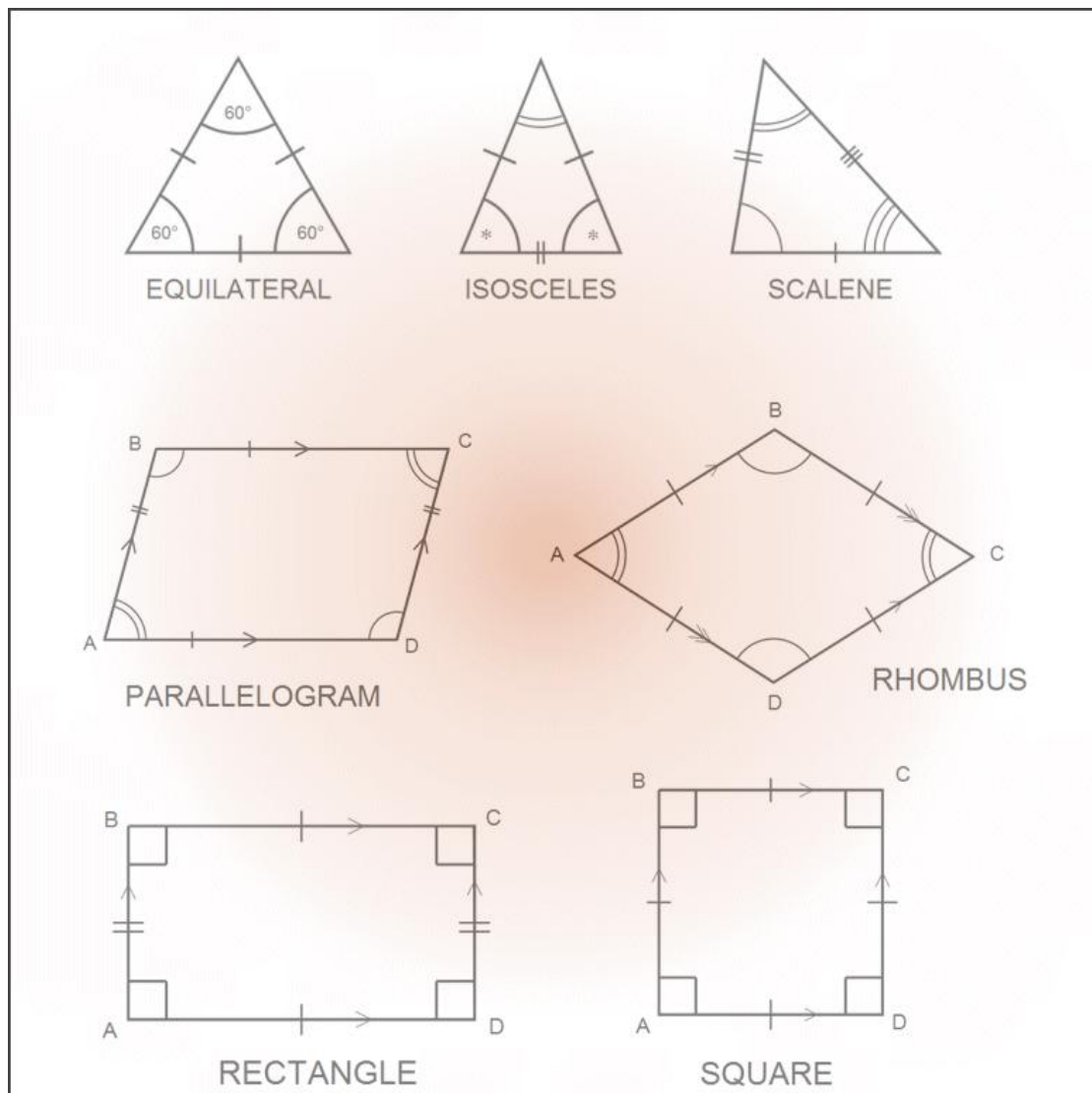


## M.K. HOME TUITION

Mathematics Revision Guides  
Level: GCSE Foundation Tier

# PROPERTIES OF TRIANGLES AND QUADRILATERALS

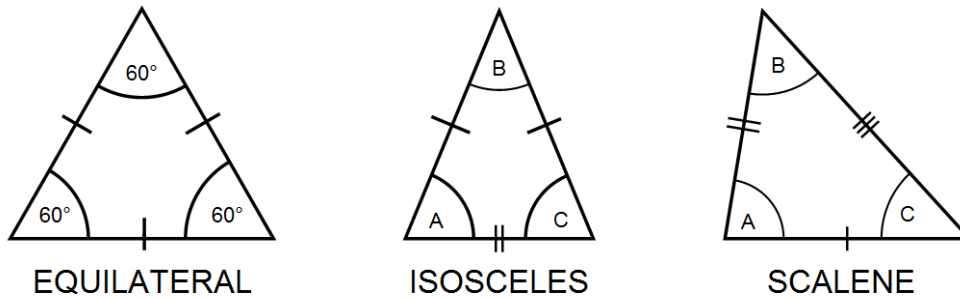
(plus polygons in general)



## PROPERTIES OF TRIANGLES AND QUADRILATERALS

### Types of triangles.

Triangles can be classified in various ways, based either on their symmetry or their angle properties.



An **equilateral** triangle has all three sides equal in length, and all three angles equal to  $60^\circ$ .

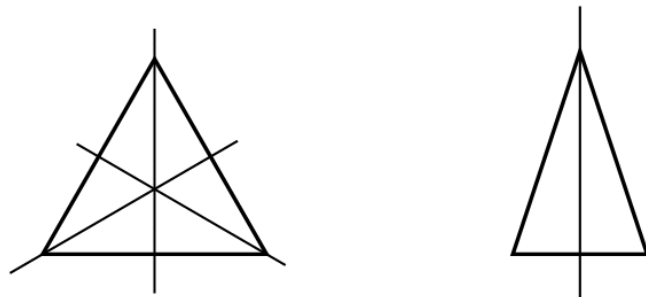
An **isosceles** triangle has two sides equal, and the two angles opposite the equal sides also the same. Thus in the diagram, angle A = angle C.

A **scalene** triangle has all three sides and angles different.

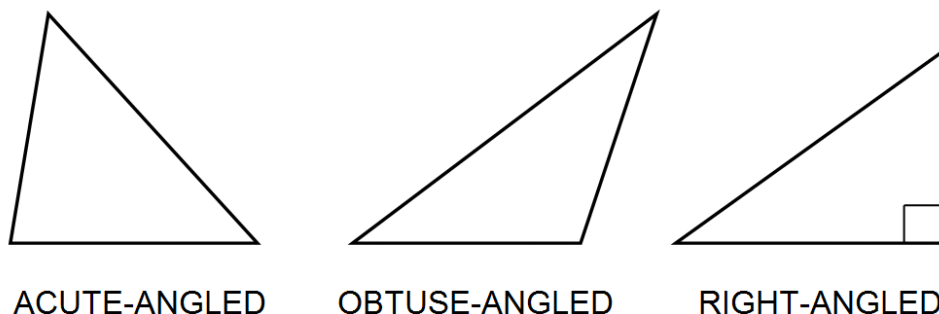
All triangles have an interior angle sum of  $180^\circ$ .

A scalene triangle has no symmetry at all, but an isosceles triangle has one line of symmetry.

An equilateral triangle has three lines of symmetry, and rotational symmetry of order 3 in addition.



Another way of classifying triangles is by the types of angle they contain.

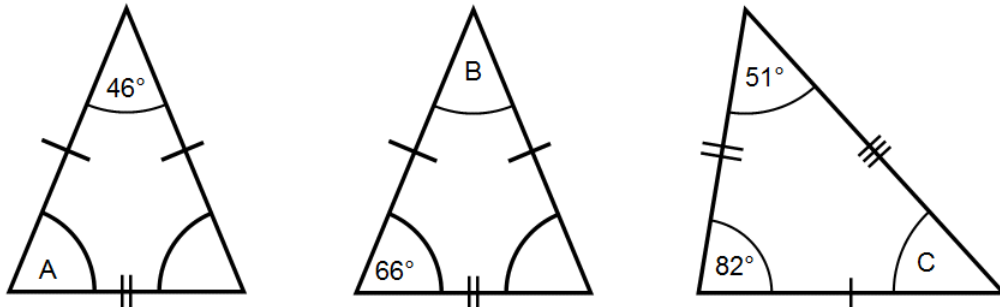


An acute-angled triangle has all its angles less than  $90^\circ$ . A right-angled triangle has one  $90^\circ$  angle, and an obtuse-angled triangle has one obtuse angle.

Because the sum of the internal angles of any triangle is  $180^\circ$ , it follows that no triangle can have more than one right angle or obtuse angle.

**Example (1):**

i) Find the angles A, B and C in the triangles below.



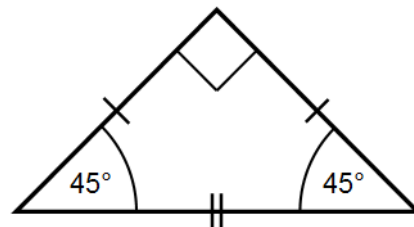
ii) Is it possible for a right-angled triangle to be isosceles? Explain with a sketch.

i) In the first triangle, the given angle is the 'different' one, so therefore the two equal angles must add to  $(180-46)^\circ$ , or  $134^\circ$ . Angle A = half of  $134^\circ$ , or  $67^\circ$ .

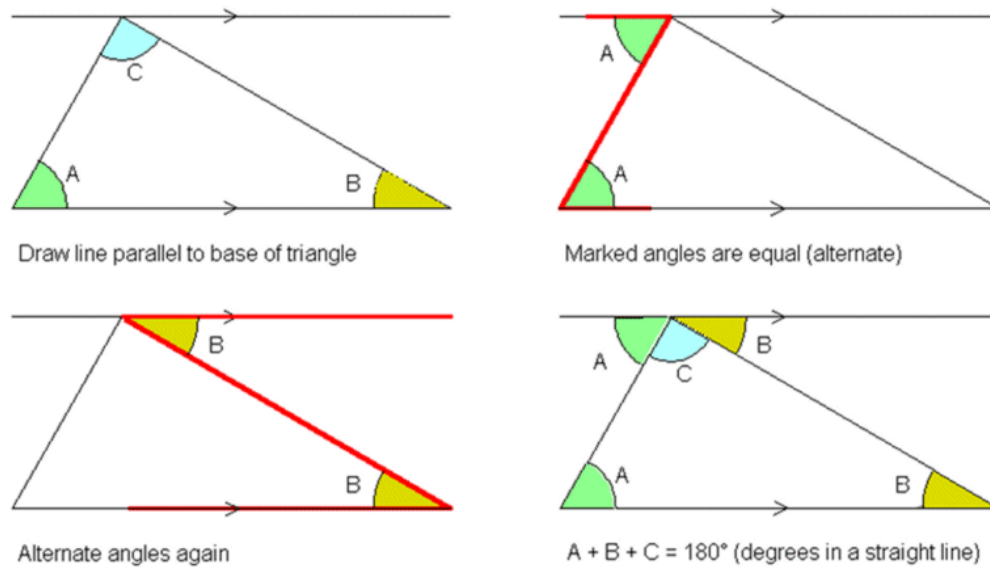
In the second triangle, the  $66^\circ$  angle is one of the two equal ones.  
Hence angle B =  $180^\circ - (66 + 66)^\circ$ , or  $48^\circ$ .

The third triangle is scalene, so angle C =  $180^\circ - (51 + 82)^\circ = 47^\circ$ .

ii) Although no triangle can have two right angles, it is perfectly possible to have an isosceles right-angled triangle. Two such triangles can be joined at their longest sides to form a square, and this shape of triangle occurs in a set square of a standard geometry set.



Here is the proof that the interior angles of any triangle add up to  $180^\circ$ .



**The exterior angle sum of a triangle.**

Since an exterior angle is obtained by extending one of the sides, it follows that the sum of an interior angle and the resulting exterior angle is  $180^\circ$ . See the diagram.

The interior angle-sum,  $A + B + C, = 180^\circ$ .

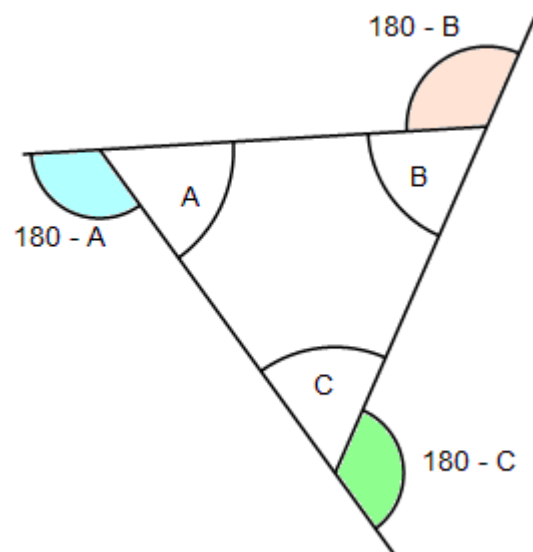
The exterior angle sum is

$$((180 - A) + (180 - B) + (180 - C))^\circ$$

$$\text{or } (540 - (A + B + C))^\circ$$

$$\text{or } 540^\circ - 180^\circ = 360^\circ.$$

**$\therefore$  The exterior angle sum of a triangle is  $360^\circ$ .**

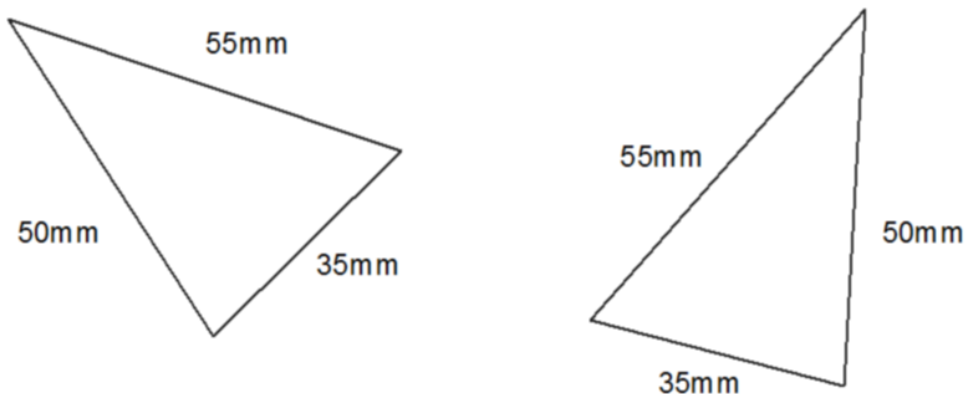


**Congruence and similarity.**

Two figures are said to be **congruent** if they are equal in size and shape.

In other words, if figure **B** can fit directly onto figure **A** by any combination of the three standard transformations (translation, rotation, reflection), then figures **A** and **B** are congruent.

**Example (2):**



The three sides of each triangle are equal in length, and therefore the triangles are congruent. (Note that the triangles are mirror images of each other !)

**Example (3):**



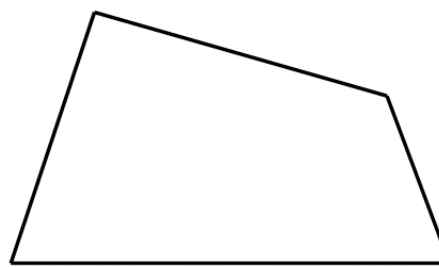
The triangles below have their *angles* all equal, but not their sides (check opposite the 81° angle). They are therefore not congruent, but they have the same shape, and therefore they are **similar**.

In brief, two figures are **congruent** if they are the same size and shape, and **similar** if they have the same shape.

### Introduction to quadrilaterals.

Quadrilaterals are plane figures bounded by four straight sides, and they too can be classified into various types, based mainly on symmetry and the properties of their sides and diagonals.

A general quadrilateral need not have any symmetry, nor any parallel sides. Its angles and sides could also all be different.



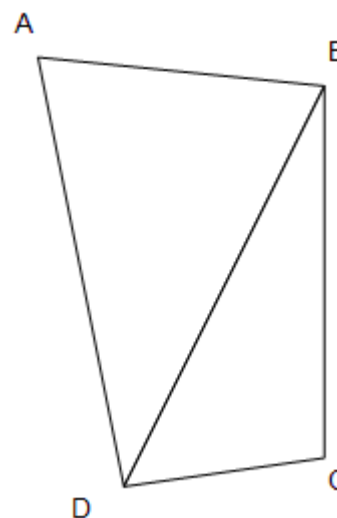
QUADRILATERAL

### Angle sum of a quadrilateral.

The square and rectangle have all their interior angles equal to  $90^\circ$ , and therefore their interior angle sum is  $360^\circ$ .

This holds true for all quadrilaterals, because *any* quadrilateral can be divided into two triangles by one of its diagonals, e.g. quadrilateral ABCD can be divided into the two triangles ABD and BCD by adding diagonal BD.

The interior angle sum of a triangle is  $180^\circ$ , and therefore the interior angle sum of a quadrilateral is  $360^\circ$ .



To find the exterior angle sum of a *convex* quadrilateral, we use the same reasoning as that for the triangle.

The interior angle-sum,  $A + B + C + D = 360^\circ$ .

The exterior angle sum is

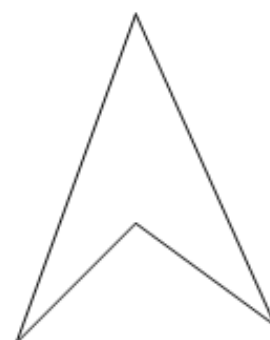
$$((180 - A) + (180 - B) + (180 - C) + (180 - D))^\circ$$

$$\text{or } (720 - (A + B + C + D))^\circ$$

$$\text{or } 720^\circ - 360^\circ = 360^\circ.$$

**$\therefore$  The exterior angle sum of a convex quadrilateral is  $360^\circ$ .**

Note that the idea of an exterior angle is meaningless when we are dealing with a reflex angle. A concave quadrilateral, such as the example shown right, has a reflex angle, and if it also has a line of symmetry, it is known as an arrowhead or delta.



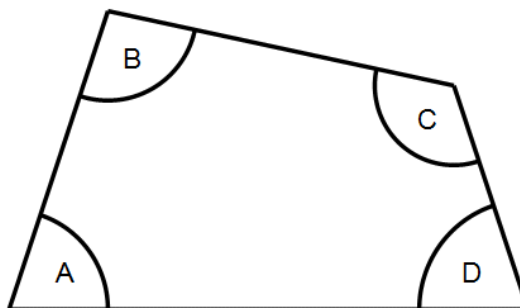
CONCAVE QUADRILATERAL

This same argument can be used to show that the exterior angle-sum of *any* convex polygon is  $360^\circ$ .

**Example (4):** Find angle C in this quadrilateral, given that angle A = 70°, angle B = 96° and angle D = angle A.

$$C = 360^\circ - (70 + 96 + 70)^\circ$$

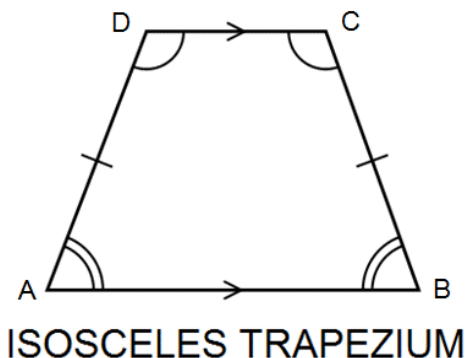
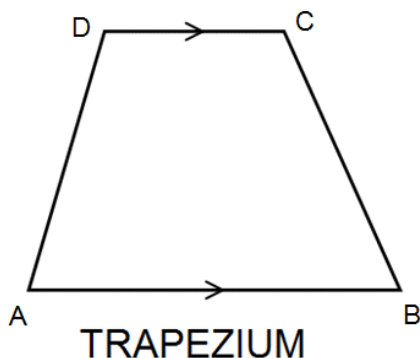
$$= (360 - 236)^\circ = 124^\circ.$$



We shall now start to examine the properties of some more special quadrilaterals.

**The trapezium.**

If one pair of sides is parallel, the quadrilateral is a **trapezium**.

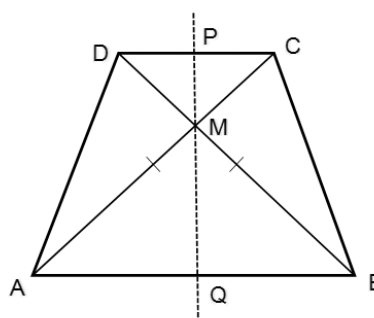


A trapezium whose non-parallel sides are equal in length is an **isosceles trapezium**.

In the diagram, sides BC and AD are equal in length.  
 An isosceles trapezium also has adjacent pairs of angles equal.  
 Thus, angles A and B are equal, as are angles C and D.

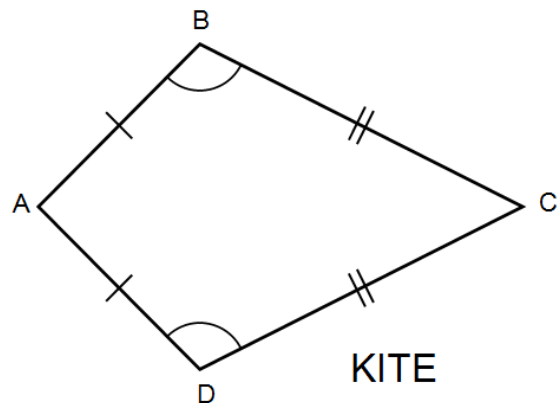
Furthermore, the diagonals of an isosceles trapezium are also equal in length, thus AC = BD. There is also a line of symmetry passing through the midpoints P and Q of the parallel sides as well as point M, the intersection of the diagonals.

(Although, in this example, the diagonals appear to meet at right angles, this is not generally true.)

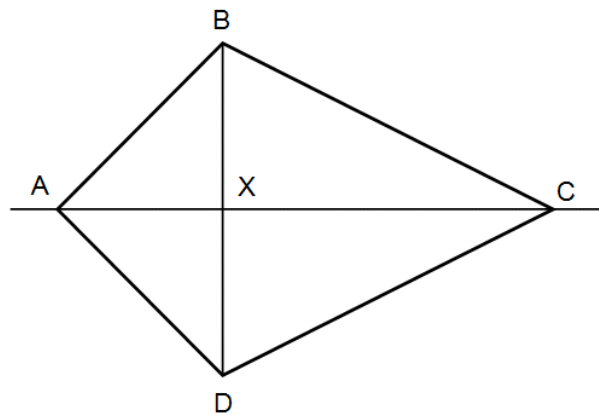


**The kite.**

A kite has one pair of opposite angles and both pairs of adjacent sides equal. In the diagram, sides AB and AD are equal in length, as are CB and CD. Also, angles B and D are equal.



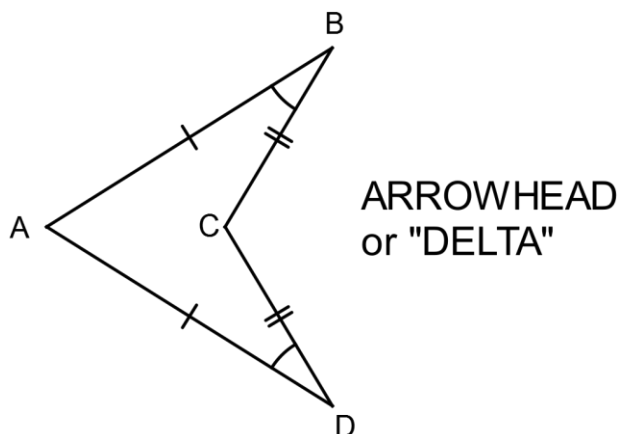
A kite is symmetrical about one diagonal, which bisects it into two mirror-image congruent triangles. In this case, the diagonal AC is the line of symmetry, and triangles ABC and ADC are thus congruent. Hence AC also bisects the angles BAD and BCD,  $BX = XD$ , and the diagonals AC and BD intersect at right angles.



**The arrowhead or “delta”.**

This quadrilateral has one reflex angle (here BCD), but shares all the other properties of the kite, although one of the “diagonals” (here BD) lies outside the figure.

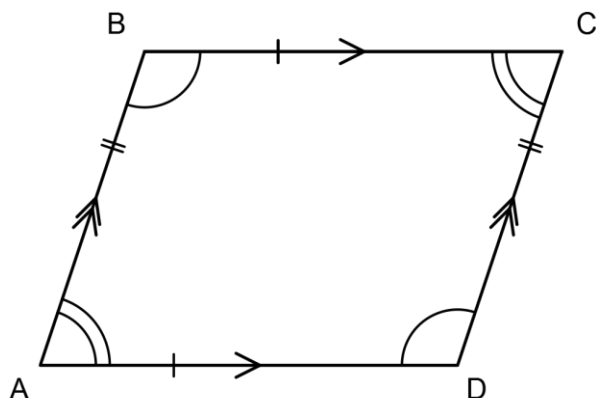
This is an example of a concave quadrilateral.





**The parallelogram.**

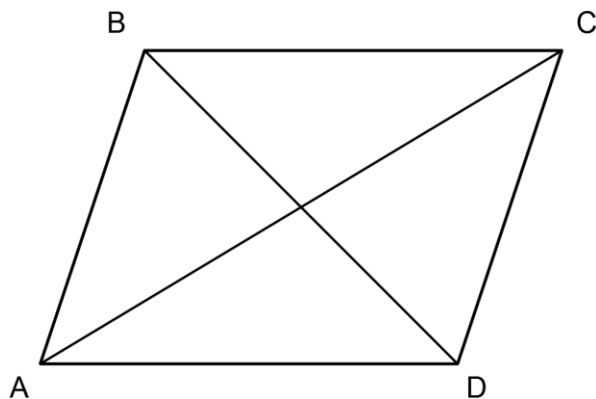
Whereas a trapezium has at one pair of sides parallel, a **parallelogram** has both pairs of opposite sides equal and parallel, as well as having opposite pairs of angles equal. Thus, in the diagram, side AD = side BC, and side AB = side CD. Additionally, angle A = angle C, and angle B = angle D.



PARALLELOGRAM

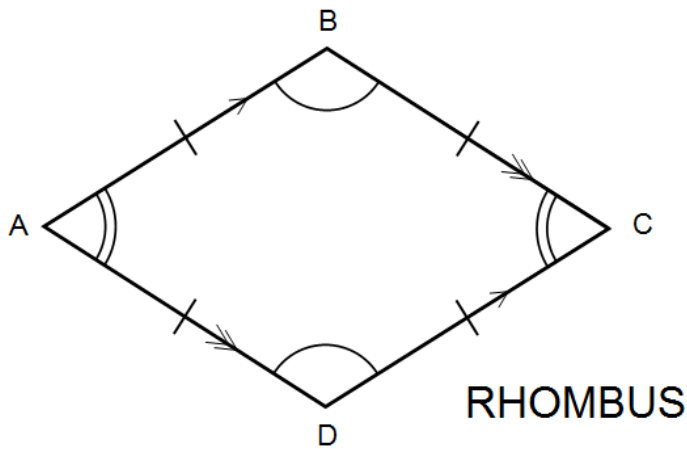
The diagonals of a parallelogram bisect each other, so in the diagram below,  $AM = MC$  and  $BM = MD$ . We also have rotational symmetry of order 2 about the point M, the midpoint of each diagonal.

Note however that a parallelogram does not generally have a line of symmetry.



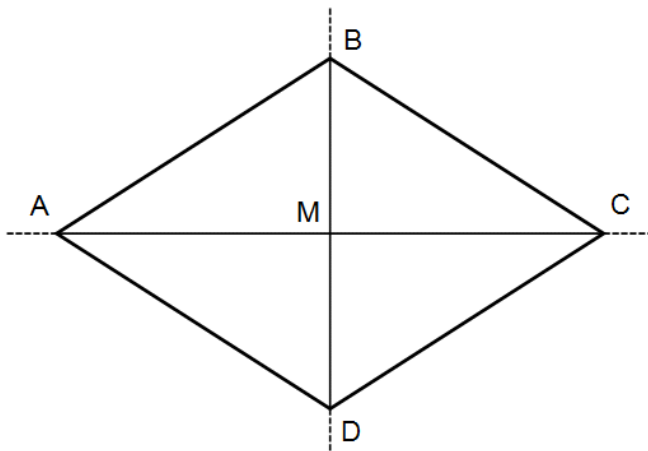
**The rhombus.**

A **rhombus** has all the properties of a parallelogram, but it also has all its sides equal in length. Hence here,  $AB = BC = CD = DA$ .



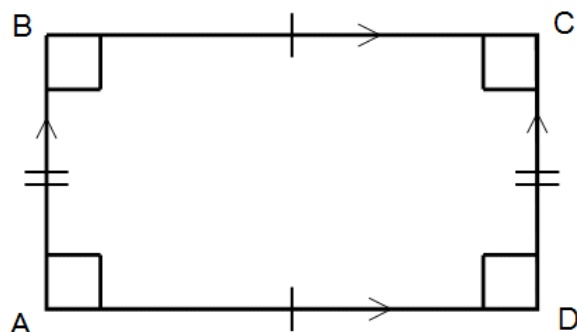
Although a parallelogram does not as a rule have any lines of symmetry, a rhombus has two lines of symmetry coinciding with the diagonals, as well as order-2 rotational symmetry.

Thus, triangles  $ABC$  and  $ACD$  are congruent, as are triangles  $BAD$  and  $BCD$ . The diagonals bisect each other at right angles, so  $AM = MC$  and  $BM = MD$ . The diagonals also bisect the angles of the rhombus.



### The rectangle.

A **rectangle** also has all the properties of a parallelogram, but it additionally has all its four angles equal to  $90^\circ$ . Hence angles A, B, C and D are all right angles.

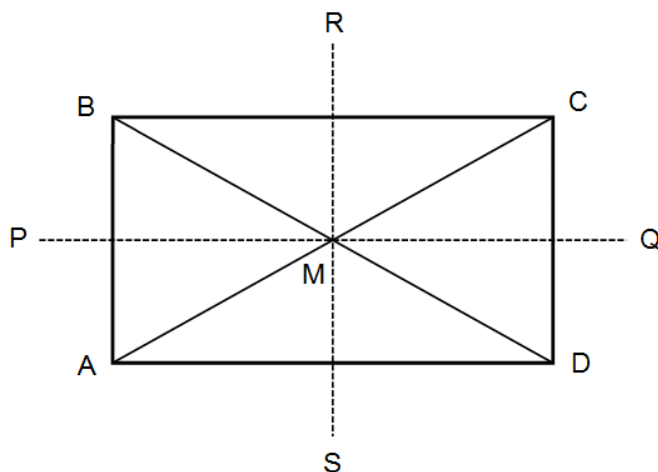


## RECTANGLE

As stated earlier, a parallelogram does not generally have any lines of symmetry, but a rectangle has two lines of symmetry passing through lines joining the midpoints of opposite pairs of sides, i.e. PQ and RS in the diagram. A rectangle also has order-2 rotational symmetry.

The diagonals of a rectangle are equal in length and bisect each other, therefore  $AC = BD$ , and  $AM = MC = BM = MD$ . They do not generally bisect at right angles, though.

Thus, triangles AMB and CMD are congruent, as are triangles BMC and AMD.



It can be seen that both the rectangle and the rhombus are not quite ‘perfect’ when it comes to symmetry, although they complement each other.

The rhombus has all its sides equal, but not all its angles; the rectangle has all its angles equal to  $90^\circ$ , but not all its sides. The diagonals of a rhombus meet at right angles, but are not equal in length, whereas those of a rectangle are equal in length but do not meet at right angles.

That leaves us with one type of quadrilateral combining the ‘best’ of both the rectangle and the rhombus.

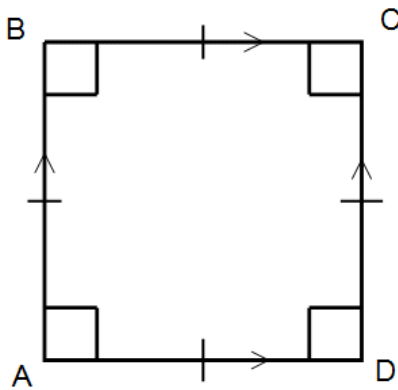
**The square.**

A **square** is the most 'perfect' of quadrilaterals, combining the symmetries and properties of the rectangle and the rhombus.

All four sides are equal. Thus  $AB = BC = CD = DA$ .

All four angles A, B, C, D are right angles.

Both pairs of sides are parallel.

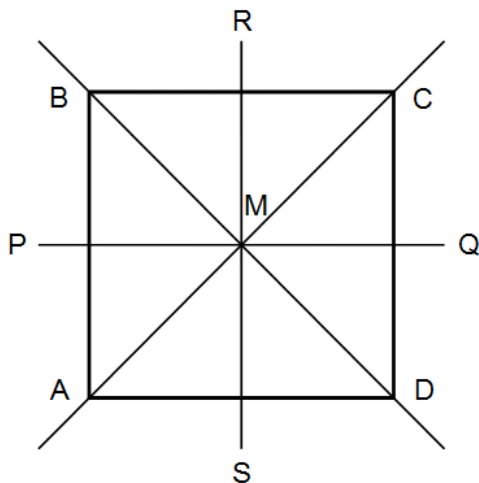


**SQUARE**

A square also has greater symmetry than a rectangle or a rhombus.

There are now four lines of symmetry; two passing through the diagonals AC and BD, and the other two passing through the midpoints of opposite sides at PQ and RS. A square also has rotational symmetry of order 4.

The diagonals bisect each other and are equal in length. Hence  $AC = BD$ , and  $AM = MB = CM = MD$ . They also bisect their respective angles - AC bisects angles A and C, and BD bisects angles B and D.

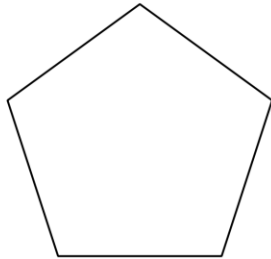


**Polygons.**

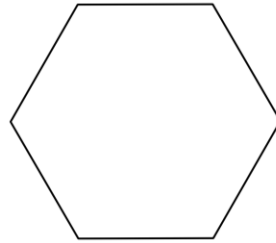
A polygon is any plane figure with three or more straight sides.

A **regular** polygon has all of its sides and angles equal.

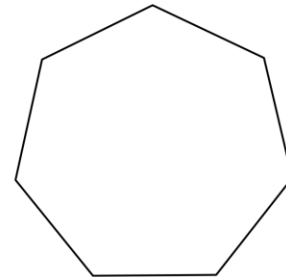
A few examples are shown as follows:



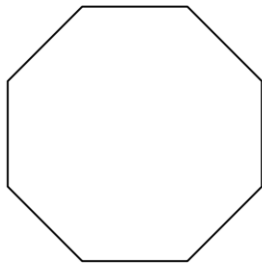
Regular pentagon  
5 equal sides and angles



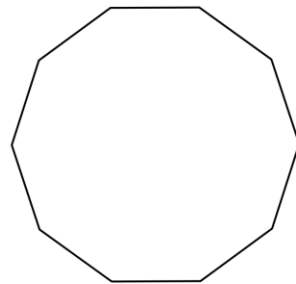
Regular hexagon  
6 equal sides and angles



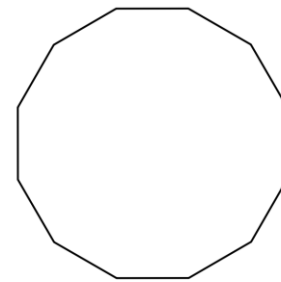
Regular heptagon  
7 equal sides and angles



Regular octagon  
8 equal sides and angles



Regular decagon  
10 equal sides and angles



Regular dodecagon  
12 equal sides and angles

Since the exterior angles of any convex polygon sum to  $360^\circ$ , it follows that the exterior angle of a *regular* polygon (in degrees) is the number of sides divided into 360.

Thus, for example, the exterior angle of a regular pentagon is  $\frac{360}{5}^\circ$  or  $72^\circ$ , and its interior angle is  $(180 - 72)^\circ$  or  $108^\circ$ .

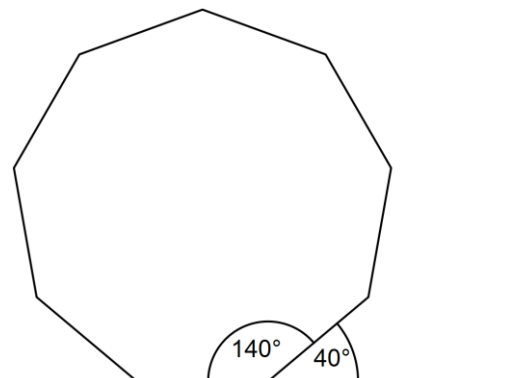
Similarly, a regular hexagon has an exterior angle of  $\frac{360}{6}^\circ$  or  $60^\circ$ , and its interior angle is  $120^\circ$ .

**Example (5):** A regular polygon has all its interior angles equal to  $140^\circ$ . How many sides does it have?

If the interior angles of the polygon are all equal to  $140^\circ$ , then its exterior angles must all be equal to  $(180 - 140)^\circ$ , or  $40^\circ$ .

Since all the exterior angles of the polygon sum to  $360^\circ$ , it follows that the number of sides is equal to  $\frac{360}{40}$  or 9.

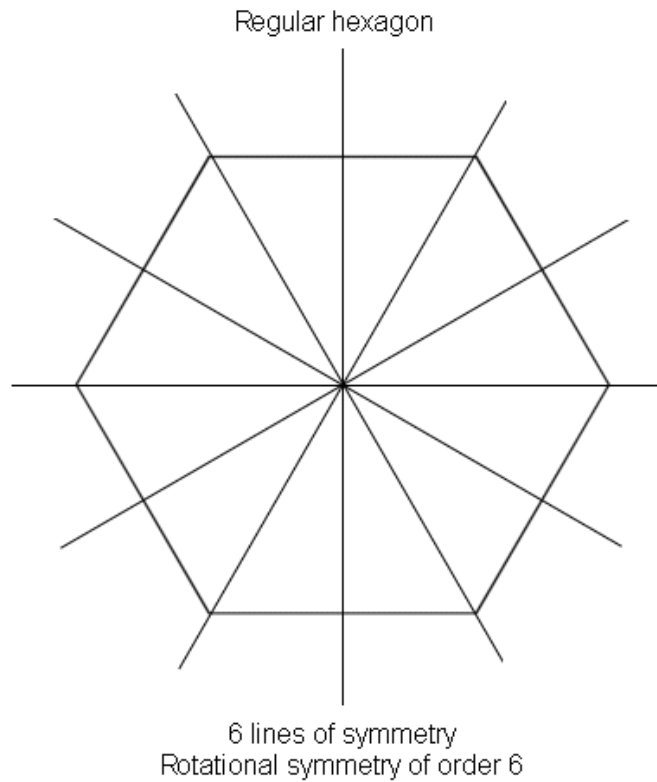
(The name for such a polygon is a **regular nonagon**).



We have seen earlier how an equilateral triangle has 3 lines of symmetry and rotational symmetry of order 3; also, how a square has 4 lines of symmetry and rotational symmetry of order 4.

This same pattern occurs in **all** regular polygons – they have as many lines of symmetry as they have sides; likewise, their order of rotational symmetry is equal to the number of sides.

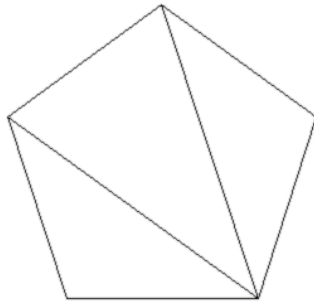
See the example of a regular hexagon below.



**The interior angle sum of a polygon.**

This general fact applies to all polygons and not just regular ones.

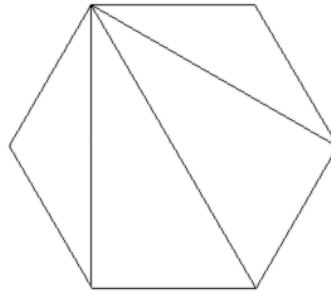
Any polygon can similarly be split up onto triangles as shown below:



PENTAGON

5 sides - 3 triangles

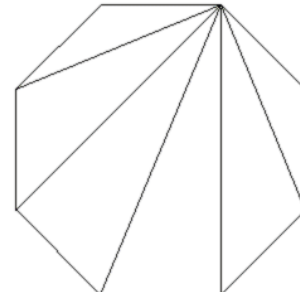
Interior angle sum:  
 $3 \times 180^\circ = 540^\circ$



HEXAGON

6 sides - 4 triangles

Interior angle sum:  
 $4 \times 180^\circ = 720^\circ$



OCTAGON

8 sides - 6 triangles

Interior angle sum:  
 $6 \times 180^\circ = 1080^\circ$

There is an obvious pattern here – any polygon with  $n$  sides can be split into  $n-2$  triangles. Since the interior angle sum of a triangle is  $180^\circ$ , the sum of the interior angles of a polygon can be given by the formula

**Angle sum =  $180(n - 2)^\circ$**  where  $n$  is the number of the sides in the polygon.

**Example (6):** A regular polygon has an interior angle sum of  $1800^\circ$ . How many sides does it have ?

We must solve the equation:  $180(n - 2) = 1800$ .

Dividing by 180 on both sides, we have  $n - 2 = 10$ , hence  $n = 12$ .

The polygon in question is therefore 12-sided.