = k$, you need to adjust the range in which you look for initial roots.



Example 2

Solve each of the following equations in the given range:

- (i) $\tan 3x = 1$ for $0 \leq x < 360^\circ$
- (ii) $\cos(2x + 40^\circ) = 0.5$ for $-180^\circ < x \leq 180^\circ$

Solution

(i) $\tan 3x = 1$
 $3x = 45^\circ, 225^\circ, 405^\circ, 585^\circ, 765^\circ, 945^\circ$
 $x = 15^\circ, 75^\circ, 135^\circ, 195^\circ, 255^\circ, 315^\circ$

(ii) $\cos(2x + 40^\circ) = 0.5$
 $2x + 40^\circ = -300^\circ, -60^\circ, 60^\circ, 300^\circ$
 $2x = -340^\circ, -100^\circ, 20^\circ, 260^\circ$
 $x = -170^\circ, -50^\circ, 10^\circ, 130^\circ$

You need to look for roots for $3x$ in the range 0° to 1080°

The lower end of the range you need to look in is $-180^\circ \times 2 + 40^\circ = -320^\circ$, and the upper end is $180^\circ \times 2 + 40^\circ = 400^\circ$

More complicated trigonometric equations

Any more complicated equations need to be manipulated algebraically before they can be solved. There are a number of techniques you can use:

1. Rearrange the equation to make $\cos \theta$, $\sin \theta$ or $\tan \theta$ the subject.
2. Check to see if the equation factorises to give two (or more) equations which involve just one trigonometric function (see Example 3).
If it is a quadratic in either $\sin \theta$, $\cos \theta$, or $\tan \theta$ it can either be factorised or solved using the formula for solving quadratic equations (see Example 4).
3. If the equation involves just $\sin \theta$ and $\cos \theta$ (and no powers), check to see if you can use the identity $\tan \theta \equiv \frac{\sin \theta}{\cos \theta}$ (see Example 5).
4. If the equation contains a mixture of trigonometric functions (e.g. $\cos^2 \theta$ and $\sin \theta$) then you may need to use the identity $\sin^2 \theta + \cos^2 \theta \equiv 1$ to make it a quadratic in either $\sin \theta$, $\cos \theta$, or $\tan \theta$ (see Example 6).

Example 3



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Solve $2\cos\theta\sin\theta + \cos\theta = 0$ for $0^\circ \leq \theta \leq 360^\circ$.



Solution

$2\cos\theta\sin\theta + \cos\theta = 0$ can be factorised as there is $\cos\theta$ in both terms on the LHS.

Factorise: $\cos\theta(2\sin\theta + 1) = 0$

So either $\cos\theta = 0$ or $2\sin\theta + 1 = 0$

$$\cos\theta = 0 \Rightarrow \theta = 90^\circ$$

$360^\circ - 90^\circ = 270^\circ$ is also a root.

$$2\sin\theta + 1 = 0 \Rightarrow \sin\theta = -\frac{1}{2}$$

This has roots in the third and fourth quadrants.

The roots are $180^\circ + 30^\circ = 210^\circ$ and $360^\circ - 30^\circ = 330^\circ$.

So the values of θ for which $2\cos\theta\sin\theta + \cos\theta = 0$ are $90^\circ, 210^\circ, 270^\circ$ and 330° .

It is wrong to divide through by $\cos\theta$ because you lose the roots to $\cos\theta = 0$.

In Example 4 you need to solve a quadratic equation.



Example 4

Solve $2\cos^2\theta + 3\cos\theta = 2$ for $0^\circ \leq \theta \leq 360^\circ$.

Solution

$2\cos^2\theta + 3\cos\theta = 2$ is a quadratic equation in $\cos\theta$

Rearrange the quadratic: $2\cos^2\theta + 3\cos\theta - 2 = 0$

Let $\cos\theta = x$: $2x^2 + 3x - 2 = 0$

Factorise: $(2x - 1)(x + 2) = 0$

$$x = \frac{1}{2} \text{ or } x = -2 \Rightarrow \cos\theta = \frac{1}{2} \text{ or } \cos\theta = -2$$

$\cos\theta = -2$ has no real roots.

So we need to solve $\cos\theta = \frac{1}{2}$

$$\Rightarrow \cos\theta = 60^\circ$$

There is also a root in the 4th quadrant, so $360^\circ - 60^\circ = 300^\circ$ is also a root.

So the values of θ for which $2\cos^2\theta + 3\cos\theta = 2$ are 60° and 300° .

You can replace $\cos\theta$ with x to make things simpler! Or factorise straightaway to get: $(2\cos\theta - 1)(\cos\theta + 2) = 0$ and then solve.

In the next example you need to use the identity $\tan\theta \equiv \frac{\sin\theta}{\cos\theta}$.



Example 5

Solve $\sin\theta - 2\cos\theta = 0$ for $0^\circ \leq \theta \leq 360^\circ$.

Solution

You need to rearrange the equation.

$$\sin\theta - 2\cos\theta = 0$$



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Dividing by $\cos \theta$:

$$\frac{\sin \theta}{\cos \theta} - 2 = 0$$

Since $\tan \theta \equiv \frac{\sin \theta}{\cos \theta}$:

$$\tan \theta - 2 = 0$$

$$\Rightarrow \tan \theta = 2$$

$$\Rightarrow \theta = 63.4^\circ \text{ to 1 d.p.}$$

You can safely divide by $\cos \theta$ because it can't be equal to 0. If it were then $\sin \theta$ would also have to be 0 and $\cos \theta$ and $\sin \theta$ are never both 0 for the same value of θ .

There is also a root in the 3rd quadrant.
So $63.4^\circ + 180^\circ = 243.4^\circ$ is also a root.

So the values of θ for which $\sin \theta - 2\cos \theta = 0$ are 63.4° and 243.4° to 1 d.p.

In the next example you need to use the trigonometric identity $\sin^2 \theta + \cos^2 \theta \equiv 1$.



Example 6

Solve $\sin^2 x + \sin x = \cos^2 x$ for $0^\circ \leq x \leq 360^\circ$

Solution

Rearranging the identity
gives:

$$\sin^2 \theta + \cos^2 \theta \equiv 1$$

$$\cos^2 x \equiv 1 - \sin^2 x$$

①

Substituting ① into the equation $\sin^2 x + \sin x = \cos^2 x$ gives:

$$\sin^2 x + \sin x = 1 - \sin^2 x$$

This is a quadratic in $\sin x$.

Rearranging: $2\sin^2 x + \sin x - 1 = 0$

Rearranging: $2\sin^2 x + \sin x - 1 = 0$

This factorises to give: $(2\sin x - 1)(\sin x + 1) = 0$

So either: $2\sin x - 1 = 0$ or $\sin x + 1 = 0$
 $\Rightarrow \sin x = \frac{1}{2}$ $\Rightarrow \sin x = -1$
 $\Rightarrow x = 30^\circ \text{ or } 150^\circ$ $\Rightarrow x = 270^\circ$

So the roots to $\sin^2 x + \sin x = \cos^2 x$ are $x = 30^\circ, 150^\circ$ or 270°

