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# GEOMETRY

## Through Trigonometry

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# Contents

|  |            |
|--|------------|
| Introduction                                     | iii        |
| <b>1 Triangle</b>                                | <b>1</b>   |
| <b>2 Quadrilateral</b>                           | <b>29</b>  |
| <b>3 Circle</b>                                  | <b>39</b>  |
| <b>4 Miscellaneous</b>                           | <b>71</b>  |
| <b>A Baudhayana Theorem</b>                      | <b>109</b> |
| <b>A.1 The Right Angled Triangle . . . . .</b>   | <b>109</b> |
| <b>A.2 Sum of Angles . . . . .</b>               | <b>112</b> |
| <b>A.3 Proof of Baudhayana Theorem . . . . .</b> | <b>114</b> |
| <b>B Area of a Triangle</b>                      | <b>121</b> |
| <b>B.1 From a Rectangle . . . . .</b>            | <b>121</b> |
| <b>B.2 Sine and Cosine formula . . . . .</b>     | <b>125</b> |
| <b>B.3 Hero's formula . . . . .</b>              | <b>132</b> |
| <b>C Circumcentre</b>                            | <b>135</b> |
| <b>C.1 Locating the Circumcentre . . . . .</b>   | <b>135</b> |
| <b>C.2 Finding the Circumradius . . . . .</b>    | <b>139</b> |

|  |            |
|--|------------|
| <b>C.3 Drawing the Circumcircle . . . . .</b>      | <b>141</b> |
| <b>D Incentre . . . . .</b>                        | <b>145</b> |
| <b>D.1 Locating the Incentre . . . . .</b>         | <b>145</b> |
| <b>D.2 Drawing the Incircle . . . . .</b>          | <b>147</b> |
| <b>D.3 Congruent Triangles . . . . .</b>           | <b>149</b> |
| <b>E Medians of a Triangle . . . . .</b>           | <b>151</b> |
| <b>E.1 Basic Proportionality Theorem . . . . .</b> | <b>151</b> |
| <b>E.2 Similar Triangles . . . . .</b>             | <b>153</b> |
| <b>E.3 Centroid . . . . .</b>                      | <b>153</b> |
| <b>E.4 Median and Area . . . . .</b>               | <b>158</b> |
| <b>E.5 Parallelogram . . . . .</b>                 | <b>159</b> |
| <b>F Circles . . . . .</b>                         | <b>167</b> |
| <b>F.1 Area of a Circle . . . . .</b>              | <b>167</b> |
| <b>F.2 Miscellaneous Properties . . . . .</b>      | <b>174</b> |
| <b>G Miscellaneous . . . . .</b>                   | <b>181</b> |
| <b>G.1 Trigonometric Identities . . . . .</b>      | <b>181</b> |
| <b>G.2 Constructions . . . . .</b>                 | <b>186</b> |
| <b>G.3 Altitudes of a Triangle . . . . .</b>       | <b>189</b> |



# Introduction

This book shows how to solve problems in geometry using trigonometry.



# Chapter 1

## Triangle

1. Each angle of an equilateral triangle is of  $60^\circ$ .

**Solution:**

- (a) Construction: See Fig. 1.1. The input parameters are

$$\mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix}, \mathbf{A} = a \begin{pmatrix} \cos 60^\circ \\ \sin 60^\circ \end{pmatrix} \quad (1.0.0.1.1)$$

- (b) Proof: Using the cosine formula,

$$\cos \angle ABC = \frac{a^2 + a^2 - a^2}{2a^2} \quad (1.0.0.1.2)$$

$$= \frac{1}{2} \quad (1.0.0.1.3)$$

$$\Rightarrow \angle ABC = 60^\circ \quad (1.0.0.1.4)$$

2. Triangles on the same base (or equal bases) and between the same parallels are equal in area.



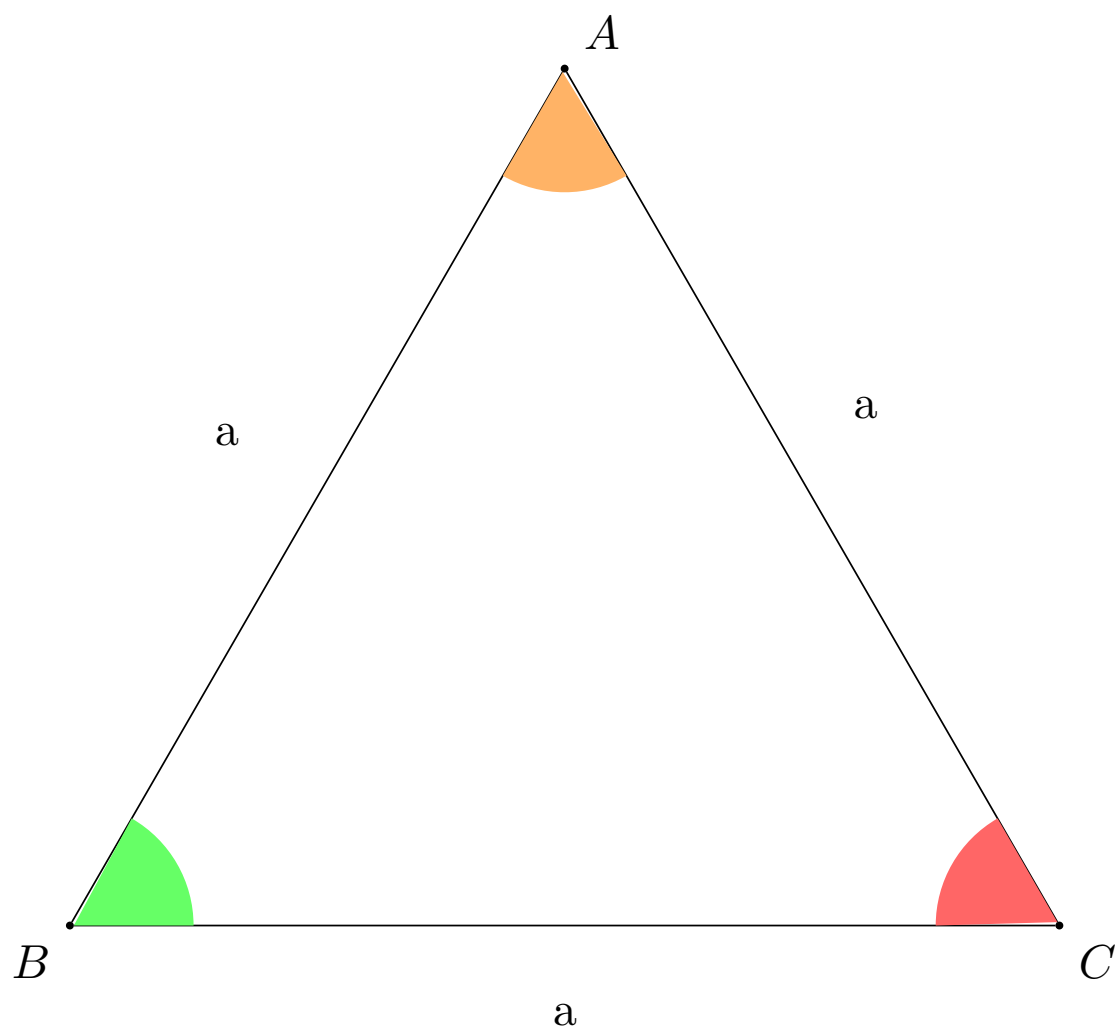


Figure 1.1:

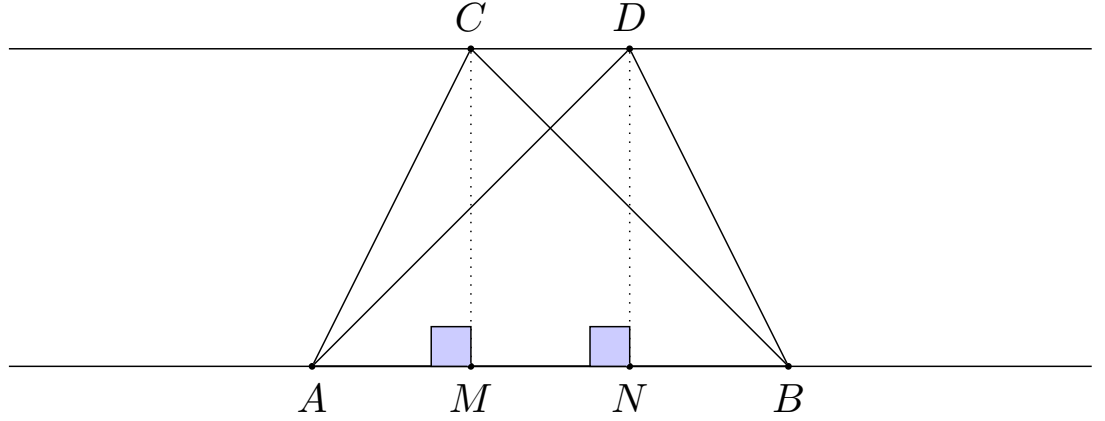


Figure 1.2:

(a) Construction: See Fig. 1.2. The design parameters are

$$\mathbf{A} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} a \\ 0 \end{pmatrix}, \quad (1.0.0.2.1)$$

$$\mathbf{C} = \begin{pmatrix} p \\ q \end{pmatrix}, p < a, \quad \mathbf{D} = \begin{pmatrix} d \\ q \end{pmatrix}, p < d < a \quad (1.0.0.2.2)$$

(b) Proof: In Fig. 1.2,

$$ar(\triangle ABC) = \frac{1}{2}aq = ar(\triangle ABD) \quad (1.0.0.2.3)$$

3. Triangles on the same base (or equal bases) and having equal areas lie between the same parallels.
4. In  $\triangle ABC$ ,  $D$ ,  $E$  and  $F$  are respectively the mid-points of sides  $AB$ ,  $BC$  and  $CA$ . Show that  $\triangle ABC$  is divided into four congruent triangles by joining  $D$ ,  $E$  and  $F$ .
5. The line-segment joining the mid-points of any two sides of a triangle is parallel to

the third side and is half of it.

6. A line through the mid-point of a side of a triangle parallel to another side bisects the third side.
7.  $ABC$  is a triangle right angled at  $C$ . A line through the mid-point  $M$  of hypotenuse  $AB$  and parallel to  $BC$  intersects  $AC$  at  $D$ . Show that (i)  $D$  is the mid-point of  $AC$  (ii)  $MD \perp AC$  (iii)  $CM = MA = \frac{1}{2}AB$
8. Sides opposite to equal angles of a triangle are equal.
9. Each angle of an equilateral triangle is of  $60^\circ$ .
10. Using cosine formula in an equilateral  $\triangle$ , show that  $\cos 60^\circ = \frac{1}{2}$ .
11. Using (A.3.0.3.1), show that  $\sin 60^\circ = \frac{\sqrt{3}}{2}$ .
12. Find  $\sin 30^\circ$  and  $\cos 30^\circ$  using (A.3.0.1.2).
13. Triangles on the same base (or equal bases) and between the same parallels are equal in area.
14. Triangles on the same base (or equal bases) and having equal areas lie between the same parallels.
15. In  $\triangle ABC$ , the bisector  $AD$  of  $\angle A$  is perpendicular to side  $BC$ . Show that  $AB = AC$  and  $\triangle ABC$  is isosceles.
16.  $E$  and  $F$  are respectively the mid-points of equal sides  $AB$  and  $AC$  of  $\triangle ABC$ . Show that  $BF = CE$ .
17. In an isosceles  $\triangle ABC$  with  $AB = AC$ ,  $D$  and  $E$  are points on  $BC$  such that  $BE = CD$ . Show that  $AD = AE$ .

18.  $AB$  is a line-segment.  $P$  and  $Q$  are points on opposite sides of  $AB$  such that each of them is equidistant from the points  $A$  and  $B$ . Show that the line  $PQ$  is the perpendicular bisector of  $AB$ .
19.  $P$  is a point equidistant from two lines  $l$  and  $m$  intersecting at point  $A$ . Show that the line  $AP$  bisects the angle between them.
20.  $D$  is a point on side  $BC$  of  $\triangle ABC$  such that  $AD = AC$ . Show that  $AB > AD$ .
21.  $AB$  is a line segment and line  $l$  is its perpendicular bisector. If a point  $P$  lies on  $l$ , show that  $P$  is equidistant from  $A$  and  $B$ .
22. Line-segment  $AB$  is parallel to another line-segment  $CD$ .  $O$  is the mid-point of  $AD$ . Show that
- (a)  $\triangle AOB \cong \triangle DOC$
- (b)  $O$  is also the mid-point of  $BC$ .
23. In quadrilateral  $ACBD$ ,  $AC = AD$  and  $AB$  bisects  $\angle A$ . Show that  $\triangle ABC \cong \triangle ABD$ . What can you say about  $BC$  and  $BD$ ?
- (a) Construxtion: See Fig. 1.3. The input parameters are

$$\mathbf{A} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (1.0.0.23.1)$$

$$\mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix}, \quad (1.0.0.23.2)$$

$$\mathbf{D} = a \begin{pmatrix} \cos \theta \\ \sin \theta \end{pmatrix} \quad (1.0.0.23.3)$$

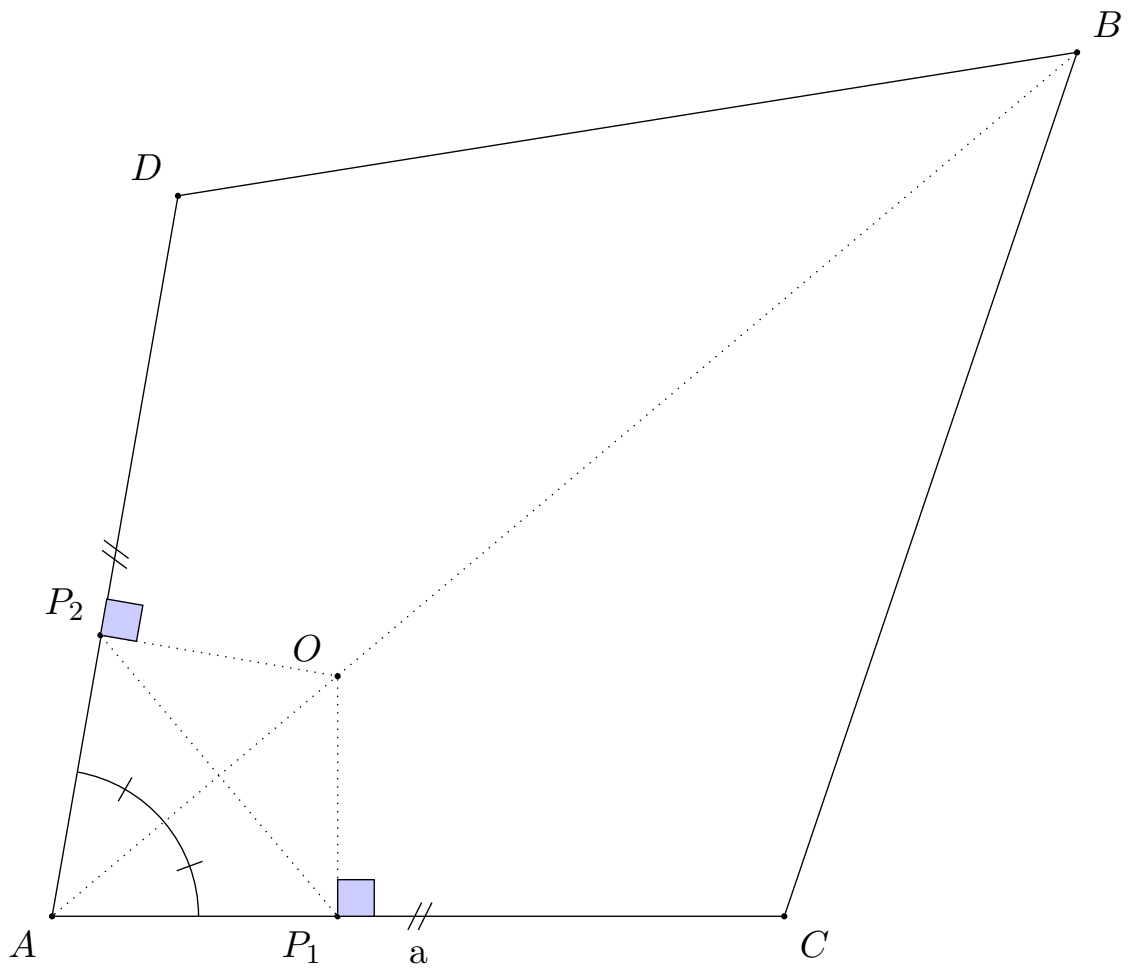


Figure 1.3:

Let

$$\begin{aligned} \mathbf{P}_1 &= \frac{\mathbf{C}}{\|\mathbf{C}\|} \\ \mathbf{P}_2 &= \frac{\mathbf{D}}{\|\mathbf{D}\|} \end{aligned} \tag{1.0.0.23.4}$$

If  $AB$  be the angle bisector, it is easy to show that

$$P_1 P_2 \perp AB \quad (1.0.0.23.5)$$

$$\implies (\mathbf{P}_1 - \mathbf{P}_2)^T (\mathbf{B} - \mathbf{A}) \quad (1.0.0.23.6)$$

However, from (1.0.0.23.4) ,

$$\|\mathbf{P}_1\| = \|\mathbf{P}_2\| = 1 \quad (1.0.0.23.7)$$

$$\implies \|\mathbf{P}_1\|^2 = \|\mathbf{P}_2\|^2 \quad (1.0.0.23.8)$$

$$\text{or, } (\mathbf{P}_1 - \mathbf{P}_2)^T (\mathbf{P}_1 + \mathbf{P}_2) = 0 \quad (1.0.0.23.9)$$

$$\implies \mathbf{P}_1 + \mathbf{P}_2 \perp \mathbf{P}_1 - \mathbf{P}_2 \quad (1.0.0.23.10)$$

From (1.0.0.23.6) and (1.0.0.23.10)

$$\mathbf{B} = \lambda (\mathbf{P}_1 + \mathbf{P}_2) \quad (1.0.0.23.11)$$

$$\implies \mathbf{B} = \lambda \left( \frac{\mathbf{C}}{\|\mathbf{C}\|} + \frac{\mathbf{D}}{\|\mathbf{D}\|} \right) \quad (1.0.0.23.12)$$

when  $\mathbf{A}$  is at the origin. In general,

$$\mathbf{B} = \mathbf{A} + \lambda \left( \frac{\mathbf{C} - \mathbf{A}}{\|\mathbf{C} - \mathbf{A}\|} + \frac{\mathbf{D} - \mathbf{A}}{\|\mathbf{D} - \mathbf{A}\|} \right) \quad (1.0.0.23.13)$$

(b) Using SAS congruence, it is trivial to show that  $BC = BD \quad \triangle ABC \cong \triangle ABD$

by SAS congruence:

$$AD = AC$$

$$\angle DAB = \angle BAC$$

*DB is common*

$$\implies BC = BD$$

24.  $ABCD$  is a quadrilateral in which  $AD = BC$  and  $\angle DAB = \angle CBA$ . Prove that

(a)  $\triangle ABD \cong \triangle BAC$

(b)  $BD = AC$

(c)  $\angle ABD = \angle BAC$ .

25.  $l$  and  $m$  are two parallel lines intersected by another pair of parallel lines  $p$  and  $q$  to form the quadrilateral  $ABCD$ . Show that  $\triangle ABC \cong \triangle CDA$ .

26. Line  $l$  is the bisector of  $\angle A$  and  $B$  is any point on  $l$ .  $BP$  and  $BQ$  are perpendiculars from  $B$  to the arms of  $\angle A$ . Show that:

(a)  $\triangle APB \cong \triangle AQB$

(b)  $BP = BQ$  or  $B$  is equidistant from the arms of  $\angle A$ .

(a) Construction: See Fig. 1.4 The input parameters are

$$\mathbf{A} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{P} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \mathbf{Q} = \begin{pmatrix} \cos \theta \\ \sin \theta \end{pmatrix} \quad (1.0.0.26.1)$$

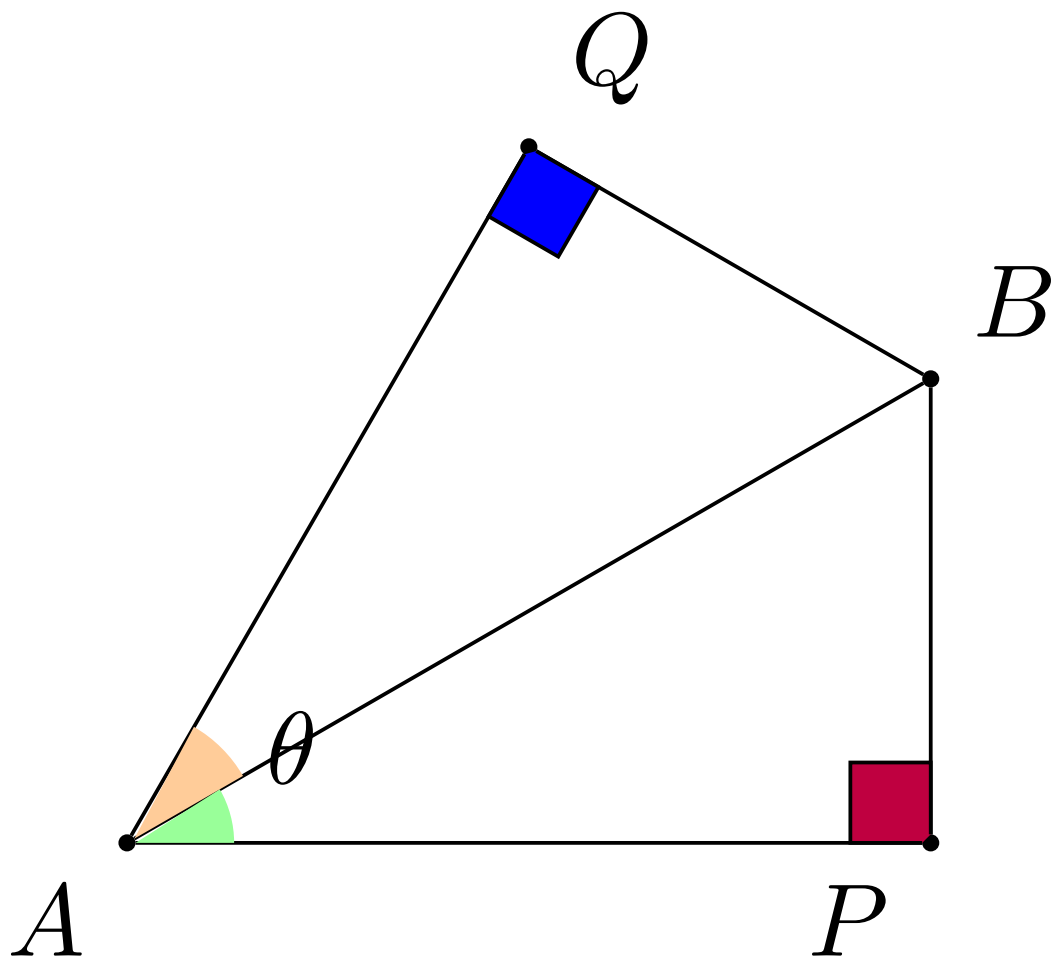


Figure 1.4:

resulting in

$$\mathbf{B} = \lambda \mathbf{P} + \mathbf{Q} \quad (1.0.0.26.2)$$

$$\because (\mathbf{B} - \mathbf{P})^T \mathbf{P} = 0, \quad (1.0.0.26.3)$$

$$(\lambda - 1) + \lambda \mathbf{Q}^T \mathbf{P} = 0 \quad (1.0.0.26.4)$$



resulting in

$$\lambda = \frac{1}{1 + \mathbf{P}^T \mathbf{Q}} \quad (1.0.0.26.5)$$

(b) In Fig. 1.4 using ASA congruence,

$$\triangle APB \cong \triangle AQB \quad (1.0.0.26.6)$$

$$\implies BP = BQ \quad (1.0.0.26.7)$$

27.  $ABCE$  is a quadrilateral and  $D$  is a point on  $BC$  such that,  $AC = AE$ ,  $AB = AD$  and  $\angle BAD = \angle EAC$ . Show that  $BC = DE$ .

28. In right triangle  $ABC$ , right angled at  $C$ ,  $M$  is the mid-point of hypotenuse  $AB$ .  $C$  is joined to  $M$  and produced to a point  $D$  such that  $DM = CM$ . Point  $D$  is joined to point  $B$ . Show that:

(a)  $\triangle AMC \cong \triangle BMD$

(b)  $\angle DBC$  is a right angle.

(c)  $\triangle DBC \cong \triangle ACB$

(d)  $CM = \frac{1}{2}AB$

See Fig. 1.5.

(a) Construction: From the given information,

$$\mathbf{A} = \begin{pmatrix} 0 \\ b \end{pmatrix} \quad (1.0.0.28.1)$$

$$\mathbf{C} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \quad (1.0.0.28.2)$$

$$\mathbf{B} = \begin{pmatrix} a \\ 0 \end{pmatrix} \quad (1.0.0.28.3)$$

$\therefore \mathbf{M}$  is the midpoint of  $AB$ ,

$$\mathbf{M} = \frac{\mathbf{A} + \mathbf{B}}{2} = \frac{1}{2} \begin{pmatrix} a \\ b \end{pmatrix} \quad (1.0.0.28.4)$$

Also,  $\mathbf{M}$  is given to be the midpoint of  $C$ . Hence,

$$\mathbf{M} = \frac{\mathbf{C} + \mathbf{D}}{2} \quad (1.0.0.28.5)$$

$$\Rightarrow \mathbf{D} = 2\mathbf{M} - \mathbf{C} = \begin{pmatrix} a \\ b \end{pmatrix} \quad (1.0.0.28.6)$$

(b) Proof: From Fig. 1.5,

$$(\mathbf{D} - \mathbf{B})^T (\mathbf{B} - \mathbf{C}) = \begin{pmatrix} 0 & b \end{pmatrix} \begin{pmatrix} a \\ 0 \end{pmatrix} = 0 \quad (1.0.0.28.7)$$

$$\Rightarrow BD \perp BC \quad (1.0.0.28.8)$$

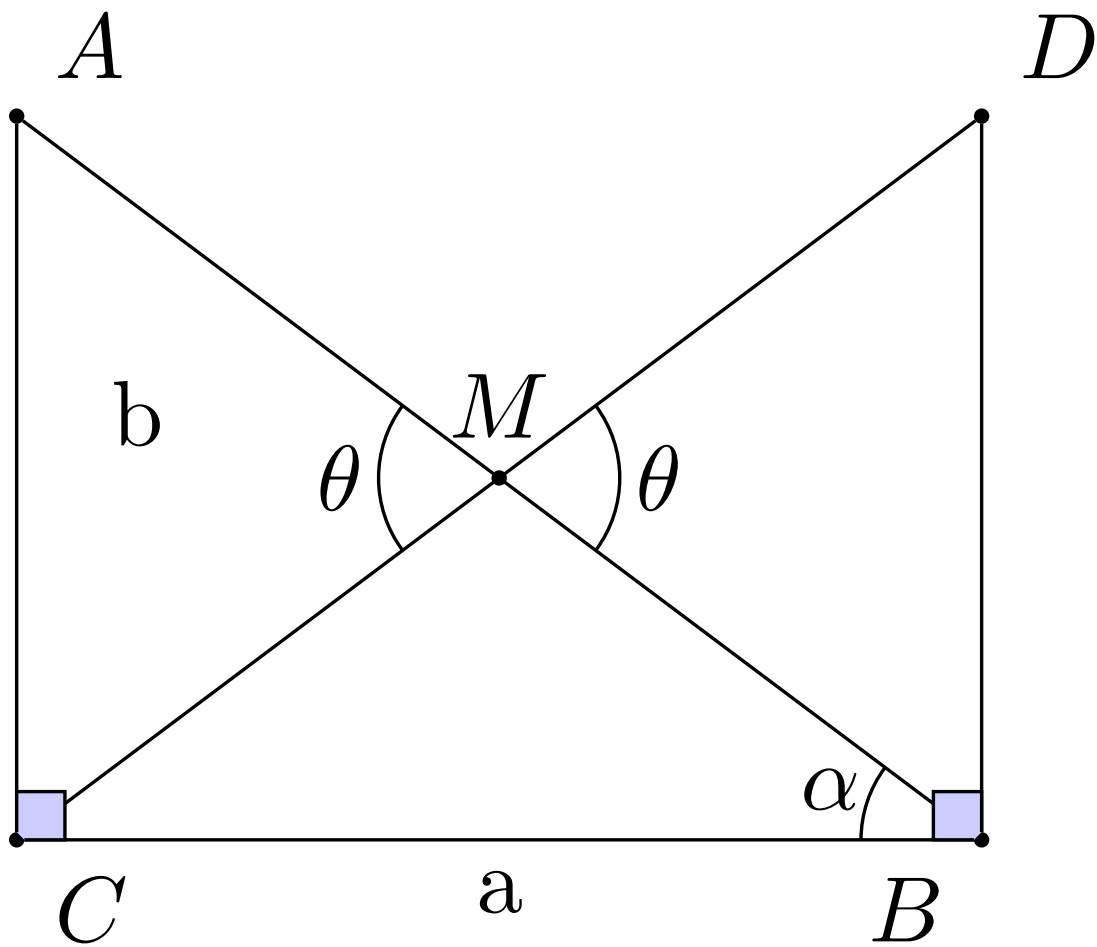


Figure 1.5:

$$\|\mathbf{A} - \mathbf{B}\| = \left\| \begin{pmatrix} -a \\ b \end{pmatrix} \right\| \quad (1.0.0.28.9)$$

$$\|\mathbf{C} - \mathbf{D}\| = \left\| \begin{pmatrix} -a \\ -b \end{pmatrix} \right\| \quad (1.0.0.28.10)$$

$$\Rightarrow \|\mathbf{A} - \mathbf{B}\| = \|\mathbf{C} - \mathbf{D}\| \quad (1.0.0.28.11)$$

$$\text{or, } AB = CD \quad (1.0.0.28.12)$$

Noting that  $BC$  is the common side, from RHS congruence,  $\triangle ACB \cong \triangle DCB$ .

From (1.0.0.28.12), noting that  $M$  is the mid point of both  $AB$  and  $CD$ ,

$$CM = \frac{1}{2}CD = \frac{1}{2}AB \quad (1.0.0.28.13)$$

29. In an isosceles  $\triangle ABC$ , with  $AB = AC$ , the bisectors of  $\angle B$  and  $\angle C$  intersect each other at  $O$ . Join  $A$  to  $O$ . Show that :
- (a)  $OB = OC$
  - (b)  $AO$  bisects  $\angle A$
30. In  $\triangle ABC$ ,  $AD$  is the perpendicular bisector of  $BC$ . Show that  $\triangle ABC$  is an isosceles triangle in which  $AB = AC$ .
31.  $ABC$  is an isosceles triangle in which altitudes  $BE$  and  $CF$  are drawn to equal sides  $AC$  and  $AB$  respectively. Show that these altitudes are equal.
32.  $ABC$  is a triangle in which altitudes  $BE$  and  $CF$  to sides  $AC$  and  $AB$  are equal. Show that
- (a)  $\triangle ABE \cong \triangle ACF$
  - (b)  $AB = AC$ , i.e.,  $ABC$  is an isosceles triangle.
33.  $ABC$  and  $DBC$  are two isosceles triangles on the same base  $BC$ . Show that  $\angle ABD = \angle ACD$ .
34.  $\triangle ABC$  and  $\triangle DBC$  are two isosceles triangles on the same base  $BC$  and vertices  $A$  and  $D$  are on the same side of  $BC$ . If  $AD$  is extended to intersect  $BC$  at  $P$ , show that

- (a)  $\triangle ABD \cong \triangle ACD$
- (b)  $\triangle ABP \cong \triangle ACP$
- (c)  $AP$  bisects  $\angle A$  as well as  $\angle D$ .
- (d)  $AP$  is the perpendicular bisector of  $BC$ .

35.  $AD$  is an altitude of an isosceles  $\triangle ABC$  in which  $AB = AC$ . Show that

- (a)  $AD$  bisects  $BC$
- (b)  $AD$  bisects  $\angle A$ .

36. Two sides  $AB$  and  $BC$  and median  $AM$  of one triangle  $ABC$  are respectively equal to sides  $PQ$  and  $QR$  and median  $PN$  of  $\triangle PQR$ . Show that:

- (a)  $\triangle ABM \cong \triangle PQN$
- (b)  $\triangle ABC \cong \triangle PQR$

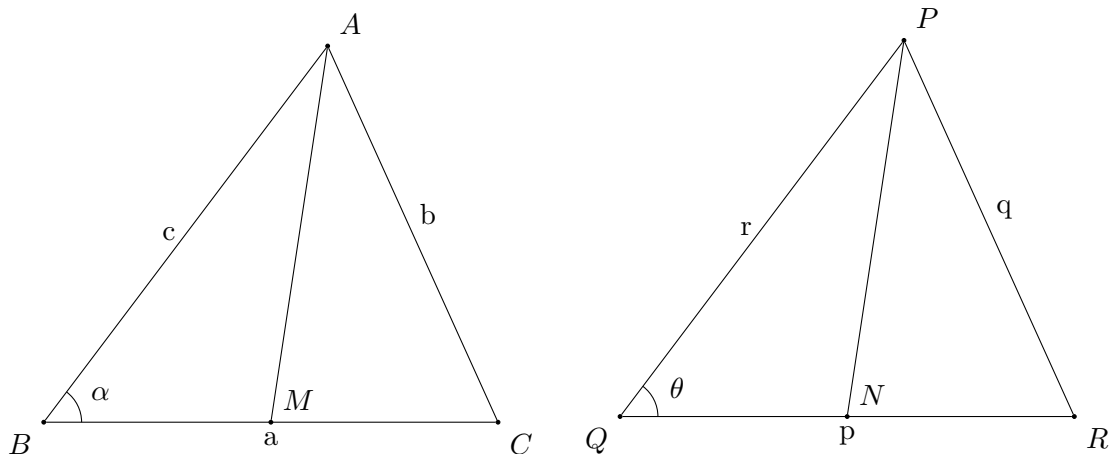


Figure 1.6:  $\triangle ABC$  and  $\triangle PQR$  by Latex-Tikz

- (a) Construction: The coordinates of the various points of triangle  $ABC$  in Fig. 1.6 are

$$\mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \quad (1.0.0.36.1)$$

$$\mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix}, \quad (1.0.0.36.2)$$

$\therefore \mathbf{M}$  is the midpoint of  $BC$ ,

$$\mathbf{M} = \frac{\mathbf{B} + \mathbf{C}}{2} = \begin{pmatrix} a/2 \\ 0 \end{pmatrix}, \quad (1.0.0.36.3)$$

$\triangle PQR$  is a horizontal translation of  $\triangle ABC$ . Hence, if

$$\mathbf{Q} = \begin{pmatrix} q \\ 0 \end{pmatrix}, \quad (1.0.0.36.4)$$

$$\mathbf{P} = \mathbf{A} + \mathbf{Q} \quad (1.0.0.36.5)$$

$$\mathbf{R} = \mathbf{C} + \mathbf{Q} \quad (1.0.0.36.6)$$

37.  $BE$  and  $CF$  are two equal altitudes of a triangle  $ABC$ . Using RHS congruence rule, prove that the triangle  $ABC$  is isosceles.
38.  $ABC$  is an isosceles triangle with  $AB = AC$ . Draw  $AP \perp BC$  to show that  $\angle B = \angle C$ .
39.  $\triangle ABC$  is an isosceles triangle in which  $AB = AC$ . Side  $BA$  is produced to  $D$  such that  $AD = AB$ . Show that  $\angle BCD$  is a right angle.

40.  $ABC$  is a right angled triangle in which  $\angle A = 90^\circ$  and  $AB = AC$ . Find  $\angle B$  and  $\angle C$ .
41. Show that in a right angled triangle, the hypotenuse is the longest side.
42. Sides  $AB$  and  $AC$  of  $\triangle ABC$  are extended to points  $P$  and  $Q$  respectively. Also,  $\angle PBC < \angle QCB$ . Show that  $AC > AB$ .
43. Line segments  $AD$  and  $BC$  intersect at  $O$  and form  $\triangle OAB$  and  $\triangle ODC$ .  $\angle B < \angle A$  and  $\angle C < \angle D$ . Show that  $AD < BC$ .
44.  $AB$  and  $CD$  are respectively the smallest and longest sides of a quadrilateral  $ABCD$ . Show that  $\angle A > \angle C$  and  $\angle B > \angle D$ .
45. In  $\triangle PQR$ ,  $PR > PQ$  and  $PS$  bisects  $\angle QPR$ . Prove that  $\angle PSR > \angle PSQ$ .

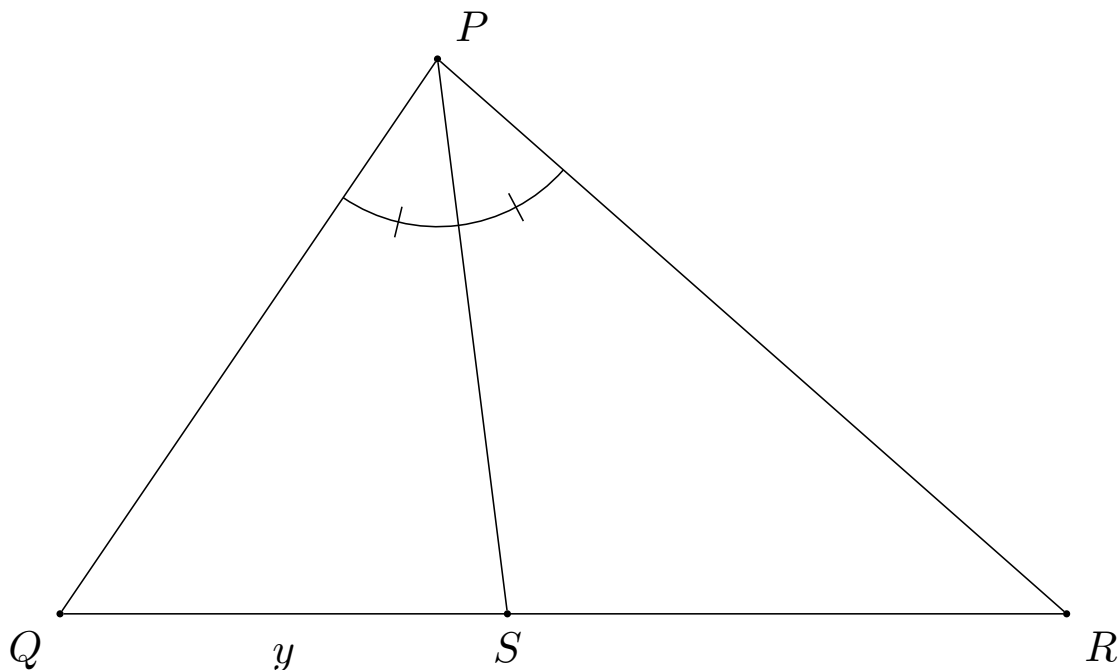


Figure 1.7:

(a) Construction: See Fig. 1.7. The input parameters are

$$\mathbf{P} = \begin{pmatrix} p \\ q \end{pmatrix}, \mathbf{Q} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \quad (1.0.0.45.1)$$

$$\mathbf{R} = \begin{pmatrix} a \\ 0 \end{pmatrix}, \quad (1.0.0.45.2)$$

where  $\mathbf{P}$  is obtained by choosing  $PR > PQ$ .  $\therefore PS$  is the angle bisector, its equation is given by (see Problem 1.0.0.23)

$$PS : \mathbf{x} = \mathbf{P} + \lambda \left( \frac{\mathbf{P} - \mathbf{Q}}{\|\mathbf{P} - \mathbf{Q}\|} + \frac{\mathbf{P} - \mathbf{R}}{\|\mathbf{P} - \mathbf{R}\|} \right) \quad (1.0.0.45.3)$$

$\mathbf{S}$  is obtained as the intersection of  $PS$  and  $QR$ .

(b) Proof: From the given information,

$$\angle Q > \angle R \quad (1.0.0.45.4)$$

$$\implies \angle Q + \angle SPQ > \angle R + \angle SPR \quad (1.0.0.45.5)$$

$$\implies \angle PSQ > \angle PSR \quad (1.0.0.45.6)$$

$\therefore PS$  is the angle bisector.

46. Show that of all line segments drawn from a given point not on it, the perpendicular line segment is the shortest.

47.  $ABCD$  is a trapezium with  $AB \parallel DC$ .  $E$  and  $F$  are points on non-parallel sides  $AD$  and  $BC$  respectively such that  $EF$  is parallel to  $AB$ . Show that  $\frac{AE}{ED} = \frac{BF}{FC}$ .



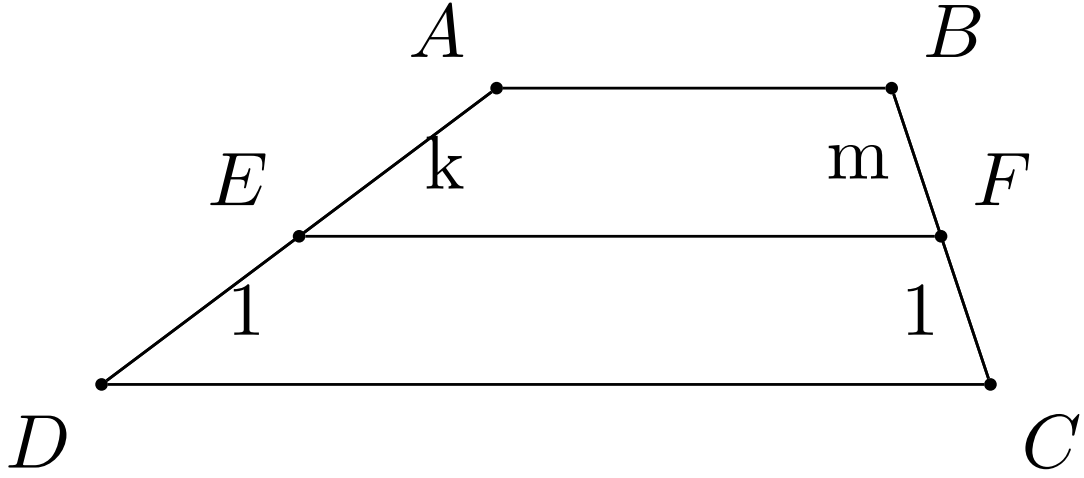


Figure 1.8:

(a) Construction: See Fig. 1.8. The input parameters are

$$\mathbf{D} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (1.0.0.47.1)$$

$$\mathbf{C} = \begin{pmatrix} c \\ 0 \end{pmatrix} \quad (1.0.0.47.2)$$

$$\mathbf{A} = \begin{pmatrix} p \\ q \end{pmatrix} \quad (1.0.0.47.3)$$

$$\mathbf{B} = \begin{pmatrix} b \\ q \end{pmatrix}, \quad b < c \quad (1.0.0.47.4)$$

For  $0 < k < 1$ ,

$$\mathbf{E} = \frac{k\mathbf{D} + \mathbf{A}}{k + 1} \quad (1.0.0.47.5)$$

$$\mathbf{F} = \frac{k\mathbf{C} + \mathbf{B}}{k + 1} \quad (1.0.0.47.6)$$

(b) Proof: Let

$$\mathbf{F} = \frac{m\mathbf{C} + \mathbf{B}}{m + 1} \quad (1.0.0.47.7)$$

From (1.0.0.47.5)

$$\mathbf{E} = \frac{k\mathbf{D} + \mathbf{A}}{k + 1} \quad (1.0.0.47.8)$$

$$\implies \mathbf{E} - \mathbf{F} = \frac{k\mathbf{D} + \mathbf{A}}{k + 1} - \frac{m\mathbf{C} + \mathbf{B}}{m + 1} \quad (1.0.0.47.9)$$

$$= \frac{\mathbf{A}}{k + 1} - \frac{m\mathbf{C} + \mathbf{B}}{m + 1} \quad (1.0.0.47.10)$$

$\therefore D = \mathbf{0}$ .

$$\therefore AB \parallel BC, \quad (1.0.0.47.11)$$

$$\mathbf{C} - \mathbf{D} = l(\mathbf{B} - \mathbf{A}) \quad (1.0.0.47.12)$$

$$\implies \mathbf{C} = l(\mathbf{B} - \mathbf{A}) \quad (1.0.0.47.13)$$

Substituting (1.0.0.47.13) in (1.0.0.47.10),

$$\mathbf{E} - \mathbf{F} = \frac{\mathbf{A}}{k + 1} - \frac{ml(\mathbf{B} - \mathbf{A}) + \mathbf{B}}{m + 1} \quad (1.0.0.47.14)$$

$$= \mathbf{A} \left( \frac{1}{k + 1} + \frac{lm}{m + 1} \right) - \mathbf{B} \left( \frac{ml + 1}{m + 1} \right) \quad (1.0.0.47.15)$$

But  $EF \parallel AB$ . So, for some  $w$

$$\implies \mathbf{E} - \mathbf{F} = w(\mathbf{A} - \mathbf{B}) \quad (1.0.0.47.16)$$

Comparing (1.0.0.47.16) and (1.0.0.47.15). We have

$$\frac{1}{k+1} + \frac{lm}{m+1} = \frac{ml+1}{m+1} = w \quad (1.0.0.47.17)$$

$$\implies m+1 + (k+1)lm = (lm+1)(k+1) \quad (1.0.0.47.18)$$

$$\text{or, } m = k \quad (1.0.0.47.19)$$

48.  $ST$  is a line joining two points on  $PQ$  and  $PR$  in  $\triangle PQR$ . If  $\frac{PS}{SQ} = \frac{PT}{TR}$  and  $\angle PST = \angle PRQ$ , prove that  $PQR$  is an isosceles triangle.

49. If  $LM \parallel CB$  and  $LN \parallel CD$ , prove that  $\frac{AM}{AB} = \frac{AN}{AD}$ .

50.  $D$  is a point on  $AB$  and  $E, F$  are points on  $BC$  such that  $DE \parallel AC$  and  $DF \parallel AE$ .  
Prove that  $\frac{BF}{FE} = \frac{BE}{EC}$ .

51.  $O$  is a point in the interior of  $\triangle ABC$ .  $D$  is a point on  $OA$ . If  $DE \parallel OB$  and  $DF \parallel OC$ .  
Show that  $EF \parallel BC$ .

(a) Construction: See Fig. 1.9. The input values are

$$\mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad \mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix} \quad \mathbf{A} = \begin{pmatrix} p \\ q \end{pmatrix} \quad (1.0.0.51.1)$$

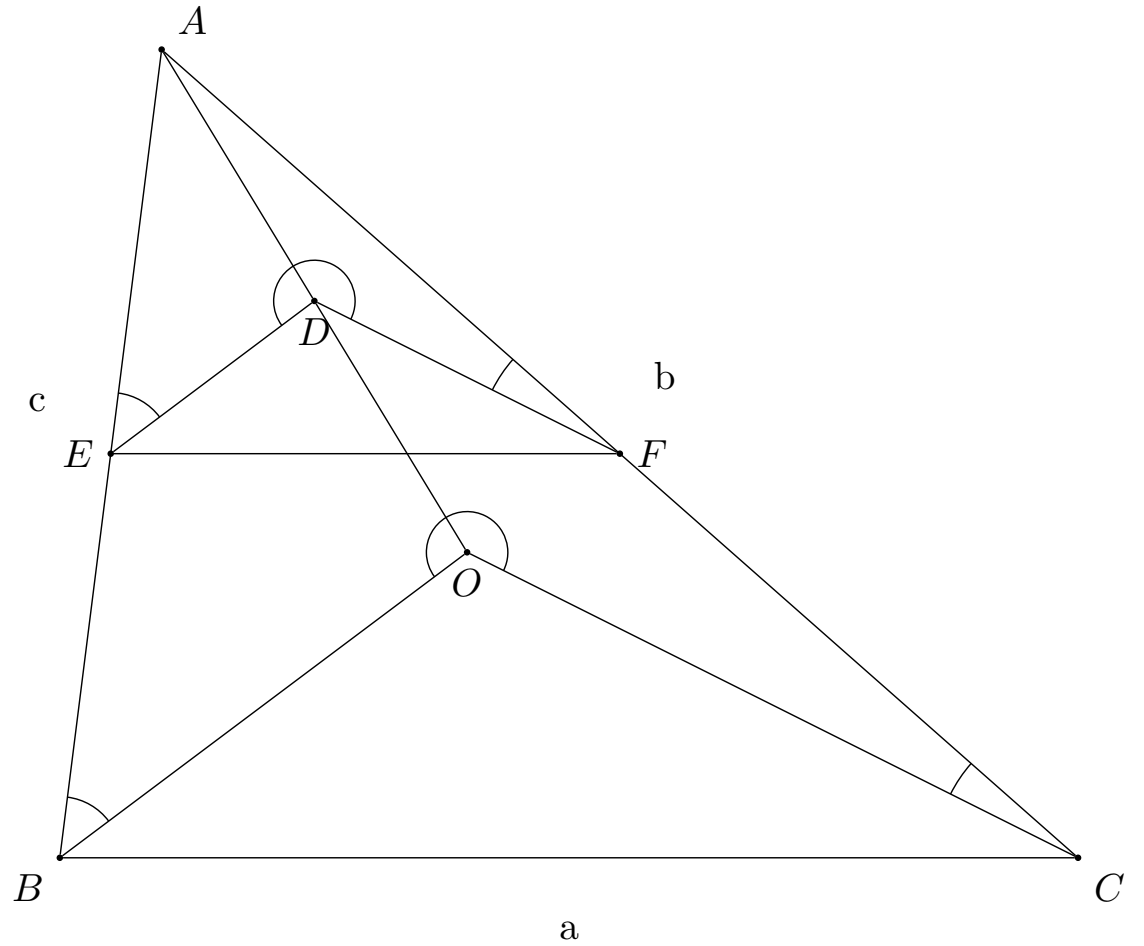


Figure 1.9:

The point inside  $\triangle ABC$  is generated as

$$\mathbf{O} = \lambda_1 (\mathbf{B} - \mathbf{A}) + \lambda_2 (\mathbf{B} - \mathbf{C}) \quad (1.0.0.51.2)$$

$$0 < \lambda_1 < 1, \quad (1.0.0.51.3)$$

$$0 < \lambda_2 < 1, \quad (1.0.0.51.4)$$

$$0 < \lambda_1 + \lambda_2 < 1, \quad (1.0.0.51.5)$$

by choosing appropriate values of  $\lambda_1, \lambda_2$ .

Determination of points D,E and F.

$$\mathbf{D} = \frac{k\mathbf{A} + \mathbf{O}}{k+1}, \quad 0 < k < 1 \quad (1.0.0.51.6)$$

where  $k$  is an input parameter.

$$\because DE \parallel OB, DF \parallel OC, \quad (1.0.0.51.7)$$

$$\begin{aligned} \mathbf{E} &= \frac{k\mathbf{A} + \mathbf{B}}{k+1}, \\ \mathbf{F} &= \frac{k\mathbf{A} + \mathbf{C}}{k+1}, \end{aligned} \quad (1.0.0.51.8)$$

(b) Proof: From (1.0.0.51.8)

$$\mathbf{E} - \mathbf{F} = \frac{\mathbf{B} - \mathbf{C}}{k+1}, \quad (1.0.0.51.9)$$

$$\implies EF \parallel BC \quad (1.0.0.51.10)$$

52.  $O$  is a point in the interior of  $\triangle PQR$ .  $A, B$  and  $C$  are points on  $OP, OQ$  and  $OR$  respectively such that  $AB \parallel PQ$  and  $AC \parallel PR$ . Show that  $BC \parallel QR$ .

53.  $ABCD$  is a trapezium in which  $AB \parallel DC$  and its diagonals intersect each other at the point  $O$ . Show that  $\frac{AO}{BO} = \frac{CO}{DO}$

54. The diagonals of a quadrilateral  $ABCD$  intersect each other at the point  $O$  such that  $\frac{AO}{BO} = \frac{CO}{DO}$ . Show that  $ABCD$  is a trapezium.

55.  $PQ \parallel RS$  and  $PS$  intersects  $QR$  at  $O$ . Show that  $\triangle OPQ \sim \triangle ORS$ .

56.  $CM$  and  $RN$  are respectively the medians of  $\triangle ABC$  and  $\triangle PQR$ . If  $\triangle ABC \sim \triangle PQR$ , prove that

(a)  $\triangle AMC \sim \triangle PNR$

(b)  $\frac{CM}{RN} = \frac{AB}{PQ}$

(c)  $\triangle CMB \sim \triangle RNQ$

57. Diagonals  $AC$  and  $BD$  of a trapezium  $ABCD$  with  $AB \parallel DC$  intersect each other at the point  $O$ . Using a similarity criterion for two triangles, show that  $\frac{OA}{OC} = \frac{OB}{OD}$

58. In  $\triangle PQR$ ,  $QP$  is extended to  $T$  and  $S$  is a point on  $QR$  such that  $\frac{QR}{QS} = \frac{QT}{PR}$ . If  $\angle PRQ = \angle PQS$ , show that  $\triangle PQS \sim \triangle TQR$ .

59.  $S$  and  $T$  are points on sides  $PR$  and  $QR$  of  $\triangle PQR$  such that  $\angle P = \angle RTS$ . Show that  $\triangle RPQ \sim \triangle RTS$ .

60. In  $\triangle ABC$ ,  $D$  and  $E$  are points on the sides  $AB$  and  $AC$  respectively. If  $\triangle ABE \cong \triangle ACD$ , show that  $\triangle ADE \sim \triangle ABC$ .

61. Altitudes  $AD$  and  $CE$  of  $\triangle ABC$  intersect each other at the point  $P$ . Show that:

(a)  $\triangle AEP \sim \triangle CDP$

(b)  $\triangle ABD \sim \triangle CBE$

(c)  $\triangle AEP \sim \triangle ADB$

(d)  $\triangle PDC \sim \triangle BEC$

62.  $E$  is a point on the side  $AD$  produced of a parallelogram  $ABCD$  and  $BE$  intersects  $CD$  at  $F$ . Show that  $\triangle ABE \sim \triangle CFB$ .

63.  $ABC$  and  $AMP$  are two right triangles, right angled at  $B$  and  $M$  respectively.  $M$  lies on  $AC$  and  $AB$  is extended to meet  $P$ . Prove that:

(a)  $\triangle ABC \sim \triangle AMP$

(b)  $\frac{CA}{PA} = \frac{BC}{MP}$

64.  $CD$  and  $GH$  are respectively the bisectors of  $\angle ACB$  and  $\angle EGF$  such that  $D$  and  $H$  lie on sides  $AB$  and  $FE$  of  $\triangle ABC$  and  $\triangle EFG$  respectively. If  $\triangle ABC \sim \triangle FEG$ , show that:

65.  $\frac{CD}{GH} = \frac{AC}{FG}$

66.  $\triangle DCB \sim \triangle HGE$

67.  $\triangle DCA \sim \triangle HGF$

68.  $E$  is a point on side  $CB$  produced of an isosceles  $\triangle ABC$  with  $AB = AC$ . If  $AD \perp BC$  and  $EF \perp AC$ , prove that  $\triangle ABD \sim \triangle ECF$ .

69. Sides  $AB$  and  $BC$  and median  $AD$  of a  $\triangle ABC$  are respectively proportional to sides  $PQ$  and  $QR$  and median  $PM$  of  $\triangle PQR$ . Show that  $\triangle ABC \sim \triangle PQR$ .

70.  $D$  is a point on the side  $BC$  of a  $\triangle ABC$  such that  $\angle ADC = \angle BAC$ . Show that  $CA^2 = CB \cdot CD$ .

71. Sides  $AB$  and  $AC$  and median  $AD$  of a  $\triangle ABC$  are respectively proportional to sides  $PQ$  and  $PR$  and median  $PM$  of another  $\triangle PQR$ . Show that  $\triangle ABC \sim \triangle PQR$ .

72. If  $AD$  and  $PM$  are medians of  $\triangle ABC$  and  $\triangle PQR$ , respectively where  $\triangle ABC \sim \triangle PQR$ , prove that  $\frac{AB}{PQ} = \frac{AD}{PM}$ .

73. The line segment  $XY$  is parallel to side  $AC$  of  $\triangle ABC$  and it divides the triangle into two parts of equal areas. Find the ratio  $\frac{AX}{AB}$ .

74. Diagonals of a trapezium  $ABCD$  with  $AB \parallel DC$  intersect each other at the point  $O$ . If  $AB = 2CD$ , find the ratio of the areas of  $\triangle AOB$  and  $COD$ .

75.  $ABC$  and  $DBC$  are two triangles on the same base  $BC$ . If  $AD$  intersects  $BC$  at  $O$ , show that  $\frac{ar(ABC)}{ar(DBC)} = \frac{AO}{DO}$ .
76. If the areas of two similar triangles are equal, prove that they are congruent.
77.  $D, E$  and  $F$  are respectively the mid-points of sides  $AB, BC$  and  $CA$  of  $\triangle ABC$ . Find the ratio of the areas of  $\triangle DEF$  and  $\triangle ABC$ .
78. Prove that the ratio of the areas of two similar triangles is equal to the square of the ratio of their corresponding medians.
79. Prove that the area of an equilateral triangle described on one side of a square is equal to half the area of the equilateral triangle described on one of its diagonals.
80.  $ABC$  and  $BDE$  are two equilateral triangles such that  $D$  is the mid-point of  $BC$ . Find the ratio of the areas of triangles  $ABC$  and  $BDE$ .
81. The sides of two similar triangles are in the ratio 4 : 9. Find the ratio the area of these triangles are in the ratio
82. In  $\triangle ABC$ ,  $\angle ACB = 90^\circ$  and  $CD \perp AB$ . Prove that  $\frac{BC^2}{AC^2} = \frac{BD}{AD}$ .
83. In  $\triangle ABC$ , if  $AD \perp BC$ , prove that  $AB^2 + CD^2 = BD^2 + AC^2$ .
84.  $BL$  and  $CM$  are medians of a  $\triangle ABC$  right angled at  $A$ . Prove that  $4(BL^2 + CM^2) = 5BC^2$ .
85.  $O$  is any point inside a rectangle  $ABCD$ . Prove that  $OB^2 + OD^2 = OA^2 + OC^2$ .
86.  $PQR$  is a triangle right angled at  $P$  and  $M$  is a point on  $QR$  such that  $PM \perp QR$ . Show that  $PM^2 = QM.MR$ .
87.  $ABD$  is a triangle right angled at  $A$  and  $AC \perp BD$ . Show that



(a)  $AB^2 = BC.BD$

(b)  $AC^2 = BC.DC$

(c)  $AD^2 = BD.CD$

88.  $ABC$  is an isosceles triangle right angled at  $C$ . Prove that  $AB^2 = 2AC^2$ .

89.  $ABC$  is an isosceles triangle with  $AC = BC$ . If  $AB^2 = 2AC^2$ , prove that  $ABC$  is a right triangle.

90.  $ABC$  is an equilateral triangle of side  $2a$ . Find each of its altitudes.

91. Prove that the sum of the squares of the sides of a rhombus is equal to the sum of the squares of its diagonals.

92.  $O$  is a point in the interior of a  $\triangle ABC$ ,  $OD \perp BC$ ,  $OE \perp AC$  and  $OF \perp AB$ . Show that

(a)  $OA^2 + OB^2 + OC^2 - OD^2 - OE^2 - OF^2 = AF^2 + BD^2 + CE^2$ .

(b)  $AF^2 + BD^2 + CE^2 = AE^2 + CD^2 + BF^2$ .

93.  $D$  and  $E$  are points on the sides  $CA$  and  $CB$  respectively of a  $\triangle ABC$  right angled at  $C$ . Prove that  $AE^2 + BD^2 = AB^2 + DE^2$ .

94. The perpendicular from  $A$  on side  $BC$  of a  $\triangle ABC$  intersects  $BC$  at  $D$  such that  $DB = 3CD$ . Prove that  $2AB^2 = 2AC^2 + BC^2$ .

95. In an equilateral  $\triangle ABC$ ,  $D$  is a point on side  $BC$  such that  $BD = \frac{1}{3}BC$ . Prove that  $9AD^2 = 7AB^2$ .

96. In an equilateral triangle, prove that three times the square of one side is equal to four times the square of one of its altitudes.

97.  $PS$  is the bisector of  $\angle QPR$  of  $\triangle PQR$ . Prove that  $\frac{QS}{SR} = \frac{PQ}{PR}$
98.  $D$  is a point on hypotenuse  $AC$  of  $\triangle ABC$ , such that  $BD \perp AC, DM \perp BC$  and  $DN \perp AB$ . Prove that :
- (a)  $DM^2 = DN \cdot MC$
- (b)  $DN^2 = DM \cdot AN$
99.  $ABC$  is a triangle in which  $\angle ABC > 90^\circ$  and  $AD \perp CB$  produced. Prove that  $AC^2 = AB^2 + BC^2 + 2BC \cdot BD$ .
100.  $ABC$  is a triangle in which  $\angle ABC < 90^\circ$  and  $AD \perp BC$ . Prove that  $AC^2 = AB^2 + BC^2 - 2BC \cdot BD$ .
101.  $AD$  is a median of a  $\triangle ABC$  and  $AM \perp BC$ . Prove that :
- (a)  $AC^2 = AD^2 + BC \cdot DM + \left(\frac{BC}{2}\right)^2$
- (b)  $AB^2 = AD^2 - BC \cdot DM + \left(\frac{BC}{2}\right)^2$
- (c)  $AC^2 + AB^2 = 2AD^2 + \frac{1}{2}BC^2$
102. Prove that the sum of the squares of the diagonals of parallelogram is equal to the sum of the squares of its sides.
103.  $D$  is a point on side  $BC$  of  $\triangle ABC$  such that  $\frac{BD}{CD} = \frac{AB}{AC}$ . Prove that  $AD$  is the bisector of  $\angle BAC$ .



## Chapter 2

# Quadrilateral

1. Parallelograms on the same base (or equal bases) and between the same parallels are equal in area.
2. If a parallelogram and a triangle are on the same base and between the same parallels, then area of the triangle is half the area of the parallelogram.
3. The quadrilateral formed by joining the mid-points of the sides of a quadrilateral, in order, is a parallelogram.
4. Two parallel lines  $l$  and  $m$  are intersected by a transversal  $p$ . Show that the quadrilateral formed by the bisectors of interior angles is a rectangle.
5. Show that the bisectors of angles of a parallelogram form a rectangle.
6.  $ABCD$  is a parallelogram in which  $P$  and  $Q$  are mid-points of opposite sides  $AB$  and  $CD$ . If  $AQ$  intersects  $DP$  at  $S$  and  $BQ$  intersects  $CP$  at  $R$ , show that:
  - (a)  $APCQ$  is a parallelogram.
  - (b)  $DPBQ$  is a parallelogram.
  - (c)  $PSQR$  is a parallelogram.

7.  $l, m$  and  $n$  are three parallel lines intersected by transversals  $p$  and  $q$  such that  $l, m$  and  $n$  cut off equal intercepts  $AB$  and  $BC$  on  $p$ . Show that  $l, m$  and  $n$  cut off equal intercepts  $DE$  and  $EF$  on  $q$  also.
8. Parallelograms on the same base (or equal bases) and between the same parallels are equal in area.
9. Area of a parallelogram is the product of its base and the corresponding altitude.
10. Parallelograms on the same base (or equal bases) and having equal areas lie between the same parallels.
11. If a parallelogram and a triangle are on the same base and between the same parallels, then area of the triangle is half the area of the parallelogram.
12. In parallelogram  $ABCD$ , two points  $P$  and  $Q$  are taken on diagonal  $BD$  such that  $DP = BQ$ . show that
  - (a)  $\triangle APD \cong \triangle CQB$
  - (b)  $AP = CQ$
  - (c)  $\triangle AQB \cong \triangle CPD$
  - (d)  $AQ = CP$
  - (e)  $APCQ$  is a parallelogram
13.  $ABCD$  is a parallelogram and  $AP$  and  $CQ$  are perpendiculars from vertices  $A$  and  $C$  on diagonal  $BD$ . Show that
  - (a)  $\triangle APB \cong \triangle CQD$
  - (b)  $AP = CQ$

14. In  $\triangle ABC$  and  $\triangle DEF$ ,  $AB = DE$ ,  $AB \parallel DE$ ,  $BC = EF$  and  $BC \parallel EF$ . Vertices  $A, B$  and  $C$  are joined to vertices  $D, E$  and  $F$  respectively. Show that
- (a) quadrilateral  $ABED$  is a parallelogram
  - (b) quadrilateral  $BEFC$  is a parallelogram
  - (c)  $AD \parallel CF$  and  $AD = CF$
  - (d) quadrilateral  $ACFD$  is a parallelogram
  - (e)  $AC = DF$
  - (f)  $\triangle ABC \cong \triangle DEF$ .
15.  $ABCD$  is a trapezium in which  $AB \parallel CD$  and  $AD = BC$ . Show that
- (a)  $\angle A = \angle B$
  - (b)  $\angle C = \angle D$
  - (c)  $\triangle ABC \cong \triangle BAD$
  - (d) diagonal  $AC =$  diagonal  $BD$
16.  $ABCD$  is a quadrilateral in which  $P, Q, R$  and  $S$  are mid-points of the sides  $AB, BC, CD$  and  $DA$   $AC$  is a diagonal. Show that
- (a)  $SR \parallel AC$  and  $SR = \frac{1}{2}AC$
  - (b)  $PQ = SR$
  - (c)  $PQRS$  is a parallelogram.
17.  $ABCD$  is a rhombus and  $P, Q, R$  and  $S$  are the mid-points of the sides  $AB, BC, CD$  and  $DA$  respectively. Show that the quadrilateral  $PQRS$  is a rectangle.
18.  $ABCD$  is a rectangle and  $P, Q, R$  and  $S$  are mid-points of the sides  $AB, BC, CD$  and  $DA$  respectively. Show that the quadrilateral  $PQRS$  is a rhombus.

19.  $ABCD$  is a trapezium in which  $AB \parallel DC$ ,  $BD$  is a diagonal and  $E$  is the mid-point of  $AD$ . A line is drawn through  $E \parallel AB$  intersecting  $BC$  at  $F$ . Show that  $F$  is the mid-point of  $BC$ .
20. In a parallelogram  $ABCD$ ,  $E$  and  $F$  are the mid-points of sides  $AB$  and  $CD$  respectively. Show that the line segments  $AF$  and  $EC$  trisect the diagonal  $BD$ .
21. Show that the line segments joining the mid-points of the opposite sides of a quadrilateral bisect each other.
22.  $ABCD$  is a parallelogram in which  $P$  and  $Q$  are mid-points of opposite sides  $AB$  and  $CD$ . If  $AQ$  intersects  $DP$  at  $S$  and  $BQ$  intersects  $CP$  at  $R$ , show that:
  - (a)  $APCQ$  is a parallelogram.
  - (b)  $DPBQ$  is a parallelogram.
  - (c)  $PSQR$  is a parallelogram.
23.  $l, m$  and  $n$  are three parallel lines intersected by transversals  $p$  and  $q$  such that  $l, m$  and  $n$  cut off equal intercepts  $AB$  and  $BC$  on  $p$ . Show that  $l, m$  and  $n$  cut off equal intercepts  $DE$  and  $EF$  on  $q$  also.
24. Diagonal  $AC$  of a parallelogram  $ABCD$  bisects  $\angle A$ . show that
  - (a) it bisects  $\angle C$  also,
  - (b)  $ABCD$  is a rhombus.
25.  $ABCD$  is a rhombus. Show that diagonal  $AC$  bisects  $\angle A$  as well as  $\angle C$  and diagonal  $BD$  bisects  $\angle B$  as well as  $\angle D$ .
26.  $ABCD$  is a rectangle in which diagonal  $AC$  bisects  $\angle A$  as well as  $\angle C$ . Show that

- (a)  $ABCD$  is a square
- (b) diagonal  $BD$  bisects  $\angle B$  as well as  $\angle D$ .

27. If  $E, F, G$  and  $H$  are respectively the mid-points of the sides of a parallelogram  $ABCD$ , show that

$$ar(EFGH) = \frac{1}{2}ar(ABCD). \quad (2.0.0.27.1)$$

28.  $P$  and  $Q$  are any two points lying on the sides  $DC$  and  $AD$  respectively of a parallelogram  $ABCD$ . Show that  $ar(APB) = ar(BQC)$ .

29.  $P$  is a point in the interior of a parallelogram  $ABCD$ . Show that

- (a)  $ar(APB) + ar(PCD) = \frac{1}{2}ar(ABCD)$
- (b)  $ar(APD) + ar(PBC) = ar(APB) + ar(PCD)$

30.  $PQRS$  and  $ABRS$  are parallelograms and  $X$  is any point on side  $BR$ . show that

- (a)  $ar(PQRS) = ar(ABRS)$
- (b)  $ar(AXS) = \frac{1}{2}ar(PQRS)$

31. A farmer was having a field in the form of a parallelogram  $PQRS$ . She took any point  $A$  on  $RS$  and joined it to points  $P$  and  $Q$ . In how many parts the field is divided? What are the shapes of these parts? The farmer wants to sow wheat and pulses in equal portions of the field separately. How should she do it?

32.  $ABCD$  is a quadrilateral and  $BE \parallel AC$  and also  $BE$  meets  $DC$  produced at  $E$ . Show that area of  $\triangle ADE$  is equal to the area of the quadrilateral  $ABCD$ .

33.  $E$  is any point on median  $AD$  of a  $\triangle ABC$ . Show that  $ar(ABE) = ar(ACE)$ .



34. In a  $\triangle ABC$ ,  $E$  is the mid-point of median  $AD$ . Show that  $ar(BED) = \frac{1}{4}ar(ABC)$ .
35. Show that the diagonals of a parallelogram divide it into four triangles of equal area.
36.  $ABC$  and  $ABD$  are two triangles on the same base  $AB$ . If line-segment  $CD$  is bisected by  $AB$  at  $O$ , show that  $ar(ABC) = ar(ABD)$ .
37.  $D$ ,  $E$  and  $F$  are respectively the mid-points of the sides  $BC$ ,  $CA$  and  $AB$  of a  $\triangle ABC$ . show that
- $BDEF$  is a parallelogram.
  - $ar(BDEF) = \frac{1}{2}ar(ABC)$
38. Diagonals  $AC$  and  $BD$  of quadrilateral  $ABCD$  intersect at  $O$  such that  $OB = OD$ . If  $AB = CD$ , then show that
- $ar(DOC) = ar(AOB)$
  - $ar(DCB) = ar(ACB)$
  - $ar(DEF) = \frac{1}{4}ar(ABC)$
39.  $D$  and  $E$  are points on sides  $AB$  and  $AC$  respectively of  $\triangle ABC$  such that  $ar(DBC) = ar(EBD)$ . Prove that  $DE \parallel BC$ .
40.  $XY$  is a line parallel to side  $BC$  of a  $\triangle ABC$ . If  $BE \parallel AC$  and  $CF \parallel AB$  meet  $XY$  at  $E$  and  $F$  respectively, show that  $ar(ABE) = ar(ACF)$ .
41. The side  $AB$  of a parallelogram  $ABCD$  is produced to any point  $P$ . A line through  $A$  and parallel to  $CP$  meets  $CB$  produced at  $Q$  and then parallelogram  $PBQR$  is completed. Show that  $ar(ABCD) = ar(PBQR)$ .
42. Diagonals  $AC$  and  $BD$  of a trapezium  $ABCD$  with  $AB \parallel DC$  intersect each other at  $O$ . Prove that  $ar(AOD) = ar(BOC)$ .

43.  $ABCDE$  is a pentagon. A line through  $B$  parallel to  $AC$  meets  $DC$  produced at  $F$ . Show that
- $ar(ACB) = ar(ACF)$
  - $ar(AEDF) = ar(ABCDE)$ .
44. A villager Itwaari has a plot of land of the shape of a quadrilateral. The Gram Panchayat of the village decided to take over some portion of his plot from one of the corners to construct a Health Centre. Itwaari agrees to the above proposal with the condition that he should be given equal amount of land in lieu of his land adjoining his plot so as to form a triangular plot. Explain how this proposal will be implemented.
45.  $ABCD$  is a trapezium with  $AB \parallel DC$ . A line parallel to  $AC$  intersects  $AB$  at  $X$  and  $BC$  at  $Y$ . Prove that  $ar(ADX) = ar(ACY)$ .
46.  $AP \parallel BQ \parallel CR$ . Prove that  $ar(AQC) = ar(PBR)$ .
47. Diagonals  $AC$  and  $BD$  of a quadrilateral  $ABCD$  intersect at  $O$  in such a way that  $ar(AOD) = ar(BOC)$ . Prove that  $ABCD$  is a trapezium.
48.  $AB \parallel DC \parallel RP$ .  $ar(DRC) = ar(DPC)$  and  $ar(BDP) = ar(ARC)$ . Show that both the quadrilaterals  $ABCD$  and  $DCPR$  are trapeziums.
49. Parallelogram  $ABCD$  and rectangle  $ABEF$  are on the same base  $AB$  and have equal areas. Show that the perimeter of the parallelogram is greater than that of the rectangle.
50. In  $\triangle ABC$ ,  $D$  and  $E$  are two points on  $BC$  such that  $BD = DE = EC$ . Show that  $ar(ABD) = ar(ADE) = ar(AEC)$ .
51.  $ABCD$ ,  $DCFE$  and  $ABFE$  are parallelograms. Show that  $ar(ADE) = ar(BCF)$ .

52.  $ABCD$  is a parallelogram and  $BC$  is produced to a point  $Q$  such that  $AD = CQ$ . If  $AQ$  intersect  $DC$  at  $P$ , show that  $ar(BPC) = ar(DPQ)$ .  $ABC$  and  $BDE$  are two equilateral triangles such that  $D$  is the mid-point of  $BC$ . If  $AE$  intersects  $BC$  at  $F$ , show that

(a)  $ar(BDE) = \frac{1}{4}ar(ABC)$

(b)  $ar(BDE) = \frac{1}{2}ar(BAE)$

(c)  $ar(ABC) = 2ar(BEC)$

(d)  $ar(BFE) = ar(AFD)$

(e)  $ar(BFE) = 2ar(FED)$

(f)  $ar(FED) = \frac{1}{8}ar(AFC)$

53. Diagonals  $AC$  and  $BD$  of a quadrilateral  $ABCD$  intersect each other at  $P$ . Show that  $ar(APB) \times ar(CPD) = ar(APD) \times ar(BPC)$ .

54.  $P$  and  $Q$  are respectively the mid-points of sides  $AB$  and  $BC$  of a  $\triangle ABC$  and  $R$  is the mid-point of  $AP$ , show that

(a)  $ar(PRQ) = \frac{1}{2}ar(ARC)$

(b)  $ar(PBQ) = ar(ARC)$

(c)  $ar(RQC) = \frac{3}{8}ar(ABC)$

55.  $ABC$  is a right triangle right angled at  $A$ .  $BCED$ ,  $ACFG$  and  $ABMN$  are squares on the sides  $BC$ ,  $CA$  and  $AB$  respectively. Line segment  $AX \perp DE$  meets  $BC$  at  $Y$ . Show that

(a)  $\triangle MBC \cong \triangle ABD$

(b)  $ar(BYXD) = ar(ABMN)$

- (c)  $ar(CYXE) = 2ar(FCB)$
- (d)  $ar(BYXD) = 2ar(MBC)$
- (e)  $\triangle FCB \cong \triangle ACE$
- (f)  $ar(CYXE) = ar(ACFG)$
- (g)  $ar(BCED) = ar(ABMN) + ar(ACFG)$

56.  $L$  is a point on the diagonal  $AC$  of quadrilateral  $ABCD$ . If  $LM \text{ --- } CB$  and  $LN \text{ --- } CD$ , prove that  $\frac{AM}{AB} = \frac{AN}{AD}$

57. The angles of quadrilateral are in the ratio 3 : 5 : 9 : 13. Find all the angles of the quadrilateral.

**Solution:** Let the measure of angles  $\angle A, \angle B, \angle C, \angle D$  of a quadrilateral are  $3x, 5x, 9x$  and  $13x$  respectively, where  $x$  is a real number.

Using angle sum property, the sum of interior angles of a quadrilateral is 360 degree.

$$3x + 5x + 9x + 13x = 360^\circ \quad (2.0.0.57.1)$$

$$30x = 360^\circ \quad (2.0.0.57.2)$$

$$x = 12^\circ \quad (2.0.0.57.3)$$

From the above calculations,

$$\angle A = 3x = 3(12) = 36^\circ \quad (2.0.0.57.4)$$

$$\angle B = 5x = 5(12) = 60^\circ \quad (2.0.0.57.5)$$

$$\angle C = 9x = 9(12) = 108^\circ \quad (2.0.0.57.6)$$

$$\angle D = 13x = 13(12) = 156^\circ \quad (2.0.0.57.7)$$



## Chapter 3

# Circle

1. Equal chords of a circle (or of congruent circles) subtend equal angles at the centre.
2. If the angles subtended by two chords of a circle (or of congruent circles) at the centre (corresponding centres) are equal, the chords are equal.
3. The perpendicular from the centre of a circle to a chord bisects the chord.
4. The line drawn through the centre of a circle to bisect a chord is perpendicular to the chord.
5. There is one and only one circle passing through three non-collinear points.
6. Equal chords of a circle (or of congruent circles) are equidistant from the centre (or corresponding centres).
7. Chords equidistant from the centre (or corresponding centres) of a circle (or of congruent circles) are equal.
8. If two arcs of a circle are congruent, then their corresponding chords are equal and conversely if two chords of a circle are equal, then their corresponding arcs (minor, major) are congruent.
9. Congruent arcs of a circle subtend equal angles at the centre.

10. The angle subtended by an arc at the centre is double the angle subtended by it at any point on the remaining part of the circle.
11. Angles in the same segment of a circle are equal.
12. Angle in a semicircle is a right angle.
13. If a line segment joining two points subtends equal angles at two other points lying on the same side of the line containing the line segment, the four points lie on a circle.

(a) Construction: See Fig. 3.1. The input parameters are

$$\mathbf{A} = \begin{pmatrix} p \\ q \end{pmatrix} \quad (3.0.0.13.1)$$

$$\mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (3.0.0.13.2)$$

$$\mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix} \quad (3.0.0.13.3)$$

$\theta_1$  is obtained using

$$\cos \theta_1 = \frac{(\mathbf{A} - \mathbf{B})^T (\mathbf{A} - \mathbf{C})}{\|\mathbf{A} - \mathbf{B}\| \|\mathbf{A} - \mathbf{C}\|} \quad (3.0.0.13.4)$$

Let

$$\mathbf{D} = b \begin{pmatrix} \cos \beta_2 \\ b \sin \beta_2 \end{pmatrix} \quad (3.0.0.13.5)$$

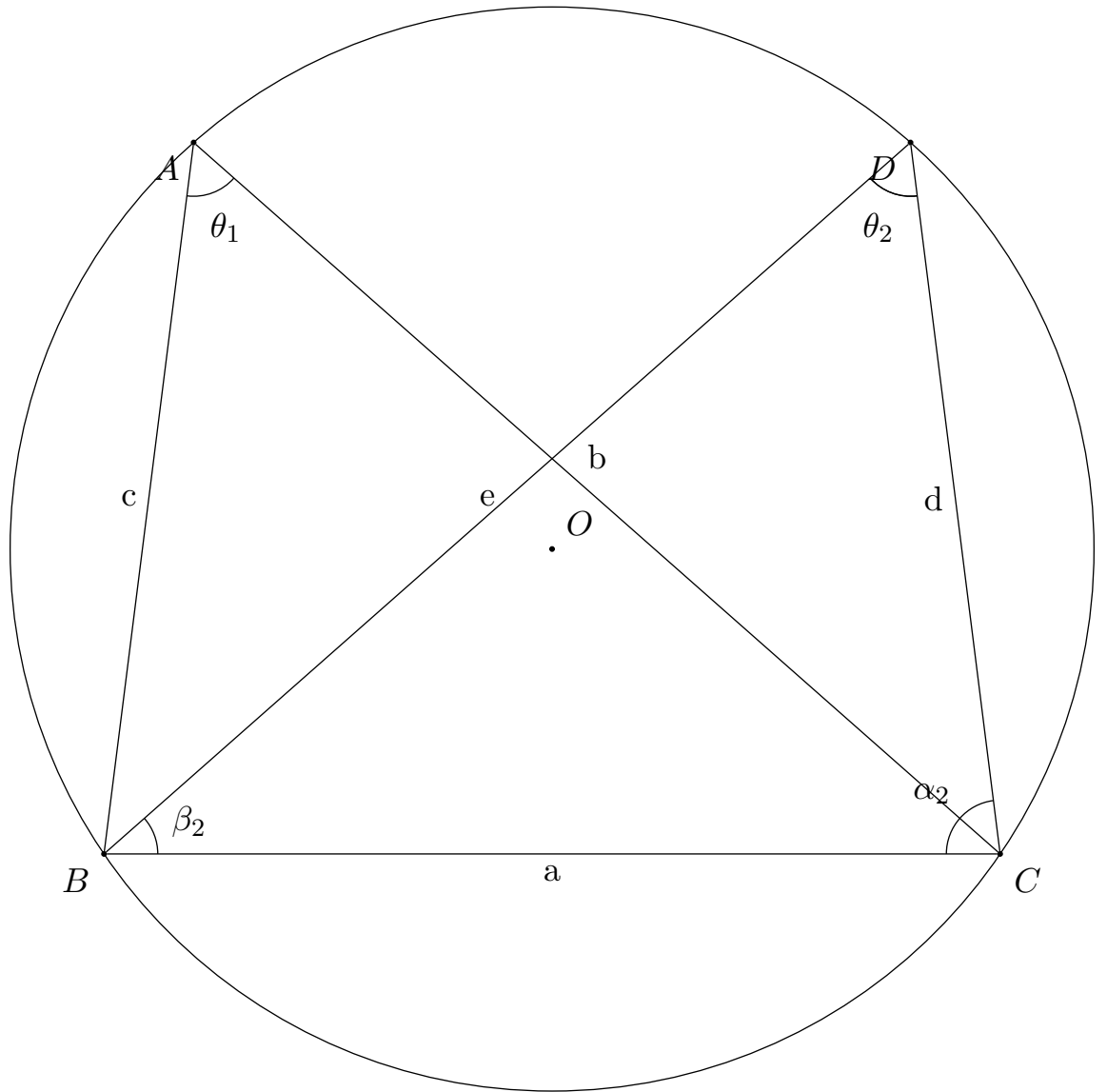


Figure 3.1:

From the given information,  $\theta_2 = \theta_1$

$$\implies \frac{b}{\sin(\theta_2 + \beta_2)} = \frac{a}{\sin \theta_2} \quad (3.0.0.13.6)$$



Choosing an appropriate value of  $\beta_2$ ,  $b$  and  $\mathbf{D}$  can be obtained from (3.0.0.13.5) and (3.0.0.13.6) respectively.

The circumcircle of  $\triangle ABC$  can then be drawn and it can be verified that  $\mathbf{D}$  lies on it.

(b) Proof: Let

$$\mathbf{O} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (3.0.0.13.7)$$

be the circumcentre of  $\triangle ABC$  and let  $r$  be the radius. Assuming that

$$\mathbf{A} = r \begin{pmatrix} \cos \theta_1 \\ \sin \theta_1 \end{pmatrix}, \mathbf{B} = r \begin{pmatrix} \cos \theta_2 \\ \sin \theta_2 \end{pmatrix} \quad (3.0.0.13.8)$$

$$\mathbf{C} = r \begin{pmatrix} \cos \theta_3 \\ \sin \theta_3 \end{pmatrix}, \mathbf{D} = k \begin{pmatrix} \cos \theta_4 \\ \sin \theta_4 \end{pmatrix} \quad (3.0.0.13.9)$$

in Fig. 3.1, from the given information

$$\frac{(\mathbf{A} - \mathbf{B})^T (\mathbf{A} - \mathbf{C})}{\|\mathbf{A} - \mathbf{B}\| \|\mathbf{A} - \mathbf{C}\|} = \frac{(\mathbf{D} - \mathbf{B})^T (\mathbf{D} - \mathbf{C})}{\|\mathbf{D} - \mathbf{B}\| \|\mathbf{D} - \mathbf{C}\|} \quad (3.0.0.13.10)$$

$$\begin{aligned} \therefore (\mathbf{A} - \mathbf{B})^T (\mathbf{A} - \mathbf{C}) &= \|\mathbf{A}\|^2 - \mathbf{A}^T \mathbf{B} \\ &\quad - \mathbf{B}^T \mathbf{A} + \mathbf{B}^T \mathbf{C} \quad (3.0.0.13.11) \end{aligned}$$

from (3.0.0.13.8)-(3.0.0.13.9), (3.0.0.13.11) can be expressed as

$$\begin{aligned}
& r^2 [1 - \cos(\theta_1 - \theta_2) \\
& \quad - \cos(\theta_1 - \theta_3) + \cos(\theta_2 - \theta_3)] \\
& = r^2 (1 - p_{12} - p_{13} + p_{23}) \quad (3.0.0.13.12)
\end{aligned}$$

which can be expressed as

$$\begin{aligned}
& 2r^2 \left[ \sin^2 \left( \frac{\theta_1 - \theta_2}{2} \right) \right. \\
& \quad \left. + \sin \left( \frac{\theta_1 - \theta_2}{2} \right) \sin \left( \frac{\theta_1 + \theta_2}{2} - \theta_3 \right) \right] \\
& \quad = 2r^2 \sin \left( \frac{\theta_1 - \theta_2}{2} \right) \\
& \quad \times \left[ \sin \left( \frac{\theta_1 - \theta_2}{2} \right) + \sin \left( \frac{\theta_1 + \theta_2}{2} - \theta_3 \right) \right] \\
& \quad = 4r^2 \sin \left( \frac{\theta_1 - \theta_2}{2} \right) \\
& \quad \times \sin \left( \frac{\theta_1 - \theta_3}{2} \right) \cos \left( \frac{\theta_2 - \theta_3}{2} \right) \quad (3.0.0.13.13)
\end{aligned}$$

Similarly,

$$\begin{aligned}
(\mathbf{D} - \mathbf{B})^T (\mathbf{D} - \mathbf{C}) &= \|\mathbf{D}\|^2 - \mathbf{D}^T \mathbf{B} \\
&\quad - \mathbf{B}^T \mathbf{D} + \mathbf{B}^T \mathbf{C} \quad (3.0.0.13.14)
\end{aligned}$$

which can be expressed using (3.0.0.13.8)-(3.0.0.13.9) as

$$\begin{aligned}
& k^2 - rk \cos(\theta_2 - \theta_4) \\
& \quad - rk \cos(\theta_3 - \theta_4) + r^2 \cos(\theta_2 - \theta_3) \\
& \quad = k^2 - rk p_{24} - rk p_{34} + r^2 p_{23} \quad (3.0.0.13.15)
\end{aligned}$$

Similarly,

$$\|\mathbf{A} - \mathbf{B}\|^2 = 2r^2 [1 - \cos(\theta_1 - \theta_2)] \quad (3.0.0.13.16)$$

$$= 2r^2 (1 - p_{12}) \quad (3.0.0.13.17)$$

$$= 2 \sin^2 \left( \frac{\theta_1 - \theta_2}{2} \right) \quad (3.0.0.13.18)$$

$$\|\mathbf{A} - \mathbf{C}\|^2 = 2r^2 [1 - \cos(\theta_1 - \theta_3)] \quad (3.0.0.13.19)$$

$$= 2r^2 (1 - p_{13}) \quad (3.0.0.13.20)$$

$$= 2 \sin^2 \left( \frac{\theta_1 - \theta_3}{2} \right) \quad (3.0.0.13.21)$$

$$\|\mathbf{D} - \mathbf{B}\|^2 = k^2 + r^2 - 2kr \cos(\theta_2 - \theta_4) \quad (3.0.0.13.22)$$

$$= k^2 + r^2 - 2kr p_{24} \quad (3.0.0.13.23)$$

$$\|\mathbf{D} - \mathbf{C}\|^2 = k^2 + r^2 - 2kr \cos(\theta_3 - \theta_4) \quad (3.0.0.13.24)$$

$$= k^2 + r^2 - 2kr p_{34} \quad (3.0.0.13.25)$$

Substituting from (3.0.0.13.15), (3.0.0.13.12), (3.0.0.13.17), (3.0.0.13.20), (3.0.0.13.23),

(3.0.0.13.25) in (3.0.0.13.10),

$$\begin{aligned} & \frac{r^2(1-p_{12}-p_{13}+p_{23})}{\sqrt{2r^2(1-p_{12})}\sqrt{2r^2(1-p_{13})}} \\ &= \frac{k^2 - rkp_{24} - rkp_{34} + r^2p_{23}}{\sqrt{k^2 + r^2 - 2krp_{24}}\sqrt{k^2 + r^2 - 2krp_{34}}} \end{aligned} \quad (3.0.0.13.26)$$

which can be expressed as

$$\begin{aligned} & \frac{1-p_{12}-p_{13}+p_{23}}{2\sqrt{(1-p_{12})(1-p_{13})}} \\ &= \frac{x^2 - xp_{24} - xp_{34} + p_{23}}{\sqrt{(x^2 + 1 - 2xp_{24})(x^2 + 1 - 2xp_{34})}} \end{aligned} \quad (3.0.0.13.27)$$

upon substituting

$$x = \frac{k}{r}. \quad (3.0.0.13.28)$$

From (3.0.0.13.13), (3.0.0.13.18) and (3.0.0.13.21),

$$\begin{aligned} & \frac{1-p_{12}-p_{13}+p_{23}}{2\sqrt{(1-p_{12})(1-p_{13})}} \\ &= \cos\left(\frac{\theta_2 - \theta_3}{2}\right) \end{aligned} \quad (3.0.0.13.29)$$

Similarly, it can be shown that

$$\begin{aligned} & \frac{1-p_{24}-p_{34}+p_{23}}{2\sqrt{(1-p_{24})(1-p_{34})}} \\ &= \cos\left(\frac{\theta_2 - \theta_3}{2}\right) \end{aligned} \quad (3.0.0.13.30)$$

From (3.0.0.13.29) and (3.0.0.13.30), (3.0.0.13.27) can be expressed as

$$\frac{1 - p_{24} - p_{34} + p_{23}}{2\sqrt{(1 - p_{24})(1 - p_{34})}} = \frac{x^2 - xp_{24} - xp_{34} + p_{23}}{\sqrt{(x^2 + 1 - 2xp_{24})(x^2 + 1 - 2xp_{34})}} \quad (3.0.0.13.31)$$

It is obvious that

$$x = 1 \quad (3.0.0.13.32)$$

is a solution of (3.0.0.13.31)

$$\implies k = r \quad (3.0.0.13.33)$$

from (3.0.0.13.28).

14. The sum of either pair of opposite angles of a cyclic quadrilateral is  $180^\circ$ .
15. If sum of a pair of opposite angles of a quadrilateral is  $180^\circ$ , the quadrilateral is cyclic.
16.  $AB$  is a diameter of the circle,  $CD$  is a chord equal to the radius of the circle.  $AC$  and  $BD$  when extended intersect at a point  $E$ . Prove that  $\angle AEB = 60^\circ$ .

(a) Construction: In Fig. 3.2 the known parameters are

$$\mathbf{O} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \quad (3.0.0.16.1)$$

$$\mathbf{A} = \begin{pmatrix} r \\ 0 \end{pmatrix}, \quad (3.0.0.16.2)$$

$$\mathbf{B} = \begin{pmatrix} -r \\ 0 \end{pmatrix} \quad (3.0.0.16.3)$$

$$\mathbf{C} = r \begin{pmatrix} \cos \theta \\ \sin \theta \end{pmatrix} \quad (3.0.0.16.4)$$

Let

$$\mathbf{D} = r \begin{pmatrix} \cos \theta_1 \\ \sin \theta_1 \end{pmatrix} \quad (3.0.0.16.5)$$

From the given information,

$$\|\mathbf{D} - \mathbf{C}\| = r \quad (3.0.0.16.6)$$

$$\implies (\mathbf{D} - \mathbf{C})^T (\mathbf{D} - \mathbf{C}) = r^2 \quad (3.0.0.16.7)$$

$$(3.0.0.16.8)$$

$$\implies \|D\|^2 - 2\mathbf{D}^T \mathbf{C} + \|C\|^2 = r^2 \quad (3.0.0.16.9)$$

In the above,

$$\because \|D\| = \|\mathbf{C}\| = r, \quad (3.0.0.16.10)$$

$$\frac{\mathbf{D}^T \mathbf{C}}{\|D\| \|\mathbf{C}\|} = \frac{1}{2} \quad (3.0.0.16.11)$$

$$\implies \cos(\theta_1 - \theta) = 60^\circ \quad (3.0.0.16.12)$$

using the definition of the inner product.  $\because \theta$  is known, we get  $\theta_1$  from (3.0.0.16.12) and  $\mathbf{D}$  from (3.0.0.16.5).

Thus,

$$BD : \mathbf{x} = \mathbf{B} + \lambda_1 (\mathbf{B} - \mathbf{D}) \quad (3.0.0.16.13)$$

$$AC : \mathbf{x} = \mathbf{A} + \lambda_2 (\mathbf{A} - \mathbf{C}) \quad (3.0.0.16.14)$$

which can be used to obtain  $\mathbf{E}$ .

(b) Proof:

$$\mathbf{D} - \mathbf{B} = r \begin{pmatrix} \cos \theta_1 + 1 & \sin \theta_1 \end{pmatrix} \quad (3.0.0.16.15)$$

$$= 2r \cos \left( \frac{\theta_1}{2} \right) \begin{pmatrix} \cos \left( \frac{\theta_1}{2} \right) \\ \sin \left( \frac{\theta_1}{2} \right) \end{pmatrix} \quad (3.0.0.16.16)$$

$$\mathbf{C} - \mathbf{A} = r \begin{pmatrix} \cos \theta - 1 & \sin \theta \end{pmatrix} \quad (3.0.0.16.17)$$

$$= 2r \sin \left( \frac{\theta}{2} \right) \begin{pmatrix} -\sin \left( \frac{\theta}{2} \right) \\ \cos \left( \frac{\theta}{2} \right) \end{pmatrix} \quad (3.0.0.16.18)$$

$$\implies \|\mathbf{D} - \mathbf{B}\| = 2r \cos \left( \frac{\theta_1}{2} \right) \quad (3.0.0.16.19)$$

$$\|\mathbf{C} - \mathbf{A}\| = 2r \sin \left( \frac{\theta}{2} \right) \quad (3.0.0.16.20)$$

Thus, using the definition of the inner product,

$$\cos \angle E = \frac{(\mathbf{D} - \mathbf{B})^T (\mathbf{C} - \mathbf{A})}{\|\mathbf{D} - \mathbf{B}\| \|\mathbf{C} - \mathbf{A}\|} \quad (3.0.0.16.21)$$

$$= \begin{pmatrix} \cos \left( \frac{\theta_1}{2} \right) & \sin \left( \frac{\theta_1}{2} \right) \end{pmatrix} \begin{pmatrix} -\sin \left( \frac{\theta}{2} \right) \\ \cos \left( \frac{\theta}{2} \right) \end{pmatrix} \quad (3.0.0.16.22)$$

which can be simplified to obtain

$$\cos \angle E = \sin \left( \frac{\theta_1 - \theta}{2} \right) \quad (3.0.0.16.23)$$

$$= \sin 30^\circ = \frac{1}{2} \quad (3.0.0.16.24)$$



from (3.0.0.16.12). Thus,

$$\underline{\angle E} = 60^\circ \quad (3.0.0.16.25)$$

17.  $ABCD$  is a cyclic quadrilateral in which  $AC$  and  $BD$  are its diagonals. If  $\angle DBC = 55^\circ$  and  $\angle BAC = 45^\circ$ , find  $\angle BCD$
18. Two circles intersect at two points  $A$  and  $B$ .  $AD$  and  $AC$  are diameters to the two circles. Prove that  $B$  lies on the line segment  $DC$ .
19. Prove that the quadrilateral formed (if possible) by the internal angle bisectors of any quadrilateral is cyclic.

(a) Construction: See Fig. 3.3. For drawing  $ABCD$ ,

$$\mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (3.0.0.19.1)$$

$$\mathbf{A} = d \begin{pmatrix} \cos \theta \\ \sin \theta \end{pmatrix} \quad (3.0.0.19.2)$$

$$\mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix} \quad (3.0.0.19.3)$$

$$\mathbf{D} = \begin{pmatrix} d_1 \\ d_2 \end{pmatrix}, \quad d_1 < a, d_2 > d \sin \theta \quad (3.0.0.19.4)$$

where

$$\theta = \underline{\angle ABC} \quad (3.0.0.19.5)$$

The direction vector of the angle bisector  $BE$  is given by

$$\frac{\mathbf{A} - \mathbf{B}}{\|A - B\|} + \frac{\mathbf{C} - \mathbf{B}}{\|C - B\|} \quad (3.0.0.19.6)$$

Thus,

$$BE : \quad \mathbf{x} = \mathbf{B} + \lambda_1 \left( \frac{\mathbf{A} - \mathbf{B}}{\|A - B\|} + \frac{\mathbf{C} - \mathbf{B}}{\|C - B\|} \right) \quad (3.0.0.19.7)$$

Similarly,

$$CE : \quad \mathbf{x} = \mathbf{C} + \lambda_2 \left( \frac{\mathbf{C} - \mathbf{D}}{\|C - D\|} + \frac{\mathbf{C} - \mathbf{B}}{\|C - B\|} \right) \quad (3.0.0.19.8)$$

$$DG : \quad \mathbf{x} = \mathbf{D} + \lambda_3 \left( \frac{\mathbf{A} - \mathbf{D}}{\|A - D\|} + \frac{\mathbf{C} - \mathbf{D}}{\|C - D\|} \right) \quad (3.0.0.19.9)$$

$$AG : \quad \mathbf{x} = \mathbf{A} + \lambda_4 \left( \frac{\mathbf{A} - \mathbf{D}}{\|A - D\|} + \frac{\mathbf{A} - \mathbf{B}}{\|A - B\|} \right) \quad (3.0.0.19.10)$$

(3.0.0.19.7)-(3.0.0.19.10) can be used to find the points  $\mathbf{E}, \mathbf{F}, \mathbf{G}, \mathbf{H}$ , any three of which can be used to draw the circle and verify the fourth point lies on this circle.

(b) Proof: In  $\triangle sBEC$  and  $DGA$ , the sum of the angles

$$\frac{B}{2} + \frac{C}{2} + E = 180^\circ \quad (3.0.0.19.11)$$

$$\frac{D}{2} + \frac{A}{2} + G = 180^\circ \quad (3.0.0.19.12)$$

yielding

$$\frac{A + B + C + D}{2} + E + F = 360^\circ \quad (3.0.0.19.13)$$

$$\implies E + F = 180^\circ \quad (3.0.0.19.14)$$

Thus,  $EFGH$  is a cyclic quadrilateral.

20. Equal chords of a circle (or of congruent circles) subtend equal angles at the centre.
21. If the angles subtended by two chords of a circle (or of congruent circles) at the centre (corresponding centres) are equal, the chords are equal.
22. The perpendicular from the centre of a circle to a chord bisects the chord.
23. The line drawn through the centre of a circle to bisect a chord is perpendicular to the chord.
24. There is one and only one circle passing through three non-collinear points.
25. Equal chords of a circle (or of congruent circles) are equidistant from the centre (or corresponding centres).
26. Chords equidistant from the centre (or corresponding centres) of a circle (or of congruent circles) are equal.
27. If two arcs of a circle are congruent, then their corresponding chords are equal and conversely if two chords of a circle are equal, then their corresponding arcs (minor, major) are congruent.
28. Congruent arcs of a circle subtend equal angles at the centre.
29. The angle subtended by an arc at the centre is double the angle subtended by it at any point on the remaining part of the circle.
30. Angles in the same segment of a circle are equal.
31. Angle in a semicircle is a right angle.

32. If a line segment joining two points subtends equal angles at two other points lying on the same side of the line containing the line segment, the four points lie on a circle.
33. The sum of either pair of opposite angles of a cyclic quadrilateral is  $180^\circ$ .
34. If sum of a pair of opposite angles of a quadrilateral is  $180^\circ$ , the quadrilateral is cyclic.
35.  $AB$  is a diameter of the circle,  $CD$  is a chord equal to the radius of the circle.  $AC$  and  $BD$  when extended intersect at a point  $E$ . Prove that  $\angle AEB = 60^\circ$ .
36. Two circles intersect at two points  $A$  and  $B$ .  $AD$  and  $AC$  are diameters to the two circles. Prove that  $B$  lies on the line segment  $DC$ .
37. Prove that the quadrilateral formed (if possible) by the internal angle bisectors of any quadrilateral is cyclic.
38. If two equal chords of a circle intersect within the circle, prove that the segments of one chord are equal to corresponding segments of the other chord.
39. If two equal chords of a circle intersect within the circle, prove that the line joining the point of intersection to the centre makes equal angles with the chords.

(a) Construction: In Fig. 3.4,

$$\mathbf{O} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (3.0.0.39.1)$$

$$\mathbf{B} = r \begin{pmatrix} \cos \theta_1 \\ \sin \theta_1 \end{pmatrix} \quad (3.0.0.39.2)$$

$$\mathbf{A} = r \begin{pmatrix} \cos \theta_2 \\ \sin \theta_2 \end{pmatrix} \quad (3.0.0.39.3)$$

$$\mathbf{D} = r \begin{pmatrix} \cos \theta_3 \\ \sin \theta_3 \end{pmatrix} \quad (3.0.0.39.4)$$

are the input parameters.

From the given information,

$$\|\mathbf{A} - \mathbf{B}\|^2 = \|\mathbf{C} - \mathbf{D}\|^2 \quad (3.0.0.39.5)$$

$$\implies \mathbf{A}^T \mathbf{B} = \mathbf{C}^T \mathbf{D} \quad (3.0.0.39.6)$$

$$\implies \theta_2 - \theta_1 = \pm (\theta_3 - \theta_4) \quad (3.0.0.39.7)$$

where

$$\mathbf{C} = \begin{pmatrix} r \cos \theta_4 \\ r \sin \theta_4 \end{pmatrix} \quad (3.0.0.39.8)$$

From (3.0.0.39.7),  $\mathbf{C}$  can be obtained.

$\mathbf{X}$  can then be obtained as the intersection of  $AB$  and  $CD$ .

$$\mathbf{M} = \frac{\mathbf{A} + \mathbf{B}}{2} \quad (3.0.0.39.9)$$

$$\mathbf{N} = \frac{\mathbf{C} + \mathbf{D}}{2} \quad (3.0.0.39.10)$$

(b) Proof:  $\triangle OMX \cong \triangle ONX$  using RHS congruence. Hence

$$\angle OXM = \angle OXN \quad (3.0.0.39.11)$$

40. If a line intersects two concentric circles (circles with the same centre) with centre  $\mathbf{O}$  at  $A, B, C$  and  $D$ , prove that  $AB = CD$ .

(a) Construction: See Fig. 3.5. The input parameters are

$$\mathbf{O} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{A} = r_1 \begin{pmatrix} \cos \theta_1 \\ \sin \theta_1 \end{pmatrix}, \mathbf{D} = r_2 \begin{pmatrix} \cos \theta_2 \\ \sin \theta_2 \end{pmatrix} \quad (3.0.0.40.1)$$

The two concentric circles with centre  $\mathbf{O}$  and radii  $r_1$  and  $r_2$  are drawn.

The equation of  $AD$  is

$$\mathbf{x} = \mathbf{A} + \lambda(\mathbf{A} - \mathbf{D}) \quad (3.0.0.40.2)$$

Points  $\mathbf{B}$  and  $\mathbf{C}$  are obtained as the intersection of  $AD$  and the circle with equation

$$\|\mathbf{x}\|^2 = r_2^2 \quad (3.0.0.40.3)$$

From (3.0.0.40.3) and (3.0.0.40.3),

$$\|\mathbf{A} + \lambda(\mathbf{A} - \mathbf{D})\|^2 = r_2^2 \quad (3.0.0.40.4)$$

$$\begin{aligned} \lambda^2 \|\mathbf{A} - \mathbf{D}\|^2 + 2\lambda \mathbf{A}^T (\mathbf{A} - \mathbf{D}) \\ + \|\mathbf{A}\|^2 - r_2^2 = 0 \end{aligned} \quad (3.0.0.40.5)$$

Solving the above quadratic equation yields two values for  $\lambda$  yielding  $\mathbf{B}$  and  $\mathbf{C}$ .

$$\mathbf{M} = \frac{\mathbf{B} + \mathbf{C}}{2} \quad (3.0.0.40.6)$$

(b) Proof: In Fig. 3.5,

$$\triangle OMB \cong \triangle OMC \quad (3.0.0.40.7)$$

$$\triangle OMA \cong \triangle OMD \quad (3.0.0.40.8)$$

resulting in

$$AM = DM \quad (3.0.0.40.9)$$

$$BM = CM \quad (3.0.0.40.10)$$

$$\implies AB = CD \quad (3.0.0.40.11)$$

41. A chord of a circle is equal to the radius of the circle. Find the angle subtended by the chord at a point on the minor arc and also at a point on the major arc.

42. If diagonals of a cyclic quadrilateral are diameters of the circle through the vertices

of the quadrilateral, prove that it is a rectangle.

43. If the non-parallel sides of a trapezium are equal, prove that it is cyclic.

(a) Construction: See Fig. 3.6 The input parameters are

$$\mathbf{A} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} b \\ 0 \end{pmatrix}, \quad (3.0.0.43.1)$$

$$\mathbf{C} = \begin{pmatrix} b - h \cot \theta \\ h \end{pmatrix} \quad (3.0.0.43.2)$$

$$\mathbf{D} = h \begin{pmatrix} \cot \theta \\ 1 \end{pmatrix} \quad (3.0.0.43.3)$$

which are sufficient to draw the trapezium. The circumcircle of  $\triangle ABC$  is then drawn. This circle passes through  $\mathbf{D}$ . From (3.0.0.43.1) - (3.0.0.43.3)

$$\mathbf{B} - \mathbf{A} = \begin{pmatrix} b \\ 0 \end{pmatrix} \quad (3.0.0.43.4)$$

$$\mathbf{D} - \mathbf{C} = \begin{pmatrix} 2h \cot \theta - b \\ 0 \end{pmatrix} \quad (3.0.0.43.5)$$

$$\mathbf{D} - \mathbf{A} = \begin{pmatrix} h \cot \theta \\ h \end{pmatrix} \quad (3.0.0.43.6)$$

$$\mathbf{B} - \mathbf{C} = \begin{pmatrix} h \cot \theta \\ -h \end{pmatrix} \quad (3.0.0.43.7)$$



Finding the scalar products:

$$(\mathbf{D} - \mathbf{A})^T (\mathbf{B} - \mathbf{A}) = \|\mathbf{D} - \mathbf{A}\| \|\mathbf{B} - \mathbf{A}\| \cos \theta \quad (3.0.0.43.8)$$

$$(\mathbf{D} - \mathbf{C})^T (\mathbf{B} - \mathbf{C}) = \|\mathbf{D} - \mathbf{C}\| \|\mathbf{B} - \mathbf{C}\| \cos \alpha \quad (3.0.0.43.9)$$

Dividing (3.0.0.43.9) with (3.0.0.43.8),

$$\frac{(\mathbf{D} - \mathbf{A})^T (\mathbf{B} - \mathbf{A})}{(\mathbf{D} - \mathbf{C})^T (\mathbf{B} - \mathbf{C})} = \frac{\|\mathbf{D} - \mathbf{A}\| \|\mathbf{B} - \mathbf{A}\| \cos \theta}{\|\mathbf{D} - \mathbf{C}\| \|\mathbf{B} - \mathbf{C}\| \cos \alpha} \quad (3.0.0.43.10)$$

$\because \|\mathbf{D} - \mathbf{A}\| = \|\mathbf{B} - \mathbf{C}\|$ , (3.0.0.43.10) can be simplified to the form

$$\frac{(\mathbf{D} - \mathbf{A})^T (\mathbf{B} - \mathbf{A})}{(\mathbf{D} - \mathbf{C})^T (\mathbf{B} - \mathbf{C})} = \frac{\|\mathbf{B} - \mathbf{A}\| \cos \theta}{\|\mathbf{D} - \mathbf{C}\| \cos \alpha} \quad (3.0.0.43.11)$$

Substituting values from (3.0.0.43.4), (3.0.0.43.5), (3.0.0.43.6) and (3.0.0.43.7):

$$\frac{bh \cot \theta}{(2h \cot \theta - b) h \cot \theta} = \frac{b \cos \theta}{b - 2h \cot \theta} \quad (3.0.0.43.12)$$

$$\implies \cos \alpha = -\cos \theta \quad (3.0.0.43.13)$$

$$\implies \alpha + \theta = 180^\circ \quad (3.0.0.43.14)$$

$\therefore ABCD$  is a cyclic quadrilateral.

44. Two circles intersect at two points  $B$  and  $C$ . Through  $B$ , two line segments  $ABD$  and  $PBQ$  are drawn to intersect the circles at  $A, D$  and  $P, Q$  respectively. Prove that  $\angle ACP = \angle QCD$ .

45. If circles are drawn taking two sides of a triangle as diameters, prove that the point

of intersection of these circles lie on the third side.

46.  $ABC$  and  $ADC$  are two right triangles with common hypotenuse  $AC$ . Prove that  $\angle CAD = \angle CBD$ .

47. Prove that a cyclic parallelogram is a rectangle.

48. Prove that the line of centres of two intersecting circles subtends equal angles at the two points of intersection.

49. Let the vertex of an angle  $ABC$  be located outside a circle and let the sides of the angle intersect equal chords  $AD$  and  $CE$  with the circle. Prove that  $\angle ABC$  is equal to half the difference of the angles subtended by the chords  $AC$  and  $DE$  at the centre.

(a) Construction: See Fig. 3.7. The input parameters are

$$\mathbf{O} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (3.0.0.49.1)$$

$$\mathbf{C} = \begin{pmatrix} r \\ 0 \end{pmatrix} \quad (3.0.0.49.2)$$

Then,

$$\mathbf{A} = r \begin{pmatrix} \cos \beta \\ -\sin \beta \end{pmatrix} \quad (3.0.0.49.3)$$

Equal chords subtend equal angles at the centre. Hence

$$\angle EOC = \angle AOD = \frac{360^\circ - \alpha - \beta}{2} \quad (3.0.0.49.4)$$

$$= 180^\circ - \frac{\alpha + \beta}{2} \quad (3.0.0.49.5)$$

Thus,

$$\mathbf{D} = r \begin{pmatrix} \cos \left( 180^\circ - \frac{\alpha + \beta}{2} + \alpha \right) \\ \sin \left( 180^\circ - \frac{\alpha + \beta}{2} + \alpha \right) \end{pmatrix} \quad (3.0.0.49.6)$$

$$= r \begin{pmatrix} -\cos \frac{\alpha - \beta}{2} \\ -\sin \frac{\alpha - \beta}{2} \end{pmatrix} \quad (3.0.0.49.7)$$

$$\mathbf{E} = r \begin{pmatrix} \cos \left( 180^\circ - \frac{\alpha + \beta}{2} \right) \\ \sin \left( 180^\circ - \frac{\alpha + \beta}{2} \right) \end{pmatrix} \quad (3.0.0.49.8)$$

$$= r \begin{pmatrix} -\cos \frac{\alpha + \beta}{2} \\ \sin \frac{\alpha + \beta}{2} \end{pmatrix} \quad (3.0.0.49.9)$$

$\mathbf{B}$  can be found as the intersection of  $AD$  and  $CE$ .

(b) Proof: From (3.0.0.49.3), (3.0.0.49.2), (3.0.0.49.7) and (3.0.0.49.9)

$$\mathbf{C} - \mathbf{E} = r \begin{pmatrix} 1 + \cos \left( \frac{\alpha + \beta}{2} \right) \\ -\sin \left( \frac{\alpha + \beta}{2} \right) \end{pmatrix} \quad (3.0.0.49.10)$$

$$= 2r \cos \left( \frac{\alpha + \beta}{4} \right) \begin{pmatrix} \cos \left( \frac{\alpha + \beta}{4} \right) \\ -\sin \left( \frac{\alpha + \beta}{4} \right) \end{pmatrix} \quad \text{and} \quad (3.0.0.49.11)$$

$$\|\mathbf{C} - \mathbf{E}\| = 2r \cos \left( \frac{\alpha + \beta}{4} \right) \quad (3.0.0.49.12)$$

and

$$\mathbf{A} - \mathbf{D} = r \begin{pmatrix} \cos \beta + \cos \left( \frac{\alpha - \beta}{2} \right) \\ -\sin \beta + \sin \left( \frac{\alpha - \beta}{2} \right) \end{pmatrix} \quad (3.0.0.49.13)$$

$$= 2r \cos \left( \frac{\alpha + \beta}{4} \right) \begin{pmatrix} \cos \left( \frac{\alpha - 3\beta}{4} \right) \\ \sin \left( \frac{\alpha - 3\beta}{4} \right) \end{pmatrix} \text{ and} \quad (3.0.0.49.14)$$

$$\|\mathbf{A} - \mathbf{D}\| = 2r \cos \left( \frac{\alpha + \beta}{4} \right) \quad (3.0.0.49.15)$$

Thus,

$$\cos \angle B = \frac{(\mathbf{A} - \mathbf{D})(\mathbf{C} - \mathbf{E})}{\|\mathbf{A} - \mathbf{D}\| \|\mathbf{C} - \mathbf{E}\|} \quad (3.0.0.49.16)$$

$$= \cos \left( \frac{\alpha - \beta}{2} \right) \quad (3.0.0.49.17)$$

$$\Rightarrow \angle B = \frac{\alpha - \beta}{2} \quad (3.0.0.49.18)$$

upon substituting from (3.0.0.49.14), (3.0.0.49.15), (3.0.0.49.11), (3.0.0.49.12) and simplifying.

50. Prove that the circle drawn with any side of a rhombus as diameter, passes through the point of intersection of its diagonals.
51.  $ABCD$  is a parallelogram. The circle through  $A, B$  and  $C$  intersect  $CD$  (produced if necessary) at  $E$ . Prove that  $AE = AD$ .
52.  $AC$  and  $BD$  are chords of a circle which bisect each other. Prove that (i)  $AC$  and  $BD$  are diameters, (ii)  $ABCD$  is a rectangle.
53. Bisectors of angles  $A, B$  and  $C$  of a  $\triangle ABC$  intersect its circumcircle at  $D, E$  and  $F$  respectively. Prove that the angles of the  $\triangle DEF$  are  $90^\circ - \frac{A}{2}, 90^\circ - \frac{B}{2}$  and  $90^\circ - \frac{C}{2}$ .

54. Two congruent circles intersect each other at points  $A$  and  $B$ . Through  $A$  any line segment  $PAQ$  is drawn so that  $P, Q$  lie on the two circles. Prove that  $BP = BQ$ .
55. In any  $\triangle ABC$ , if the angle bisector of  $\angle A$  and perpendicular bisector of  $BC$  intersect, prove that they intersect on the circumcircle of the  $\triangle ABC$ .
56. The lengths of tangents drawn from an external point to a circle are equal.
57. Prove that in two concentric circles, the chord of the larger circle, which touches the smaller circle, is bisected at the point of contact.
58. Two tangents  $TP$  and  $TQ$  are drawn to a circle with centre  $O$  from an external point  $T$ . Prove that  $\angle PTQ = 2\angle OPQ$ .
59. Prove that the tangents drawn at the ends of a diameter of a circle are parallel.
60. Prove that the perpendicular at the point of contact to the tangent to a circle passes through the centre.
61. A quadrilateral  $ABCD$  is drawn to circumscribe a circle. Prove that  $AB + CD = AD + BC$ .
62.  $XY$  and  $X'Y'$  are two parallel tangents to a circle with centre  $O$  and another tangent  $AB$  with point of contact  $C$  intersecting  $XY$  at  $A$  and  $X'Y'$  at  $B$ . Prove that  $\angle AOB = 90^\circ$
63. Prove that the angle between the two tangents drawn from an external point to a circle is supplementary to the angle subtended by the line-segment joining the points of contact at the centre.
64. Prove that the parallelogram circumscribing a circle is a rhombus.

65. Prove that opposite sides of a quadrilateral circumscribing a circle subtend supplementary angles at the centre of the circle.
66. Find the area of a sector of angle  $p$  (in degrees) of a circle with radius  $R$ .
67. Two chords  $AB$  and  $CD$  intersect each other at the point  $P$ . Prove that :
- (a)  $\triangle APC \sim \triangle DPB$
  - (b)  $AP.PB = CP.DP$
68. Two chords  $AB$  and  $CD$  of a circle intersect each other at the point  $P$  (when produced) outside the circle. Prove that
- (a)  $\triangle PAC \sim \triangle PDB$
  - (b)  $PA.PB = PC.PD$

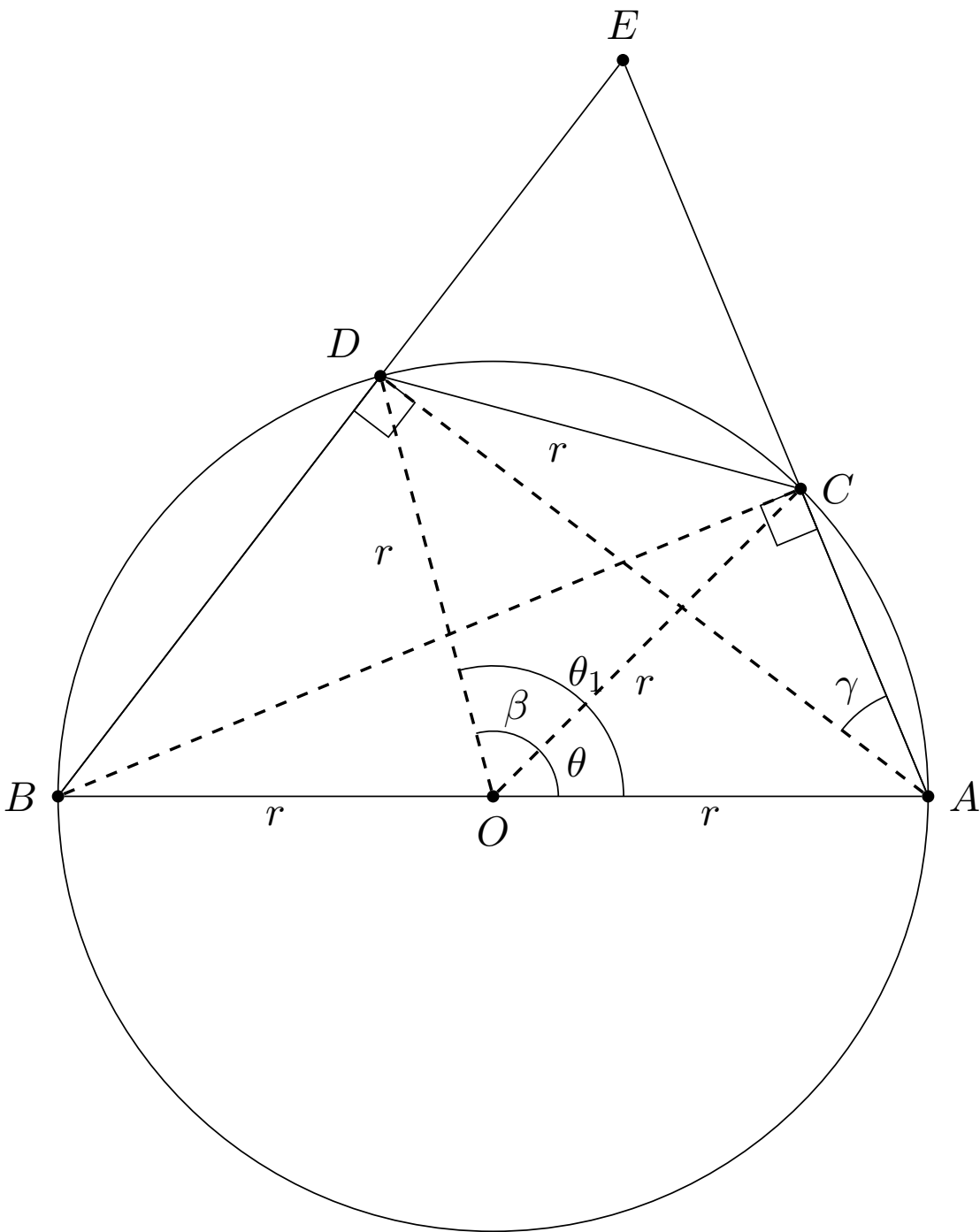


Figure 3.2:

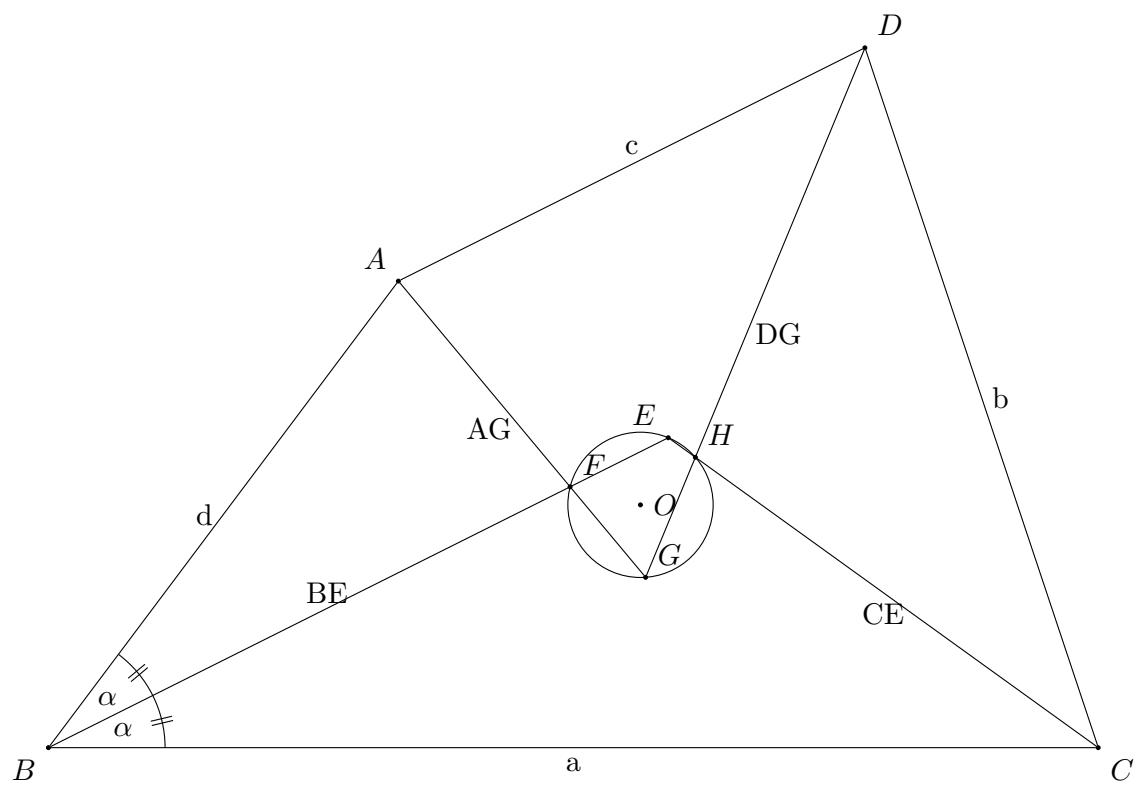


Figure 3.3:



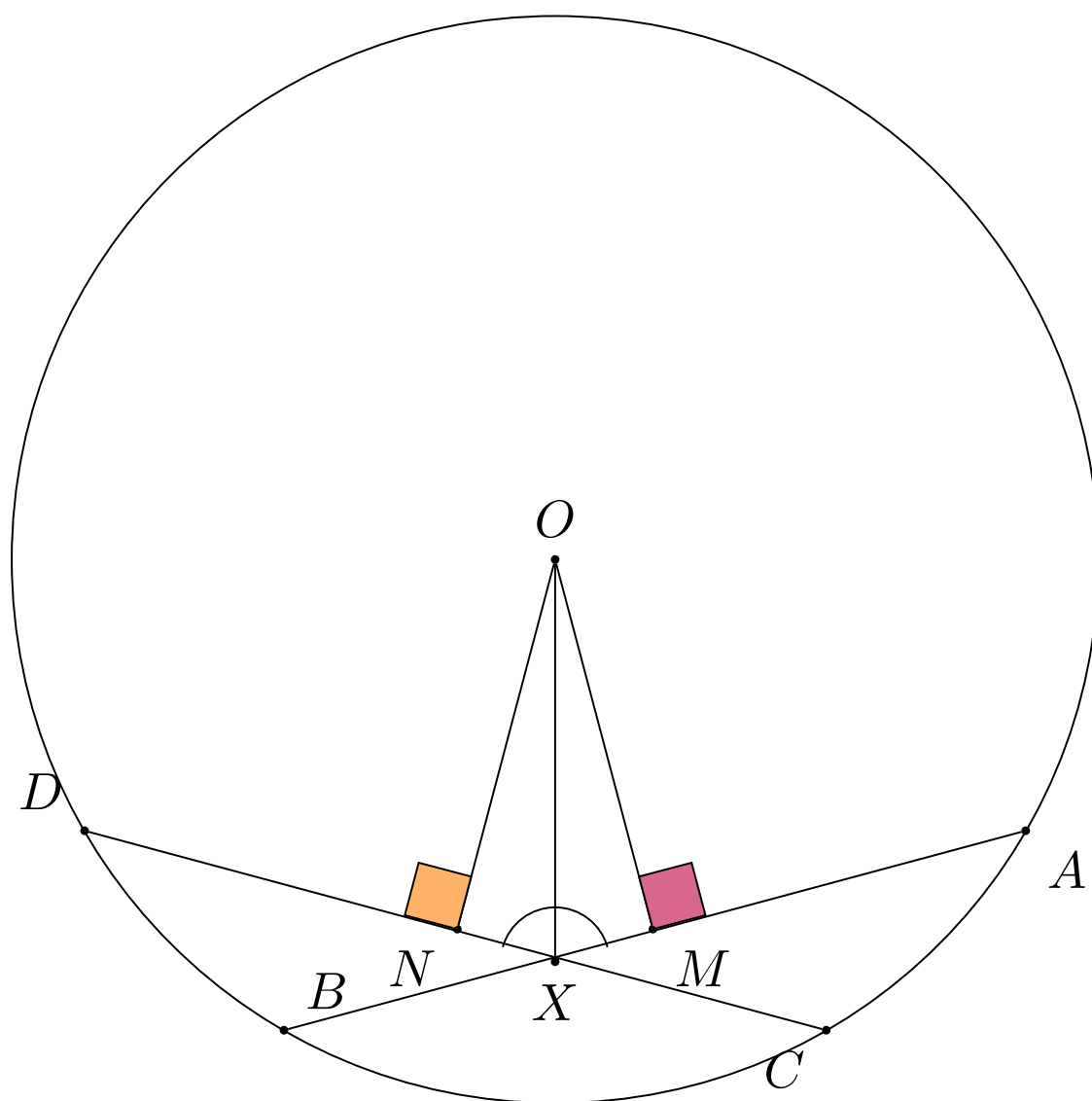


Figure 3.4: Circle by Latex-Tikz

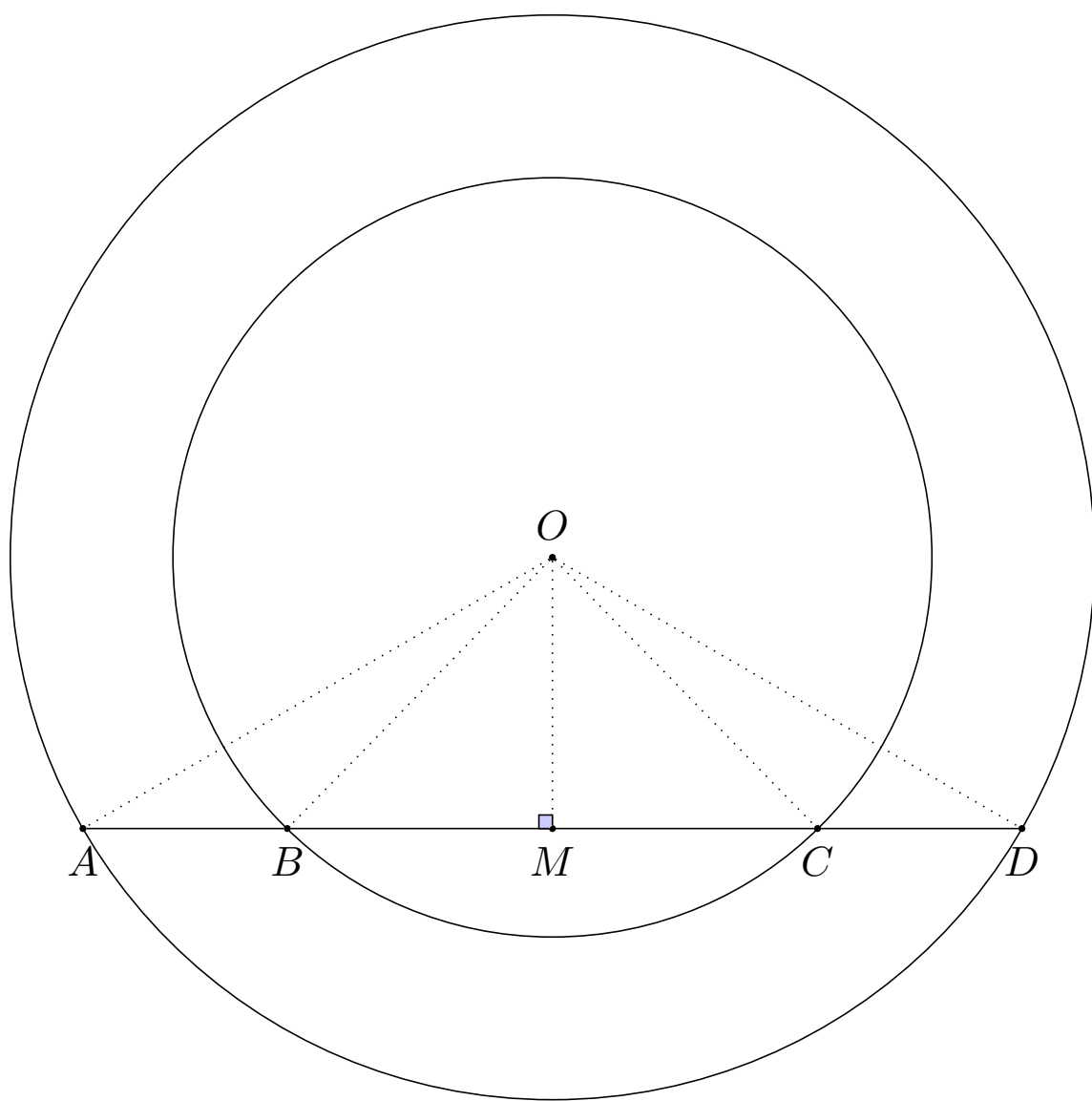


Figure 3.5:

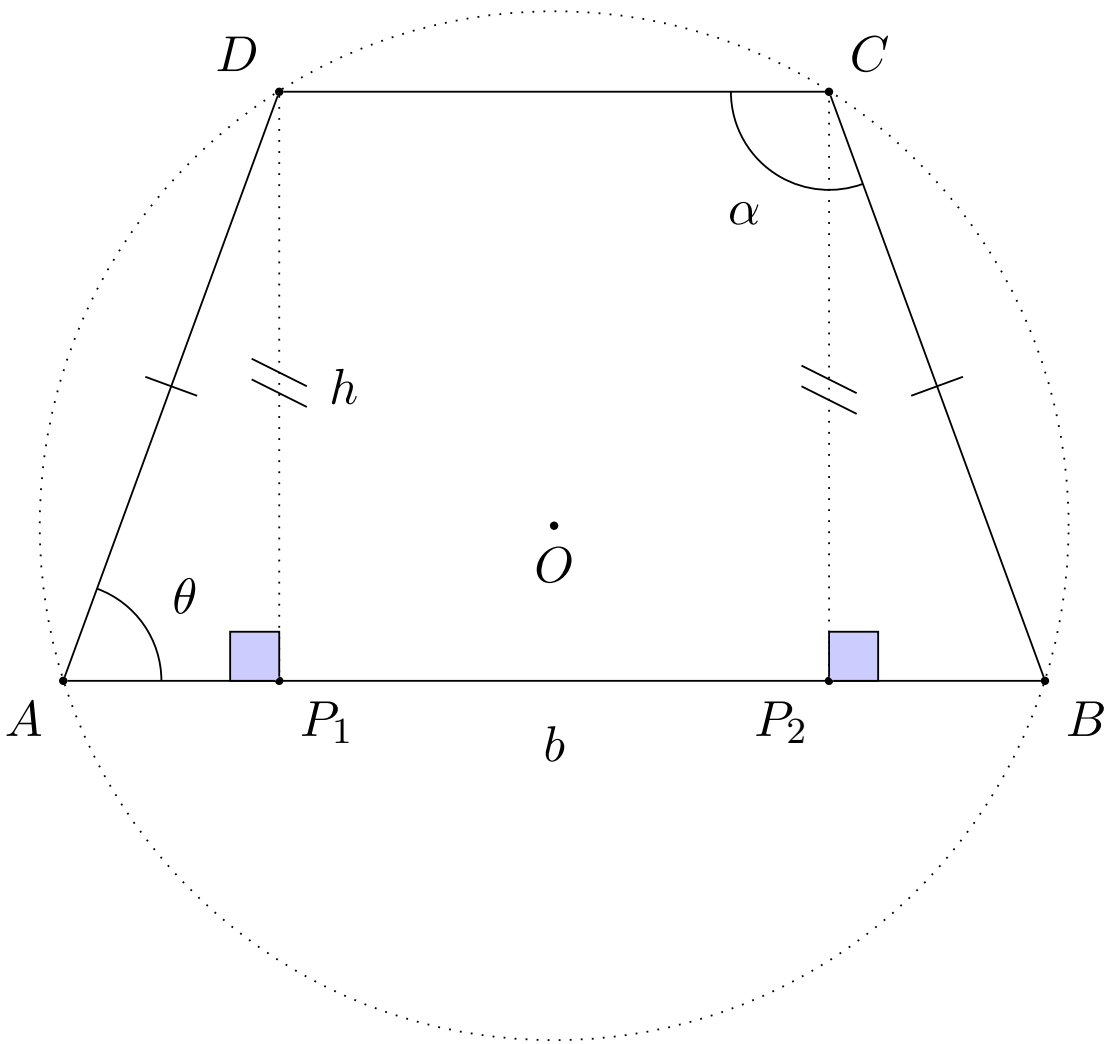


Figure 3.6:

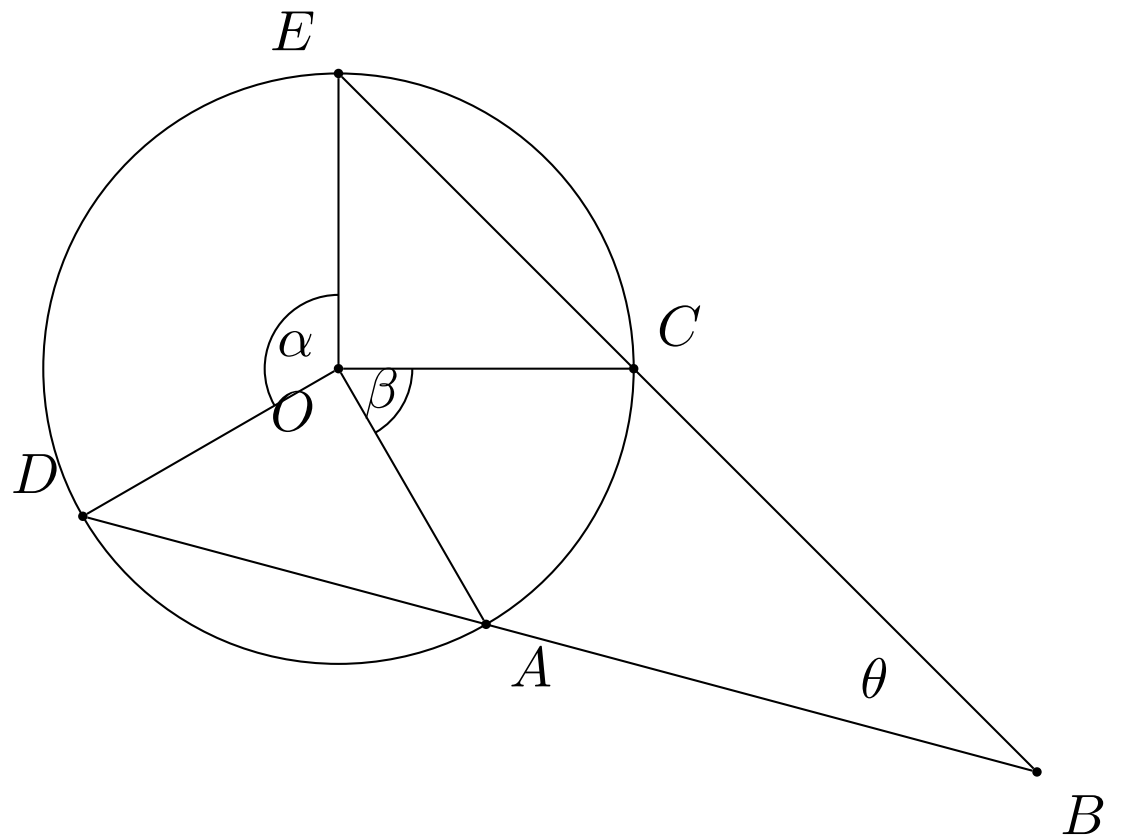


Figure 3.7:



## Chapter 4

### Miscellaneous

1.  $ABCD$  is a cyclic quadrilateral in which  $AC$  and  $BD$  are its diagonals. If  $\angle DBC = 55^\circ$  and  $\angle BAC = 45^\circ$ , find  $\angle BCD$
2. Two circles of radii 5 cm and 3 cm intersect at two points and the distance between their centres is 4 cm. Find the length of the common chord.
3. A, B and C are three points on a circle with centre  $O$  such that  $\angle BOC = 30^\circ$  and  $\angle AOB = 60^\circ$ . If D is a point on the circle other than the arc ABC, find  $\angle ADC$ .
4.  $\angle PQR = 100^\circ$ , where  $P, Q$  and R are points on a circle with centre  $O$ . Find  $\angle OPR$ .
5.  $A, B, C, D$  are points on a circle such that  $\angle ABC = 69^\circ, \angle ACB = 31^\circ$ , find  $\angle BDC$ .
6.  $A, B, C$  and  $D$  are four points on a circle.  $AC$  and  $BD$  intersect at a point  $E$  such that  $\angle BEC = 130^\circ$  and  $\angle ECD = 20^\circ$ . Find  $\angle BAC$ .
7.  $ABCD$  is a cyclic quadrilateral whose diagonals intersect at a point  $E$ . If  $\angle DBC = 70^\circ, \angle BAC = 30^\circ$ , find  $\angle BCD$ . Further, if  $AB = BC$ , find  $\angle ECD$ .
8. Two chords  $AB$  and  $CD$  of lengths 5 cm and 11 cm respectively of a circle are parallel to each other and are on opposite sides of its centre. If the distance between  $AB$  and  $CD$  is 6 cm, find the radius of the circle.

9. The lengths of two parallel chords of a circle are 6 cm and 8 cm. If the smaller chord is at distance 4 cm from the centre, what is the distance of the other chord from the centre?
10. A tangent  $PQ$  at a point  $P$  of a circle of radius 5 cm meets a line through the centre  $O$  at a point  $Q$  so that  $OQ = 12$  cm. Find the length of  $PQ$ .
11.  $PQ$  is a chord of length 8 cm of a circle of radius 5 cm. The tangents at  $P$  and  $Q$  intersect at a point  $T$ . Find the length  $TP$ .
12. From a point  $Q$ , the length of the tangent to a circle is 24 cm and the distance of  $Q$  from the centre is 25 cm. Find the radius of the circle is
13. If  $TP$  and  $TQ$  are the two tangents to a circle with centre  $O$  so that  $\angle POQ = 110^\circ$ , then find  $\angle PTQ$
14. If tangents  $PA$  and  $PB$  from a point  $P$  to a circle with centre  $O$  are inclined to each other at angle of  $80^\circ$ , then find  $\angle POA$
15. The length of a tangent from a point  $A$  at distance 5 cm from the centre of the circle is 4 cm. Find the radius of the circle.
16. Two concentric circles are of radii 5 cm and 3 cm. Find the length of the chord of the larger circle which touches the smaller circle.
17. A  $\triangle ABC$  is drawn to circumscribe a circle of radius 4 cm such that the segments  $BD$  and  $DC$  into which  $BC$  is divided by the point of contact  $D$  are of lengths 8 cm and 6 cm respectively. Find the sides  $AB$  and  $AC$ .
18. The radii of two circles are 19 cm and 9 cm respectively. Find the radius of the circle which has circumference equal to the sum of the circumferences of the two circles.

19. The radii of two circles are 8 cm and 6 cm respectively. Find the radius of the circle having area equal to the sum of the areas of the two circles.
20. A circular archery target is marked with its five scoring regions from the centre outwards as Gold, Red, Blue, Black and White. The diameter of the region representing Gold score is 21 cm and each of the other bands is 10.5 cm wide. Find the area of each of the five scoring regions.
21. The wheels of a car are of diameter 80 cm each. How many complete revolutions does each wheel make in 10 minutes when the car is travelling at a speed of 66 km per hour?
22. Find the area of the sector of a circle with radius 4 cm and of angle  $30^\circ$ . Also, find the area of the corresponding major sector.
23. Find the area of the segment  $AYB$ , if radius of the circle is 21 cm and  $\angle AOB = 120^\circ$ .
24. Find the area of a sector of a circle with radius 6 cm if angle of the sector is  $60^\circ$ .
25. Find the area of a quadrant of a circle whose circumference is 22 cm. 3. The length of the minute hand of a clock is 14 cm. Find the area swept by the minute hand in 5 minutes.
26. A chord of a circle of radius 10 cm subtends a right angle at the centre. Find the area of the corresponding :
- (a) minor segment
- (b) major sector.
27. In a circle of radius 21 cm, an arc subtends an angle of  $60^\circ$  at the centre. Find:



- (a) the length of the arc
  - (b) area of the sector formed by the arc
  - (c) area of the segment formed by the corresponding chord
28. A chord of a circle of radius 15 cm subtends an angle of  $60^\circ$  at the centre. Find the areas of the corresponding minor and major segments of the circle.
29. A chord of a circle of radius 12 cm subtends an angle of  $120^\circ$  at the centre. Find the area of the corresponding segment of the circle.
30. A horse is tied to a peg at one corner of a square shaped grass field of side 15 m by means of a 5 m long rope. Find
- (a) the area of that part of the field in which the horse can graze.
  - (b) the increase in the grazing area if the rope were 10 m long instead of 5 m.
31. A brooch is made with silver wire in the form of a circle with diameter 35 mm. The wire is also used in making 5 diameters which divide the circle into 10 equal sectors. Find :
- (a) the total length of the silver wire required.
  - (b) the area of each sector of the brooch
32. An umbrella has 8 ribs which are equally spaced. Assuming umbrella to be a flat circle of radius 45 cm, find the area between the two consecutive ribs of the umbrella.
33. A car has two wipers which do not overlap. Each wiper has a blade of length 25 cm sweeping through an angle of  $115^\circ$ . Find the total area cleaned at each sweep of the blades.

34. To warn ships for underwater rocks, a lighthouse spreads a red coloured light over a sector of angle  $80^\circ$  to a distance of 16.5 km. Find the area of the sea over which the ships are warned.
35. Two circular flower beds are located on opposite sides of a square lawn  $ABCD$  of side 56 m. If the centre  $O$  of each circular flower bed is the point of intersection  $O$  of the diagonals of the square lawn, find the sum of the areas of the lawn and the flower beds.
36. Four circles are inscribed inside a square  $ABCD$  of side 14 cm such that each one touches externally two adjacent sides of the square and two other circles. Find the region between the circles and the square.
37.  $ABCD$  is a square of side 10 cm and semicircles are drawn with each side of the square as diameter. Find the area enclosed by the circular arcs.
38.  $P$  is a point on the semi-circle formed with diameter  $QR$ . Find the area between the semi-circle and  $\triangle PQR$  if  $PQ = 24$  cm,  $PR = 7$  cm and  $O$  is the centre  $O$  of the circle.
39.  $AC$  and  $BD$  are two arcs on concentric circles with radii 14 cm and 7 cm respectively, such that  $\angle AOC = 40^\circ$ . Find the area of the region  $ABDC$ .
40. Find the area between a square  $ABCD$  of side 14cm and the semi circles  $APD$  and  $BPC$ .
41. Find the area of the region enclosed by a circular arc of radius 6 cm drawn with vertex  $O$  of an equilateral triangle  $OAB$  of side 12 cm as centre.
42. From each corner of a square of side 4 cm a quadrant of a circle of radius 1 cm is cut and also a circle of diameter 2 cm is cut. Find the area of the remaining portion of the square.

43. In a circular table cover of radius 32 cm, a design is formed leaving an equilateral  $\triangle ABC$  in the middle. Find the area of the design.
44.  $ABCD$  is a square of side 14 cm. With centres A, B, C and D, four circles are drawn such that each circle touches externally two of the remaining three circles. Find the area within the square that lies outside the circles.
45. The left and right ends of a racing track are semicircular. The distance between the two inner parallel line segments is 60 m and they are each 106 m long. If the track is 10 m wide, find :
- the distance around the track along its inner edge
  - the area of the track.
46.  $AB$  and  $CD$  are two diameters of a circle (with centre  $O$ ) perpendicular to each other and  $OD$  is the diameter of a smaller circle inside. If  $OA = 7$  cm, find the area of the smaller circle.
47. The area of an equilateral  $\triangle ABC$  is  $17320.5 \text{ cm}^2$ . With each vertex of the triangle as centre, a circle is drawn with radius equal to half the length of the side of the triangle. Find the area of region within the triangle but outside the circles.
48. On a square handkerchief, nine circular designs are inscribed touching each other, each of radius 7 cm. Find the area of the remaining portion of the handkerchief.
49.  $OACB$  is a quadrant of a circle with centre  $O$  and radius 3.5 cm.  $D$  is a point on  $OA$ . If  $OD = 2$  cm, find the area of the
- quadrant  $OACB$ ,
  - the region between the quadrant and  $\triangle OBD$ .

50. A square  $OABC$  is inscribed in a quadrant  $OPBQ$ . If  $OA = 20$  cm, find the area between the square and the quadrant.
51.  $AB$  and  $CD$  are respectively arcs of two concentric circles of radii 21 cm and 7 cm and centre  $O$ . If  $\angle AOB = 30^\circ$ , find the area of the region  $ABCD$ .
52.  $ABC$  is a quadrant of a circle of radius 14 cm and a semicircle is drawn with  $BC$  as diameter. Find the area of the crescent formed.
53. Find the area common between the two quadrants of circles of radius 8 cm each if the centres of the circles lie on opposite sides of a square.
54. Find the area of the sector of a circle with radius 4 cm and of angle  $30^\circ$ . Also, find the area of the corresponding major sector.
55. A pole has to be erected at a point on the boundary of a circular park of diameter 13 metres in such a way that the differences of its distances from two diametrically opposite fixed gates A and B on the boundary is 7 metres. Is it possible to do so? If yes, at what distances from the two gates should the pole be erected?
56. Draw a triangle whose sides are 8cm and 11cm and the perimeter is 32 cm and find its area.
57. The sides of a triangular plot are in the ratio of 3 : 5 : 7 and its perimeter is 300 m. Draw the plot and find its area.
58. A tower stands vertically on the ground. From a point on the ground, which is 15m away from the foot of the tower, the angle of elevation of the top of the tower is found to be  $60^\circ$ . Find the height of the tower.

59. An electrician has to repair an electric fault pole of height 5m. She needs to reach a point 1.3m below the top of the pole to undertake the repair work. What should be the length of the ladder that she should use which, when inclined at an angle of  $60^\circ$  to the horizontal, would enable her to reach the required position? Also, how far from the foot of the pole should she place the foot of the ladder?
60. An observer 1.5m tall is 28.5m away from a chimney. The angle of elevation of the top of the chimney from her eyes is  $45^\circ$ . What is the height of the chimney?
61. From a point **P** on the ground the angle of elevation of the top of a 10m tall building is  $30^\circ$ . A flag is hoisted at the top of the building and the angle of elevation of the top of the flagstaff from **P** is  $45^\circ$ . Find the length of the flagstaff and the distance of the building from the point **P**.
62. The shadow of a tower standing on a level ground is found to be 40m longer when the Sun's altitude is  $30^\circ$  than when it is  $60^\circ$ . Find the height of the tower.
63. The angles of depression of the top and the bottom of an 8m tall building from the top of a multi-storeyed building are  $30^\circ$  and  $45^\circ$  respectively. Find the height of the multi-storeyed building and the distance between the two buildings.
64. A traffic signal board, indicating 'SCHOOL AHEAD', is an equilateral triangle with side 'a'. Find the area of the signal board, using Heron's formula. If its perimeter is 180 cm, what will be the area of the signal board?
65. There is a slide in a park. One of its side walls has been painted in some colour with a message "KEEP THE PARK GREEN AND CLEAN". If the sides of the wall are 15 m, 11 m and 6 m, find the area painted in colour.

66. Find the area of a triangle two sides of which are 18cm and 10cm and the perimeter is 42cm.
67. Sides of a triangle are in the ratio of 12 : 17 : 25 and its perimeter is 540cm. Find its area.
68. An isosceles triangle has perimeter 30 cm and each of the equal sides is 12 cm. Find the area of the triangle.
69. A girl walks 4km west, then she walks 3km in a direction  $30^\circ$  east of north and stops. Determine the girl's displacement from her initial point of departure.
70. A circus artist is climbing a 20m long rope, which is tightly stretched and tied from the top of a vertical pole to the ground. Find the height of the pole, if the angle made by the rope with the ground level is  $30^\circ$ .
71. A tree breaks due to storm and the broken part bends so that the top of the tree touches the ground making an angle of  $30^\circ$  with it. The distance between the foot of the tree to the point where the top touches the ground is 8m. Find the height of the tree.
72. A contractor plans to install two slides for the children to play in a park. For the children below the age of 5 years, she prefers to have a slide whose top is at a height of 1.5m, and is inclined at an angle of  $30^\circ$  to the ground, whereas for elder children she wants to have a steep slide at a height of 3m, and inclined at an angle of  $60^\circ$  to the ground. What should be the length of the slide in each case?
73. The angle of elevation of the top of a tower from a point on the ground, which is 30m away from the foot of the tower, is  $30^\circ$ . Find the height of the tower.

74. A kite is flying at a height of 60m above the ground. The string attached to the kite is temporarily tied to a point on the ground. The inclination of the string with the ground is  $60^\circ$ . Find the length of the string, assuming that there is no slack in the string.
75. A 1.5m tall boy is standing at some distance from a 30m tall building. The angle of elevation from his eyes to the top of the building increases from  $30^\circ$  to  $60^\circ$  as he walks towards the building. Find the distance he walked towards the building.
76. From a point on the ground, the angles of elevation of the bottom and the top of a transmission tower fixed at the top of a 20 m high building are  $45^\circ$  and  $60^\circ$  respectively. Find the height of the tower.
77. A statue, 1.6 m tall, stands on the top of a pedestal. From a point on the ground, the angle of elevation of the top of the statue is  $60^\circ$  and from the same point the angle of elevation of the top of the pedestal is  $45^\circ$ . Find the height of the pedestal.
78. The angle of elevation of the top of a building from the foot of the tower is  $30^\circ$  and the angle of elevation of the top of the tower from the foot of the building is  $60^\circ$ . If the tower is 50 m high, find the height of the building.
79. Two poles of equal heights are standing opposite each other on either side of the road, which is 80 m wide. From a point between them on the road, the angles of elevation of the top of the poles are  $60^\circ$  and  $30^\circ$ , respectively. Find the height of the poles and the distances of the point from the poles.
80. A TV tower stands vertically on a bank of a canal. From a point on the other bank directly opposite the tower, the angle of elevation of the top of the tower is  $60^\circ$ . From another point 20 m away from this point on the line joining this point to the foot of

the tower, the angle of elevation of the top of the tower is  $30^\circ$ . Find the height of the tower and the width of the canal.

81. From the top of a 7 m high building, the angle of elevation of the top of a cable tower is  $60^\circ$  and the angle of depression of its foot is  $45^\circ$ . Determine the height of the tower.
82. As observed from the top of a 75 m high lighthouse from the sea-level, the angles of depression of two ships are  $30^\circ$  and  $45^\circ$ . If one ship is exactly behind the other on the same side of the lighthouse, find the distance between the two ships.
83. A 1.2 m tall girl spots a balloon moving with the wind in a horizontal line at a height of 88.2 m from the ground. The angle of elevation of the balloon from the eyes of the girl at any instant is  $60^\circ$ . After some time, the angle of elevation reduces to  $30^\circ$ . Find the distance travelled by the balloon during the interval.
84. A straight highway leads to the foot of a tower. A man standing at the top of the tower observes a car at an angle of depression of  $30^\circ$ , which is approaching the foot of the tower with a uniform speed. Six seconds later, the angle of depression of the car is found to be  $60^\circ$ . Find the time taken by the car to reach the foot of the tower from this point.
85. The angles of elevation of the top of a tower from two points at a distance of 4 m and 9 m from the base of the tower and in the same straight line with it are complementary. Prove that the height of the tower is 6 m.
86.  $E$  and  $F$  are points on the sides  $PQ$  and  $PR$  respectively of a  $\triangle PQR$ . For each of the following cases, state whether  $EF \parallel QR$
- (a)  $PE = 3.9\text{cm}$ ,  $EQ = 3\text{cm}$ ,  $PF = 3.6\text{cm}$  and  $FR = 2.4\text{cm}$
- (b)  $PE = 4\text{cm}$ ,  $QE = 4.5\text{cm}$ ,  $PF = 8\text{cm}$  and  $RF = 9\text{cm}$



(c)  $PQ = 1.28\text{cm}$ ,  $PR = 2.56\text{cm}$ ,  $PE = 0.18\text{cm}$  and  $PF = 0.36\text{cm}$

87. A girl of height 90 cm is walking away from the base of a lamp-post at a speed of 1.2 m/s. If the lamp is 3.6 m above the ground, find the length of her shadow after 4 seconds.
88.  $\triangle ODC \sim \triangle OBA$ ,  $\angle BOC = 125^\circ$  and  $\angle CDO = 70^\circ$ . Find  $\angle DOC$ ,  $\angle DCO$  and  $\angle OAB$ .
89. Nazima is fly fishing in a stream. The tip of her fishing rod is 1.8 m above the surface of the water and the fly at the end of the string rests on the water 3.6 m away and 2.4 m from a point directly under the tip of the rod. Assuming that her string (from the tip of her rod to the fly) is taut, how much string does she have out? If she pulls in the string at the rate of 5 cm per second, what will be the horizontal distance of the fly from her after 12 seconds?
90. A vertical pole of length 6 m casts a shadow 4 m long on the ground and at the same time a tower casts a shadow 28 m long. Find the height of the tower.
91. Let  $\triangle ABC \sim \triangle DEF$  and their areas be, respectively,  $64\text{ cm}^2$  and  $121\text{ cm}^2$ . If  $EF = 15.4\text{cm}$ , find BC.
92. A ladder is placed against a wall such that its foot is at a distance of 2.5 m from the wall and its top reaches a window 6 m above the ground. Find the length of the ladder.
93. Sides of triangles are given below. Determine which of them are right triangles. In case of a right triangle, write the length of its hypotenuse.

(a) 7 cm, 24 cm, 25 cm

(b) 3 cm, 8 cm, 6 cm

(c) 50 cm, 80 cm, 100 cm

(d) 13 cm, 12 cm, 5 cm

94. A ladder 10 m long reaches a window 8 m above the ground. Find the distance of the foot of the ladder from base of the wall.
95. A guy wire attached to a vertical pole of height 18 m is 24 m long and has a stake attached to the other end. How far from the base of the pole should the stake be driven so that the wire will be taut?
96. An aeroplane leaves an airport and flies due north at a speed of 1000 km per hour. At the same time, another aeroplane leaves the same airport and flies due west at a speed of 1200 km per hour. How far apart will be the two planes after  $1\frac{1}{2}$  hours?
97. Two poles of heights 6 m and 11 m stand on a plane ground. If the distance between the feet of the poles is 12 m, find the distance between their tops.
98. In  $\triangle ABC$ ,  $AB = 6\sqrt{3}cm$ ,  $AC = 12cm$  and  $BC = 6cm$ . Find the angle  $B$ .
99. A park, in the shape of a quadrilateral  $ABCD$ , has  $\angle C = 90^\circ$ ,  $AB = 9m$ ,  $BC = 12m$ ,  $CD = 5m$  and  $AD = 8m$ . How much area does it occupy? 2. Find the area of a quadrilateral  $ABCD$  in which  $AB = 3cm$ ,  $BC = 4cm$ ,  $CD = 4cm$ ,  $DA = 5cm$  and  $AC = 5cm$ .
100. A triangle and a parallelogram have the same base and the same area. If the sides of the triangle are 26 cm, 28 cm and 30 cm, and the parallelogram stands on the base 28 cm, find the height of the parallelogram.

101. A rhombus shaped field has green grass for 18 cows to graze. If each side of the rhombus is 30 m and its longer diagonal is 48 m, how much area of grass field will each cow be getting?
102. A field is in the shape of a trapezium whose parallel sides are 25 m and 10 m. The non-parallel sides are 14 m and 13 m. Find the area of the field.
103.  $ABCD$  is a parallelogram,  $AE \perp DC$  and  $CF \perp AD$ . If  $AB = 16\text{cm}$ ,  $AE = 8\text{ cm}$  and  $CF = 10\text{ cm}$ , find  $AD$ .
104. Kamla has a triangular field with sides 240 m, 200 m, 360 m, where she grew wheat. In another triangular field with sides 240 m, 320 m, 400 m adjacent to the previous field, she wanted to grow potatoes and onions. She divided the field in two parts by joining the mid-point of the longest side to the opposite vertex and grew potatoes in one part and onions in the other part. Draw the figure for this problem. How much area (in hectares) has been used for wheat, potatoes and onions? (1 hectare = 10000  $\text{m}^2$ ).
105. Students of a school staged a rally for cleanliness campaign. They walked through the lanes in two groups. One group walked through the lanes AB, BC and CA; while the other through AC, CD and DA. Then they cleaned the area enclosed within their lanes. If  $AB = 9\text{ m}$ ,  $BC = 40\text{ m}$ ,  $CD = 15\text{ m}$ ,  $DA = 28\text{ m}$  and  $\angle B = 90^\circ$ , which group cleaned more area and by how much? Draw the corresponding figure. Find the total area cleaned by the students (neglecting the width of the lanes).
106. Sanya has a piece of land which is in the shape of a rhombus. She wants her one daughter and one son to work on the land and produce different crops. She divided the land in two equal parts. If the perimeter of the land is 400 m and one of the

diagonals is 160 m, how much area each of them will get for their crops? Draw the rhombus.

107. Three girls Reshma, Salma and Mandip are playing a game by standing on a circle of radius 5m drawn in a park. Reshma throws a ball to Salma, Salma to Mandip, Mandip to Reshma. If the distance between Reshma and Salma and between Salma and Mandip is 6m each, what is the distance between Reshma and Mandip?
108. A circular park of radius 20m is situated in a colony. Three boys Ankur, Syed and David are sitting at equal distance on its boundary each having a toy telephone in his hands to talk each other. Find the length of the string of each phone.
109. The longest side of a triangle is 3 times the shortest side and the third side is 2 cm shorter than the longest side. If the perimeter of the triangle is at least 61 cm, find the minimum length of the shortest side.
110. A rectangular park is to be designed whose breadth is 3 m less than its length. Its area is to be 4 square metres more than the area of a park that has already been made in the shape of an isosceles triangle with its base as the breadth of the rectangular park and of altitude 12 m. Find its length and breadth.
111. The area of a rectangular plot is  $528 \text{ m}^2$ . The length of the plot (in metres) is one more than twice its breadth. We need to find the length and breadth of the plot.
112. The altitude of a right triangle is 7 cm less than its base. If the hypotenuse is 13 cm, find the other two sides.
113. The diagonal of a rectangular field is 60 metres more than the shorter side. If the longer side is 30 metres more than the shorter side, find the sides of the field.

114. Is it possible to design a rectangular mango grove whose length is twice its breadth, and the area is  $800\text{ m}^2$  ? If so, find its length and breadth.
115. Is it possible to design a rectangular park of perimeter 80 m and area  $400\text{ m}^2$  If so, find its length and breadth.
116. On an open ground, a motorist follows a track that turns to his left by an angle of  $60^\circ$  after every 500 m. Starting from a given turn, specify the displacement of the motorist at the third, sixth and eighth turn. Compare the magnitude of the displacement with the total path length covered by the motorist in each case.
117. A passenger arriving in a new town wishes to go from the station to a hotel located 10 km away on a straight road from the station. A dishonest cabman takes him along a circuitous path 23 km long and reaches the hotel in 28 min. What is
- (a) the average speed of the taxi,
  - (b) the magnitude of average velocity ? Are the two equal ?
118. An aircraft is flying at a height of 3400 m above the ground. If the angle subtended at a ground observation point by the aircraft positions 10.0 s apart is  $30^\circ$ , what is the speed of the aircraft ?
119. Two identical billiard balls strike a rigid wall with the same speed but at different angles, and get reflected without any change in speed, as shown in Fig. 4.1. What is
- (a) the direction of the force on the wall due to each ball?
  - (b) the ratio of the magnitudes of impulses imparted to the balls by the wall ?
120. See Fig. 4.2. A mass of 6 kg is suspended by a rope of length 2 m from the ceiling. A force of 50 N in the horizontal direction is applied at the midpoint P of the rope, as

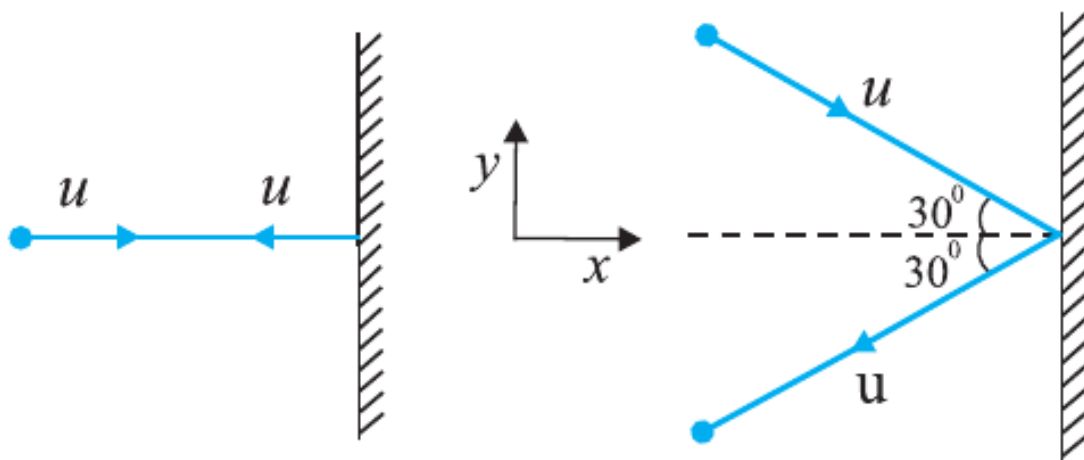


Figure 4.1:

shown. What is the angle the rope makes with the vertical in equilibrium ? (Take  $g = 10 \text{ ms}^{-2}$ ).

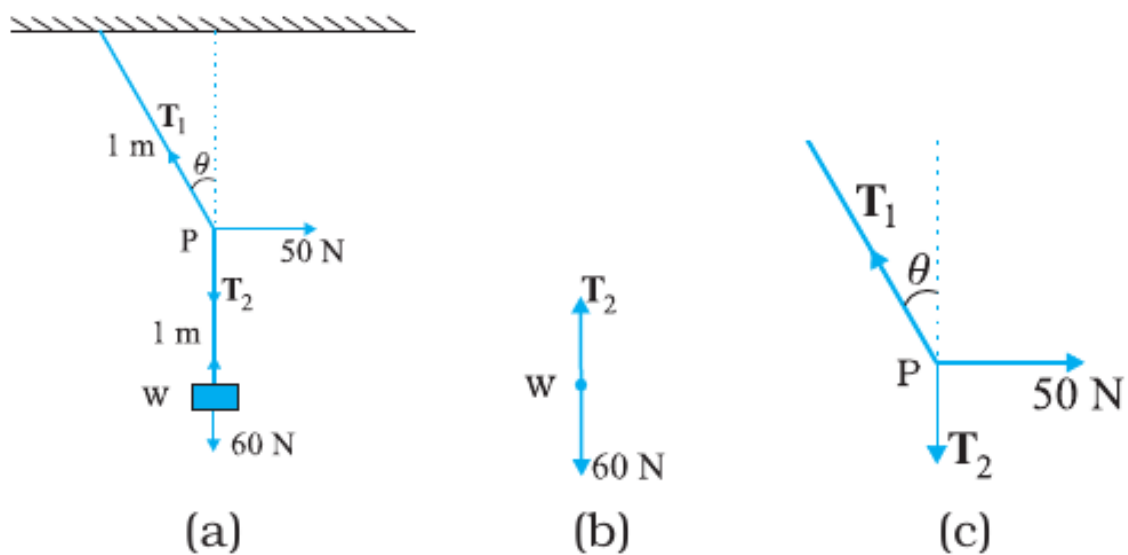


Figure 4.2:

121. See Fig. 4.3. A mass of 4 kg rests on a horizontal plane. The plane is gradually inclined until at an angle  $\theta = 15^\circ$  with the horizontal, the mass just begins to slide. What is the coefficient of static friction between the block and the surface ?

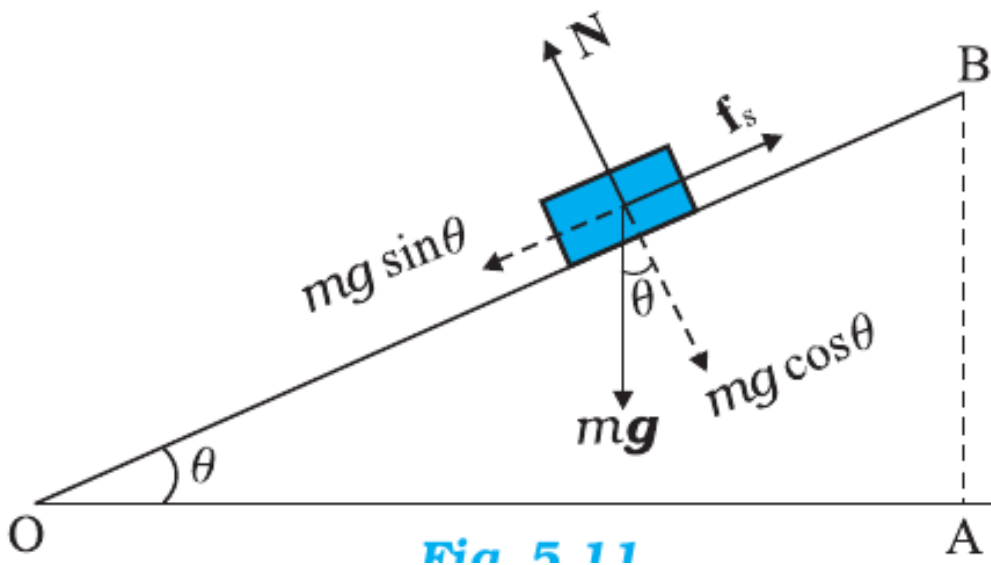


Figure 4.3:

122. A cyclist speeding at 18 km/h on a level road takes a sharp circular turn of radius 3 m without reducing the speed. The co-efficient of static friction between the tyres and the road is 0.1. Will the cyclist slip while taking the turn?
123. A circular racetrack of radius 300 m is banked at an angle of  $15^\circ$ . If the coefficient of friction between the wheels of a race-car and the road is 0.2, what is the
- optimum speed of the racecar to avoid wear and tear on its tyres, and
  - maximum permissible speed to avoid slipping ?
124. An aircraft executes a horizontal loop at a speed of 720 km/h with its wings banked at  $15^\circ$ . What is the radius of the loop ?

125. A train runs along an unbanked circular track of radius 30 m at a speed of 54 km/h. The mass of the train is  $10^6$  kg. What provides the centripetal force required for this purpose - The engine or the rails ? What is the angle of banking required to prevent wearing out of the rail ?
126. A disc revolves with a speed of  $33\frac{1}{3}$  rev/min and has a radius of 15 cm. Two coins are placed at 4 cm and 14 cm away from the centre of the record. If the co-efficient of friction between the coins and the record is 0.15, which of the coins will revolve with the record ?
127. A 70 kg man stands in contact against the inner wall of a hollow cylindrical drum of radius 3 m rotating about its vertical axis with 200 rev/min. The coefficient of friction between the wall and his clothing is 0.15. What is the minimum rotational speed of the cylinder to enable the man to remain stuck to the wall (without falling) when the floor is suddenly removed ?
128. A thin circular loop of radius  $R$  rotates about its vertical diameter with an angular frequency  $\omega$ . Show that a small bead on the wire loop remains at its lowermost point for  $\omega \leq \sqrt{\frac{g}{R}}$ . What is the angle made by the radius vector joining the centre to the bead with the vertical downward direction for  $\omega = \sqrt{\frac{2g}{R}}$  ? Neglect friction.
129. A stone of mass 0.25 kg tied to the end of a string is whirled round in a circle of radius 1.5 m with a speed of 40 rev./min in a horizontal plane. What is the tension in the string ? What is the maximum speed with which the stone can be whirled around if the string can withstand a maximum tension of 200 N ?
130. A woman pushes a trunk on a railway platform which has a rough surface. She applies a force of 100 N over a distance of 10 m. Thereafter, she gets progressively tired and her applied force reduces linearly with distance to 50 N. The total distance through



which the trunk has been moved is 20 m. Plot the force applied by the woman and the frictional force, which is 50 N versus displacement. Calculate the work done by the two forces over 20 m.

131. A bob of mass  $m$  is suspended by a light string of length  $L$ . It is imparted a horizontal velocity  $v_o$  such that it completes a semi-circular trajectory in the vertical plane with the string becoming slack only on reaching the topmost point, C. This is shown in Fig. 4.4. Obtain an expression for

- (a)  $v_o$ ;
- (b) the speeds at points B and C;
- (c) the ratio of the kinetic energies ( $K_B/K_C$ ) at B and C.

Comment on the nature of the trajectory of the bob after it reaches the point C.

132. The bob A of a pendulum released from  $30^\circ$  to the vertical hits another bob B of the same mass at rest on a table as shown in Fig. 4.5. How high does the bob A rise after the collision? Neglect the size of the bobs and assume the collision to be elastic.
133. The bob of a pendulum is released from a horizontal position. If the length of the pendulum is 1.5 m, what is the speed with which the bob arrives at the lowermost point, given that it dissipated 5% of its initial energy against air resistance ?
134. The blades of a windmill sweep out a circle of area  $A$ .
- (a) If the wind flows at a velocity  $v$  perpendicular to the circle, what is the mass of the air passing through it in time  $t$  ?
  - (b) What is the kinetic energy of the air ?

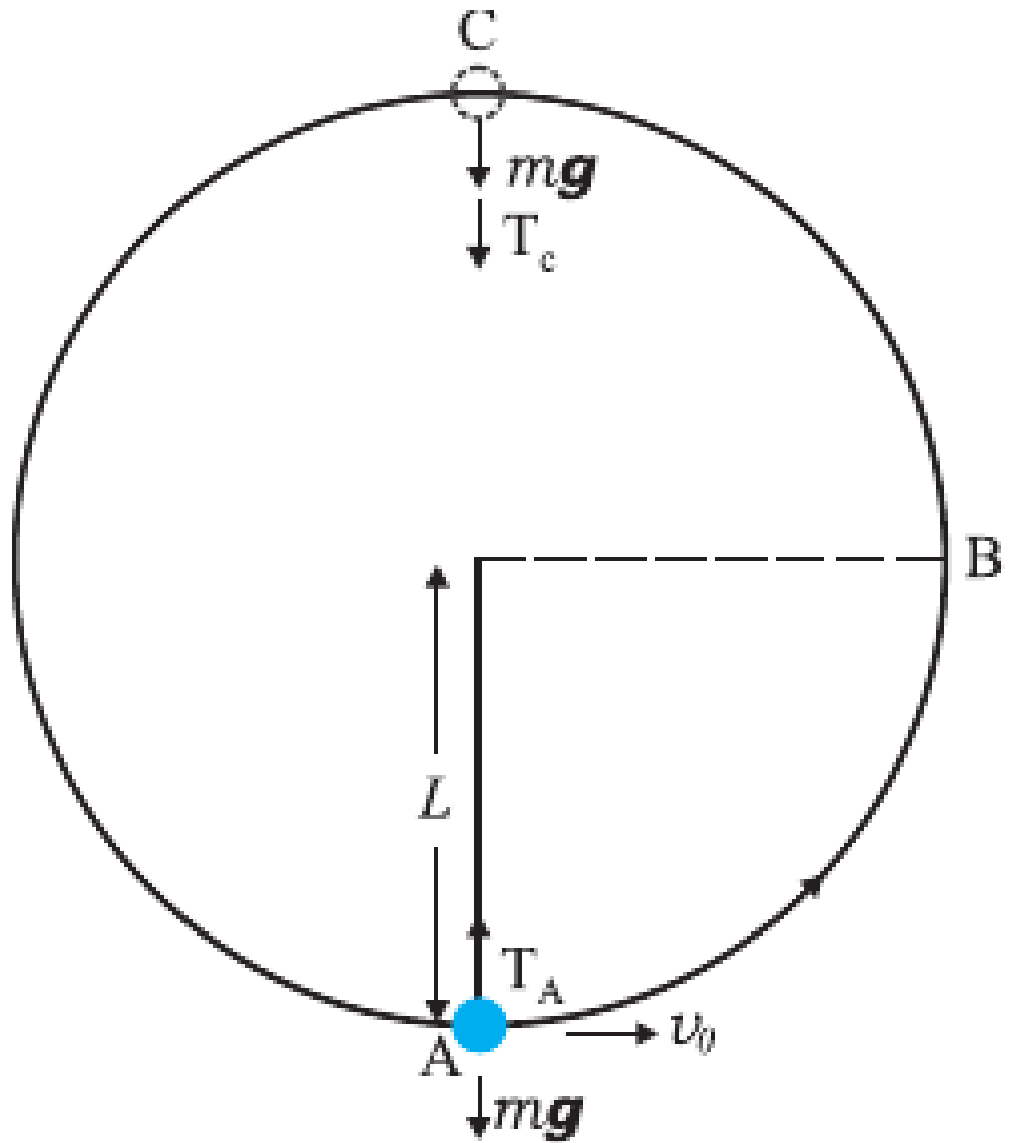


Figure 4.4:

- (c) Assume that the windmill converts 25% of the wind's energy into electrical energy, and that  $A = 30m^2$ ,  $v = 36km/h$  and the density of air is  $1.2kgm^{-3}$ . What is the electrical power produced ?

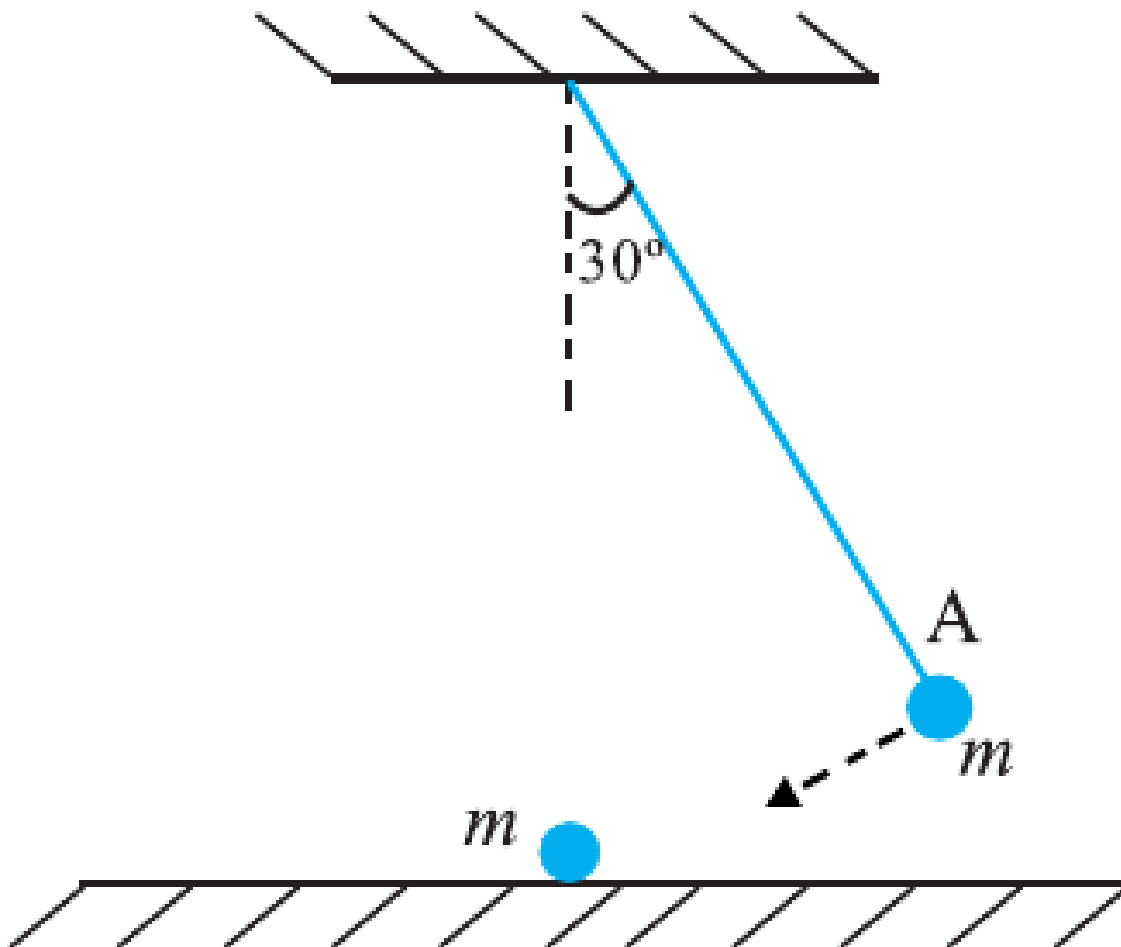


Figure 4.5:

135. A bullet of mass  $0.012 \text{ kg}$  and horizontal speed  $70 \text{ m s}^{-1}$ , strikes a block of wood of mass  $0.4 \text{ kg}$  and instantly comes to rest with respect to the block. The block is suspended from the ceiling by means of thin wires. Calculate the height to which the block rises. Also, estimate the amount of heat produced in the block.

136. Two inclined frictionless tracks, one gradual and the other steep meet at A from where

two stones are allowed to slide down from rest, one on each track (Fig. 4.6). Will the stones reach the bottom at the same time? Will they reach there with the same speed? Explain. Given  $\theta_1 = 30^\circ$   $\theta_2 = 60^\circ$  and  $h = 10\text{m}$ , what are the speeds and times taken by the two stones?

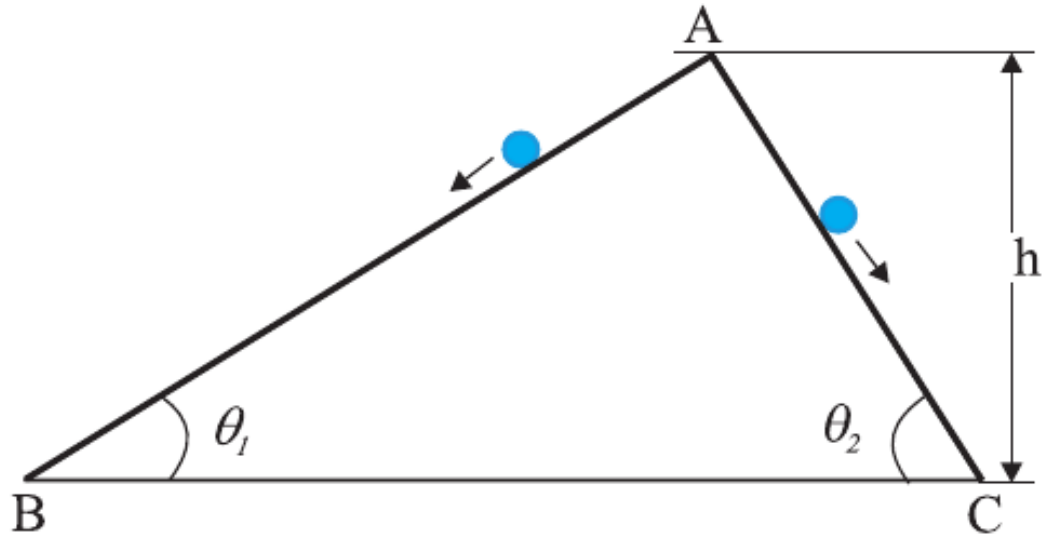


Figure 4.6:

137. A 1 kg block situated on a rough incline is connected to a spring of spring constant  $100\text{ N m}^{-1}$  as shown in Fig. 4.7. The block is released from rest with the spring in the unstretched position. The block moves 10 cm down the incline before coming to rest. Find the coefficient of friction between the block and the incline. Assume that the spring has a negligible mass and the pulley is frictionless.
138. Find the centre of mass of three particles at the vertices of an equilateral triangle. The masses of the particles are 100g, 150g, and 200g respectively. Each side of the equilateral triangle is 0.5m long.

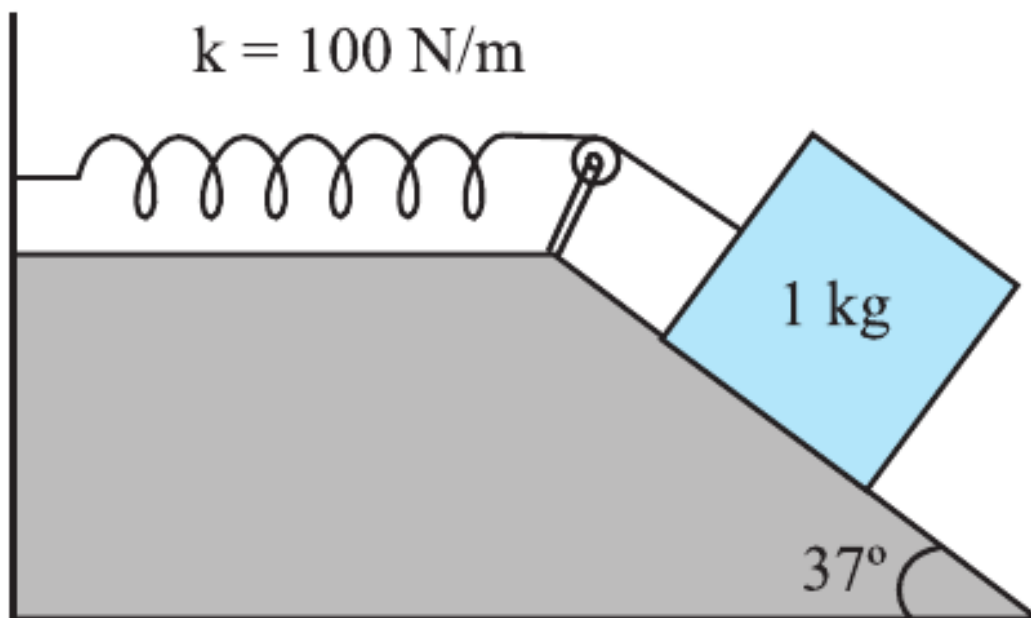


Figure 4.7:

139. Find the centre of mass of a triangular lamina.
140. Find the centre of mass of a uniform L-shaped lamina (a thin flat plate) with dimensions as shown in Fig. 4.8. The mass of the lamina is 3 kg.
141. A metal bar 70 cm long and 4.00 kg in mass supported on two knife-edges placed 10 cm from each end. A 6.00 kg load is suspended at 30 cm from one end. Find the reactions at the knifeedges. (Assume the bar to be of uniform cross section and homogeneous.)
142. A 3m long ladder weighing 20 kg leans on a frictionless wall. Its feet rest on the floor 1 m from the wall as shown in Fig. 4.9. Find the reaction forces of the wall and the floor.
143. What is the moment of inertia of a rod of mass  $M$ , length  $l$  about an axis perpendicular

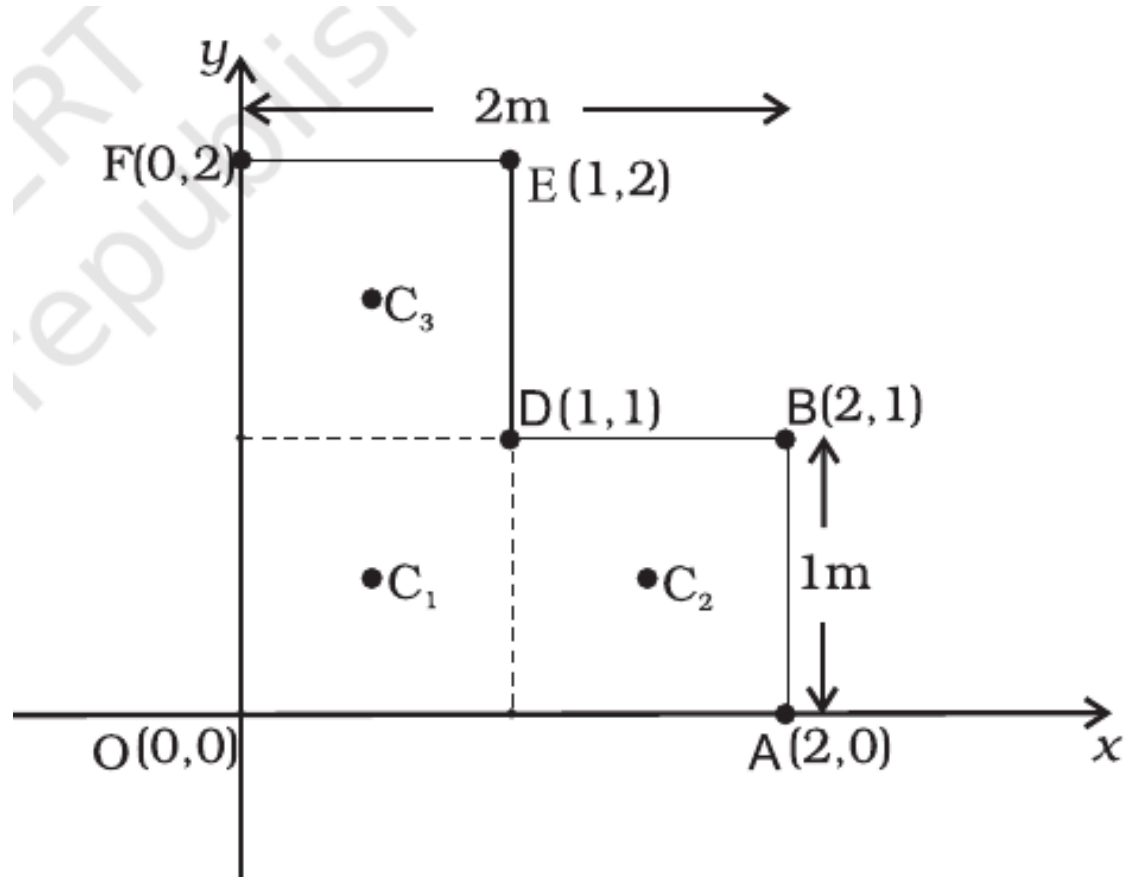


Figure 4.8:

to it through one end?

144. What is the moment of inertia of a ring about a tangent to the circle of the ring?
145. A cord of negligible mass is wound round the rim of a fly wheel of mass 20 kg and radius 20 cm. A steady pull of 25 N is applied on the cord as shown in Fig. 4.10. The flywheel is mounted on a horizontal axle with frictionless bearings.
  - (a) Compute the angular acceleration of the wheel.
  - (b) Find the work done by the pull, when 2m of the cord is unwound.

- (c) Find also the kinetic energy of the wheel at this point. Assume that the wheel starts from rest.
- (d) Compare answers to parts (b) and (c).
146. Three bodies, a ring, a solid cylinder and a solid sphere roll down the same inclined plane without slipping. They start from rest. The radii of the bodies are identical. Which of the bodies reaches the ground with maximum velocity?
147. A non-uniform bar of weight  $W$  is suspended at rest by two strings of negligible weight as shown in Fig. 4.11. The angles made by the strings with the vertical are  $36.9^\circ$  and  $53.1^\circ$  respectively. The bar is 2 m long. Calculate the distance  $d$  of the centre of gravity of the bar from its left end.
148. A car weighs 1800 kg. The distance between its front and back axles is 1.8 m. Its centre of gravity is 1.05 m behind the front axle. Determine the force exerted by the level ground on each front wheel and each back wheel.
149. (a) Find the moment of inertia of a sphere about a tangent to the sphere, given the moment of inertia of the sphere about any of its diameters to be  $\frac{2MR^2}{5}$  where  $M$  is the mass of the sphere and  $R$  is the radius of the sphere.
- (b) Given the moment of inertia of a disc of mass  $M$  and radius  $R$  about any of its diameters to be  $\frac{MR^2}{4}$ , find its moment of inertia about an axis normal to the disc and passing through a point on its edge.
150. Torques of equal magnitude are applied to a hollow cylinder and a solid sphere, both having the same mass and radius. The cylinder is free to rotate about its standard axis of symmetry, and the sphere is free to rotate about an axis passing through its centre. Which of the two will acquire a greater angular speed after a given time.

151. A solid cylinder of mass 20 kg rotates about its axis with angular speed  $100 \text{ rads}^{-1}$ . The radius of the cylinder is 0.25 m. What is the kinetic energy associated with the rotation of the cylinder? What is the magnitude of angular momentum of the cylinder about its axis?
152. (a) A child stands at the centre of a turntable with his two arms outstretched. The turntable is set rotating with an angular speed of 40 rev/min. How much is the angular speed of the child if he folds his hands back and thereby reduces his moment of inertia to  $2/5$  times the initial value ? Assume that the turntable rotates without friction.
- (b) Show that the child's new kinetic energy of rotation is more than the initial kinetic energy of rotation. How do you account for this increase in kinetic energy?
153. A rope of negligible mass is wound round a hollow cylinder of mass 3 kg and radius 40 cm. What is the angular acceleration of the cylinder if the rope is pulled with a force of 30 N ? What is the linear acceleration of the rope ? Assume that there is no slipping.
154. To maintain a rotor at a uniform angular speed of  $200 \text{ rads}^{-1}$ , an engine needs to transmit a torque of 180 N m. What is the power required by the engine ? (Note: uniform angular velocity in the absence of friction implies zero torque. In practice, applied torque is needed to counter frictional torque). Assume that the engine is 100% efficient.
155. From a uniform disk of radius  $R$ , a circular hole of radius  $R/2$  is cut out. The centre of the hole is at  $R/2$  from the centre of the original disc. Locate the centre of gravity of the resulting flat body.



156. A metre stick is balanced on a knife edge at its centre. When two coins, each of mass 5 g are put one on top of the other at the 12.0 cm mark, the stick is found to be balanced at 45.0 cm. What is the mass of the metre stick?
157. A solid sphere rolls down two different inclined planes of the same heights but different angles of inclination.
- Will it reach the bottom with the same speed in each case?
  - Will it take longer to roll down one plane than the other?
  - If so, which one and why?
158. A hoop of radius 2 m weighs 100 kg. It rolls along a horizontal floor so that its centre of mass has a speed of 20 cm/s. How much work has to be done to stop it?
159. The oxygen molecule has a mass of  $5.30 \times 10^{-26}$  kg and a moment of inertia of  $1.94 \times 10^{-46} \text{ kgm}^2$  about an axis through its centre perpendicular to the lines joining the two atoms. Suppose the mean speed of such a molecule in a gas is 500 m/s and that its kinetic energy of rotation is two thirds of its kinetic energy of translation. Find the average angular velocity of the molecule.
160. A solid cylinder rolls up an inclined plane of angle of inclination  $30^\circ$ . At the bottom of the inclined plane the centre of mass of the cylinder has a speed of 5 m/s.
- How far will the cylinder go up the plane?
  - How long will it take to return to the bottom?
161. As shown in Fig. 4.12, the two sides of a step ladder BA and CA are 1.6 m long and hinged at A. A rope DE, 0.5 m is tied half way up. A weight 40 kg is suspended from a point F, 1.2 m from B along the ladder BA. Assuming the floor to be frictionless and

neglecting the weight of the ladder, find the tension in the rope and forces exerted by the floor on the ladder. (Take  $g = 9.8\text{m/s}^2$ ) (Hint: Consider the equilibrium of each side of the ladder separately.)

162. A man stands on a rotating platform, with his arms stretched horizontally holding a 5 kg weight in each hand. The angular speed of the platform is 30 revolutions per minute. The man then brings his arms close to his body with the distance of each weight from the axis changing from 90cm to 20cm. The moment of inertia of the man together with the platform may be taken to be constant and equal to  $7.6\text{ kgm}^2$ .

- (a) What is his new angular speed? (Neglect friction.)
- (b) Is kinetic energy conserved in the process? If not, from where does the change come about?

163. A bullet of mass 10 g and speed 500 m/s is fired into a door and gets embedded exactly at the centre of the door. The door is 1.0 m wide and weighs 12 kg. It is hinged at one end and rotates about a vertical axis practically without friction. Find the angular speed of the door just after the bullet embeds into it. (Hint: The moment of inertia of the door about the vertical axis at one end is  $\frac{ML^2}{3}$ .)

164. Two discs of moments of inertia  $I_1$  and  $I_2$  about their respective axes (normal to the disc and passing through the centre), and rotating with angular speeds  $\omega_1$  and  $\omega_2$  are brought into contact face to face with their axes of rotation coincident.

- (a) What is the angular speed of the two-disc system?
- (b) Show that the kinetic energy of the combined system is less than the sum of the initial kinetic energies of the two discs. How do you account for this loss in energy? Take  $\omega_1 \neq \omega_2$ .

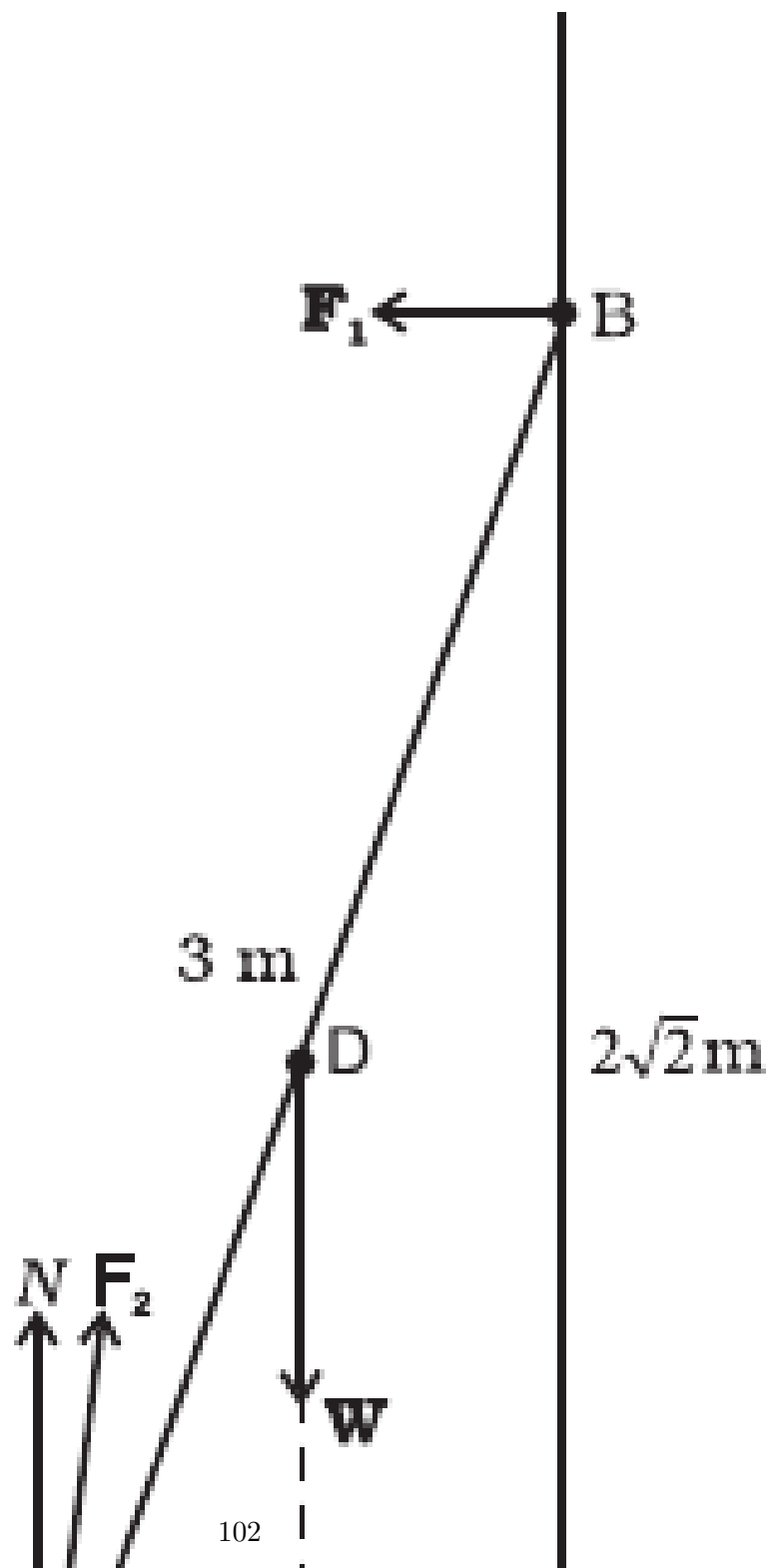
165. Prove the result that the velocity  $v$  of translation of a rolling body (like a ring, disc, cylinder or sphere) at the bottom of an inclined plane of a height  $h$  is given by

$$v^2 = \frac{2gh}{1 + \frac{k^2}{R^2}} \quad (4.0.0.165.1)$$

using dynamical consideration (i.e. by consideration of forces and torques). Note  $k$  is the radius of gyration of the body about its symmetry axis, and  $R$  is the radius of the body. The body starts from rest at the top of the plane.

166. A disc rotating about its axis with angular speed  $\omega_0$  is placed lightly (without any translational push) on a perfectly frictionless table. The radius of the disc is  $R$ . What are the linear velocities of the points A, B and C on the disc shown in Fig. 4.13? Will the disc roll in the direction indicated ?
167. Explain why friction is necessary to make the disc in Fig. 4.13 roll in the direction indicated.
- (a) Give the direction of frictional force at B, and the sense of frictional torque, before perfect rolling begins.
  - (b) What is the force of friction after perfect rolling begins ?
168. A solid disc and a ring, both of radius 10 cm are placed on a horizontal table simultaneously, with initial angular speed equal to  $10 \pi \text{ rad s}^{-1}$ . Which of the two will start to roll earlier ? The coefficient of kinetic friction is  $\mu_k = 0.2$ .
169. A cylinder of mass 10 kg and radius 15 cm is rolling perfectly on a plane of inclination  $30^\circ$ . The coefficient of static friction  $\mu_s = 0.25$ .
- (a) How much is the force of friction acting on the cylinder ?

- (b) What is the work done against friction during rolling ?
  - (c) If the inclination  $\theta$  of the plane is increased, at what value of  $\theta$  does the cylinder begin to skid, and not roll perfectly ?
170. Three equal masses of  $m$  kg each are fixed at the vertices of an equilateral triangle ABC.
- (a) What is the force acting on a mass  $2m$  placed at the centroid  $G$  of the triangle?
  - (b) What is the force if the mass at the vertex A is doubled ? Take  $AG = BG = CG = 1$  m (see Fig. 4.14)
171. Find the potential energy of a system of four particles placed at the vertices of a square of side  $l$ . Also obtain the potential at the centre of the square.
172. Two uniform solid spheres of equal radii  $R$ , but mass  $M$  and  $4M$  have a centre to centre separation  $6R$ , as shown in Fig. 4.15. The two spheres are held fixed. A projectile of mass  $m$  is projected from the surface of the sphere of mass  $M$  directly towards the centre of the second sphere. Obtain an expression for the minimum speed  $v$  of the projectile so that it reaches the surface of the second sphere.



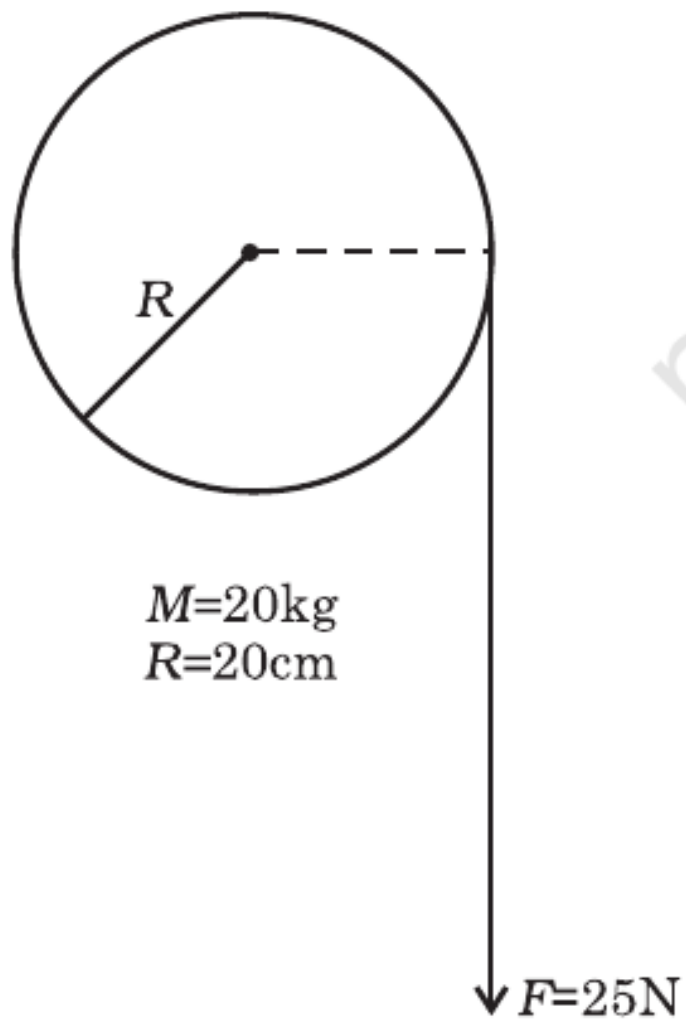


Figure 4.10:

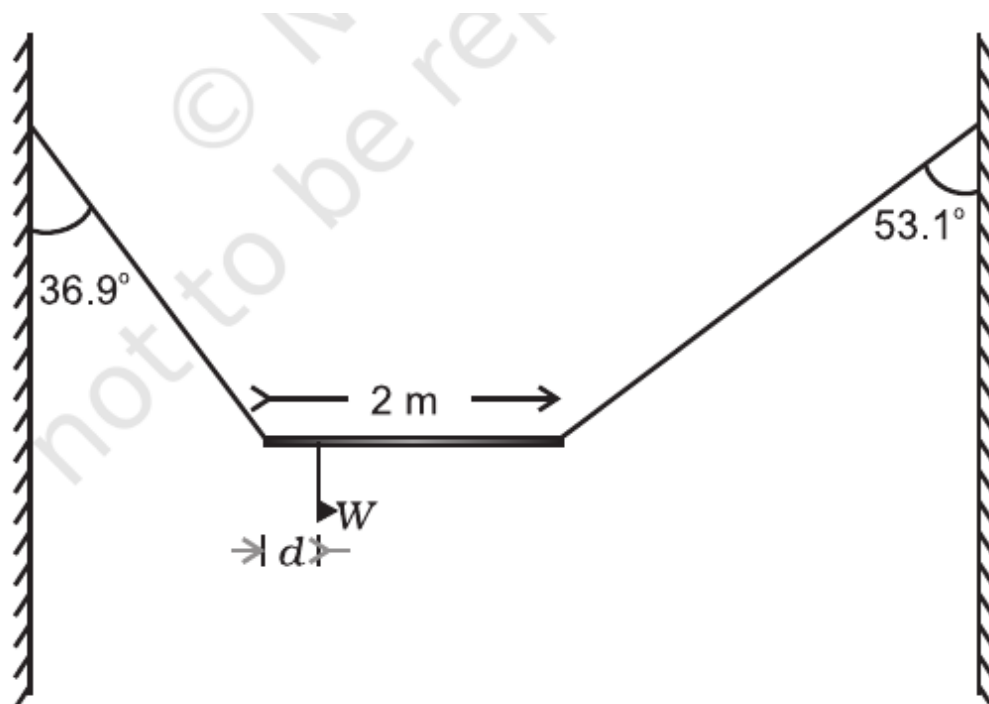


Figure 4.11:

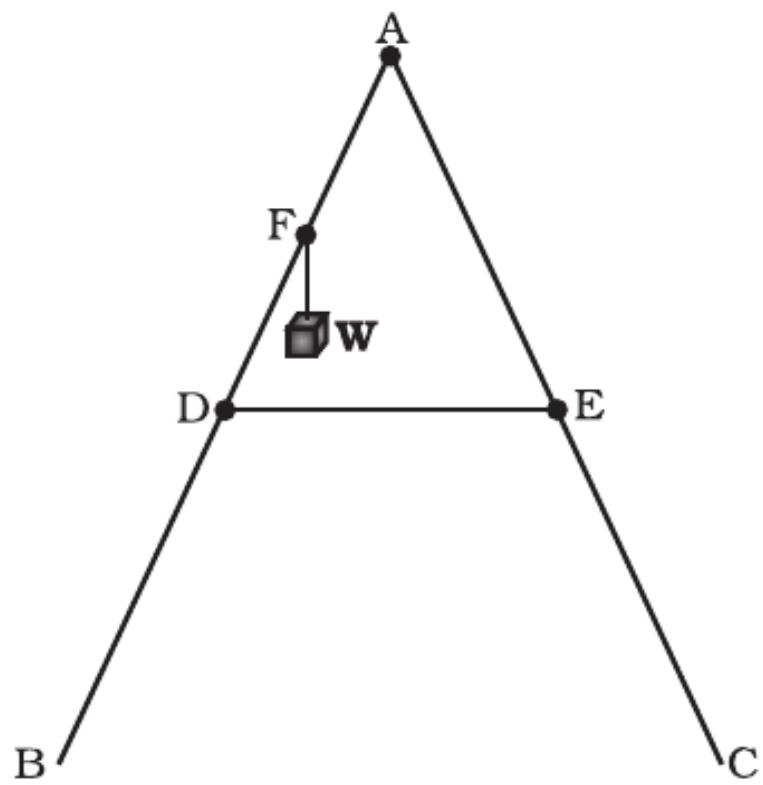


Figure 4.12:



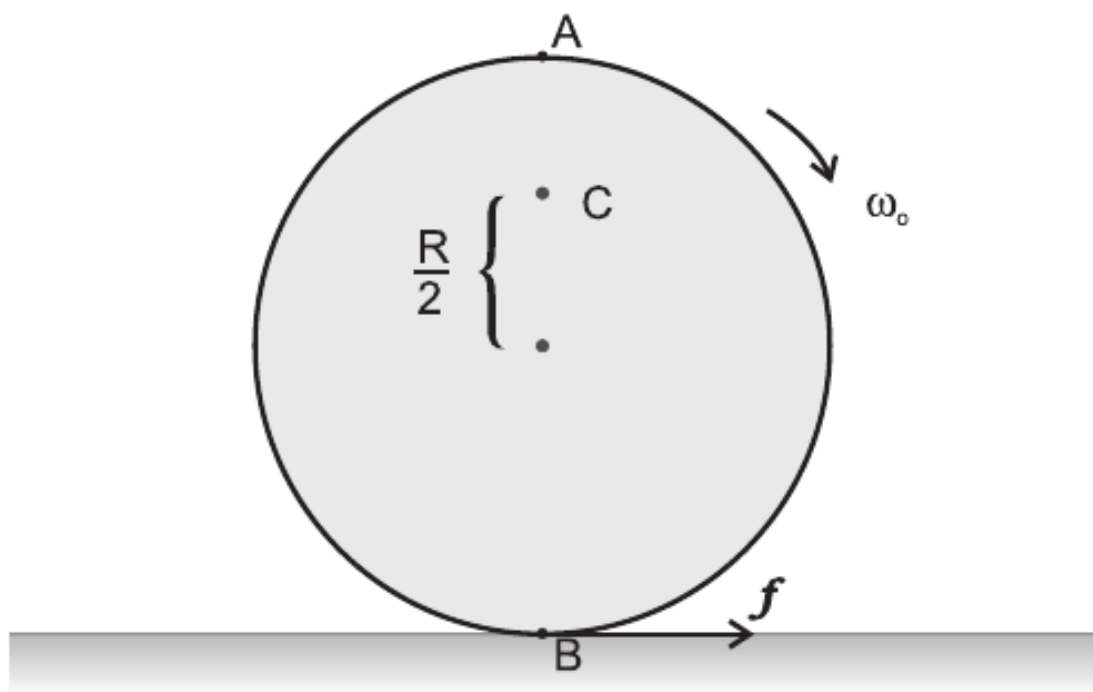


Figure 4.13:

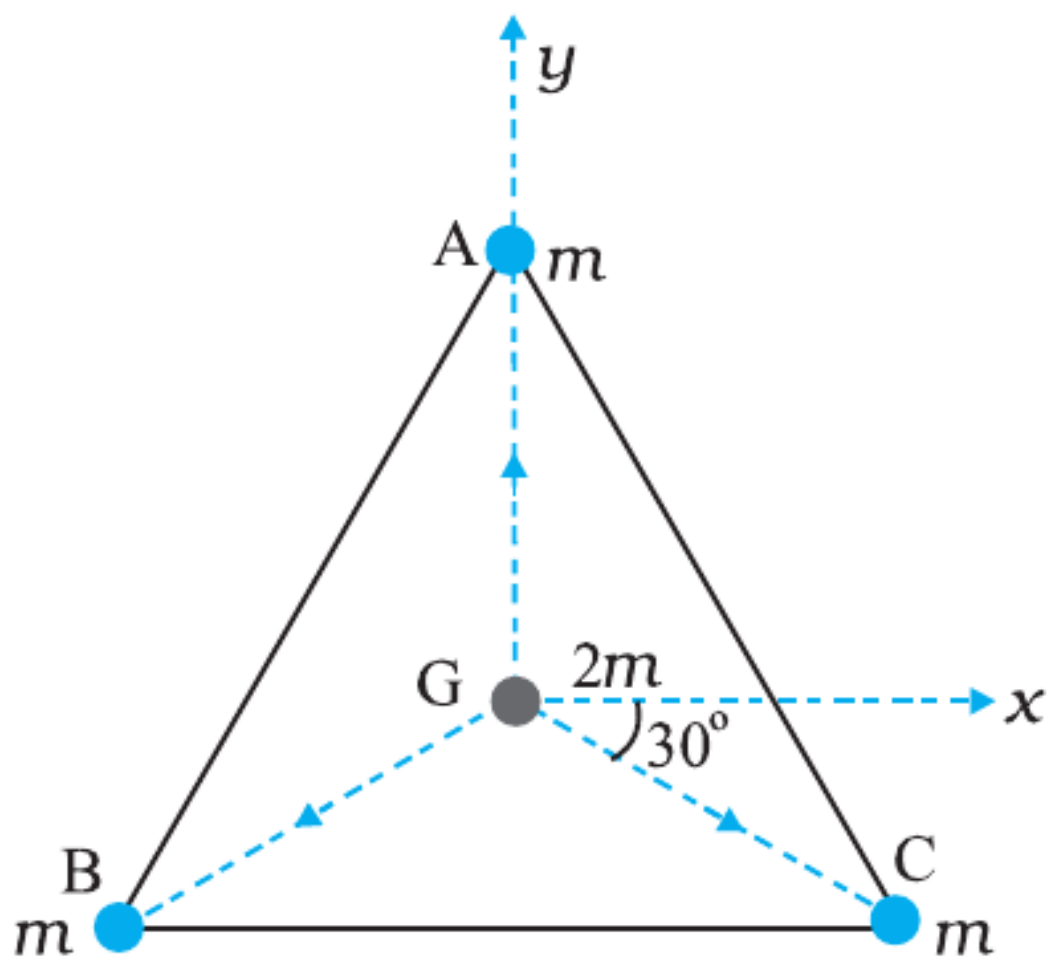


Figure 4.14:

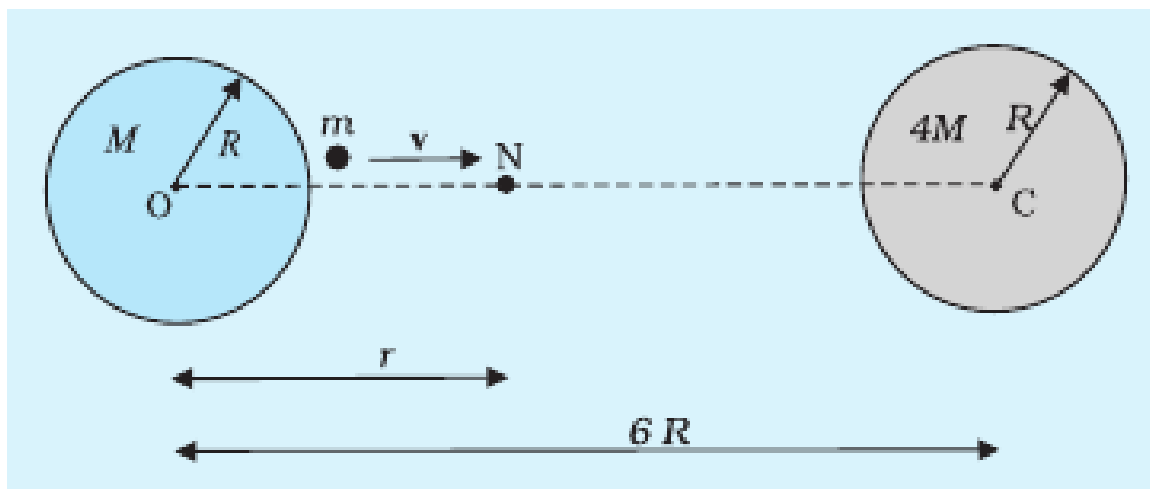


Figure 4.15:

## Appendix A

# Baudhayana Theorem

### A.1. The Right Angled Triangle

1. A right angled triangle looks like Fig. A.1. with angles  $\angle A, \angle B$  and  $\angle C$  and sides  $a, b$  and  $c$ . The unique feature of this triangle is  $\angle B$  which is defined to be  $90^\circ$ .
2. For simplicity, let the greek letter  $\theta = \angle C$ . We have the following definitions.

$$\begin{aligned}\sin \theta &= \frac{c}{b} & \cos \theta &= \frac{a}{b} \\ \tan \theta &= \frac{c}{a} & \cot \theta &= \frac{1}{\tan \theta} \\ \csc \theta &= \frac{1}{\sin \theta} & \sec \theta &= \frac{1}{\cos \theta}\end{aligned}\tag{A.1.0.2.1}$$

3. Draw Fig. A.1 for  $a = 4, c = 3$ .

**Solution:** The vertices of  $\triangle ABC$  are

$$\mathbf{A} = \begin{pmatrix} 0 \\ c \end{pmatrix} = \begin{pmatrix} 0 \\ 3 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix} = \begin{pmatrix} 4 \\ 0 \end{pmatrix}\tag{A.1.0.3.1}$$

The python code for Fig. A.1 is

`codes/triangle/tri_right_angle.py`

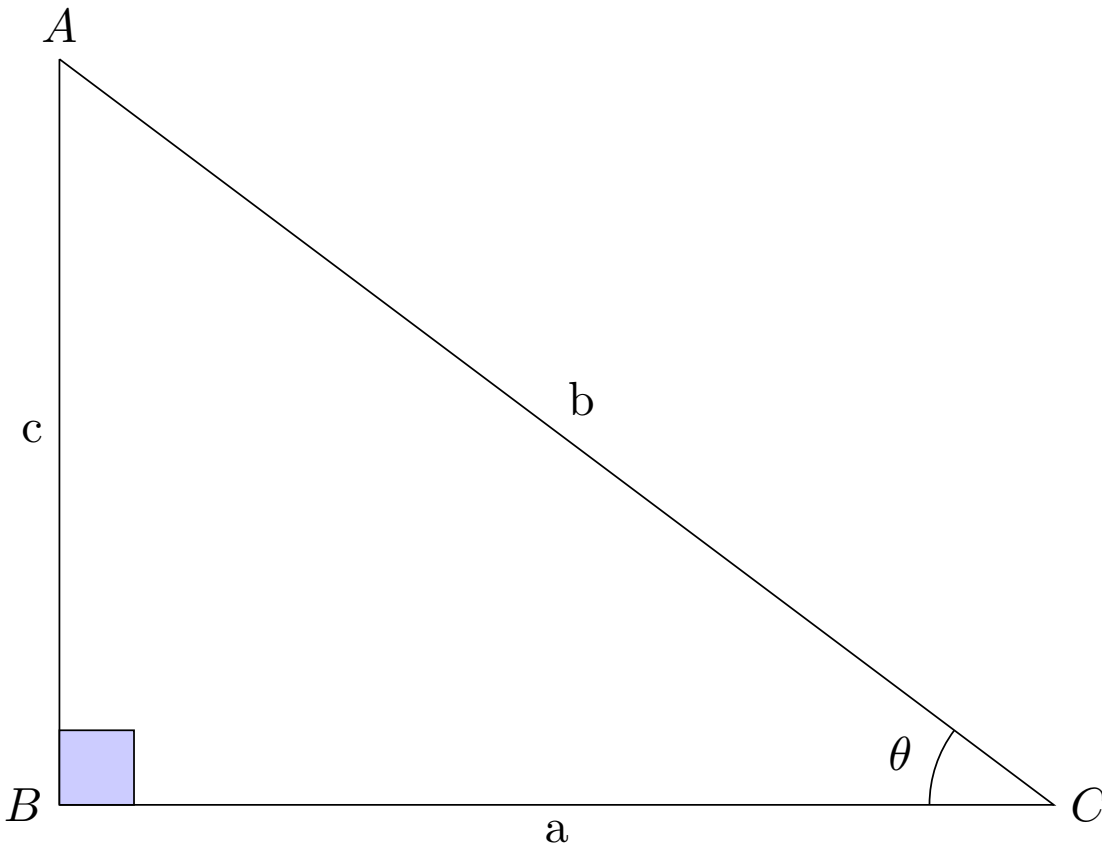


Figure A.1: Right Angled Triangle

and the equivalent latex-tikz code is

```
figs/triangle/tri_right_angle.tex
```

The above latex code can be compiled as a standalone document as

```
figs/triangle/tri_right_angle_alone.tex
```

4. Draw Fig. A.2 for  $a = 4, c = 3$ .

**Solution:** The vertices of  $\triangle ABC$  are

$$\mathbf{A} = \begin{pmatrix} a \\ c \end{pmatrix} = \begin{pmatrix} 4 \\ 3 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} a \\ 0 \end{pmatrix} = \begin{pmatrix} 4 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}. \quad (\text{A.1.0.4.1})$$

The python code for Fig. A.2 is

`codes/triangle/tri_polar.py`

and the equivalent latex-tikz code is

`figs/triangle/tri_polar.tex`

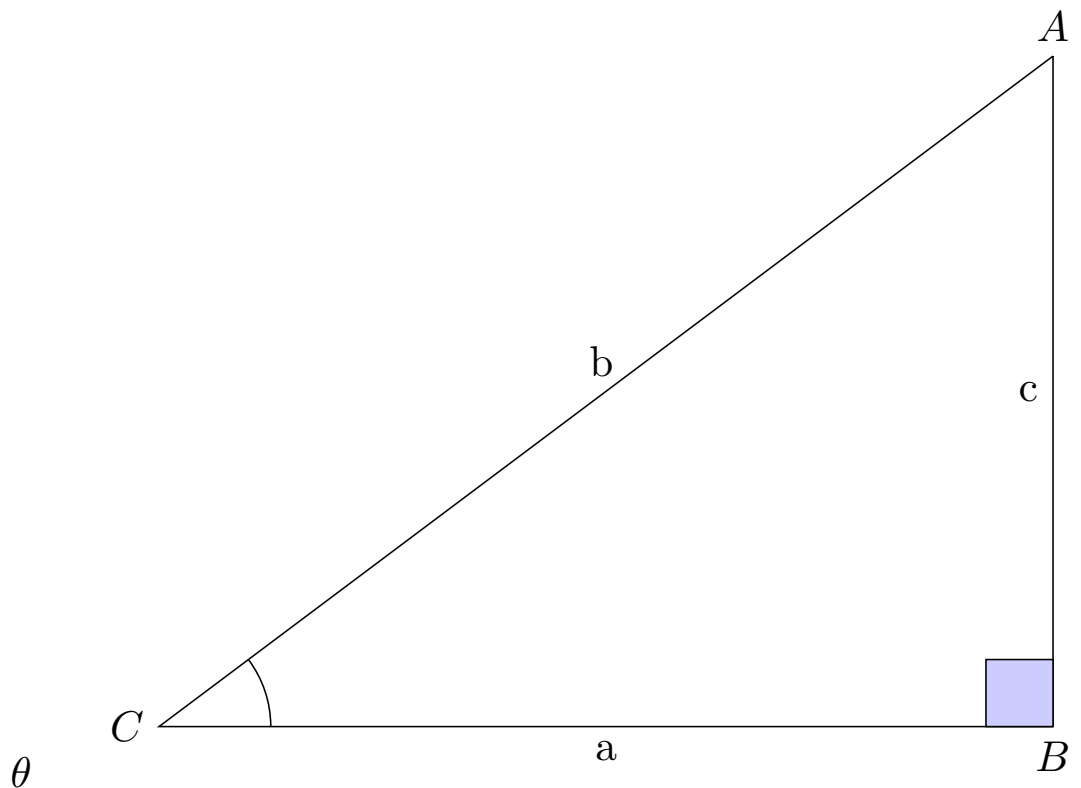


Figure A.2: Right Angled Triangle

5. The vertex **A** can also be expressed in polar coordinate form as

$$\mathbf{A} = \begin{pmatrix} b \cos \theta \\ b \sin \theta \end{pmatrix} \quad (\text{A.1.0.5.1})$$

## A.2. Sum of Angles

1. In Fig. A.3, the sum of all the angles on the top or bottom side of the straight line  $XY$  is  $180^\circ$ .
2. In Fig. A.3, the straight line making an angle of  $90^\circ$  to the side  $AB$  is said to be parallel to the side  $BC$ . Note there is an angle at  $A$  that is equal to  $\theta$ . This is one property of parallel lines. Thus,  $\angle YAZ = 90^\circ$ .
3. Show that  $\angle VAT = 90^\circ - \theta$

**Solution:** Considering the line  $XAT$ ,

$$\theta + 90^\circ + \angle VAT = 180^\circ \quad (\text{A.2.0.3.1})$$

$$\Rightarrow \angle VAT = 90^\circ - \theta \quad (\text{A.2.0.3.2})$$

4. Show that  $\angle BAC = 90^\circ - \theta$ .

**Solution:** Consider the line  $VAB$  and use the approach in the previous problem.

Note that this implies that  $\angle VAT = \angle BAC$ . Such angles are known as vertically opposite angles.

5. Sum of the angles of a triangle is equal to  $180^\circ$ .
6. Draw Fig. A.3 for  $a = 4, c = 3$ .

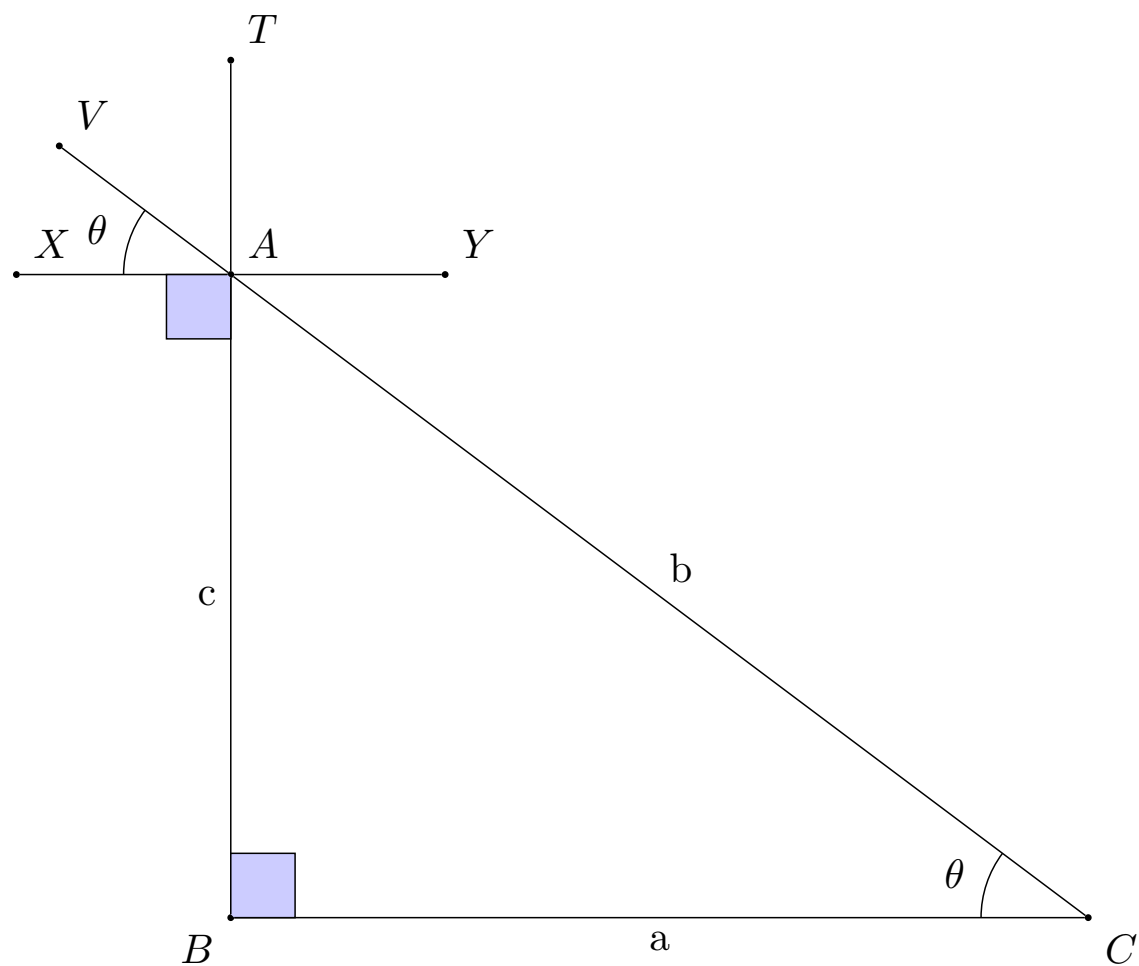


Figure A.3: Sum of angles of a triangle

**Solution:** Problem A.1.0.3 is used to draw  $\triangle ABC$ . The remaining points are obtained as



$$\mathbf{Y} = \mathbf{A} + \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 3 \end{pmatrix} \quad (\text{A.2.0.6.1})$$

$$\mathbf{X} = \mathbf{A} - \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} -1 \\ 3 \end{pmatrix} \quad (\text{A.2.0.6.2})$$

$$\mathbf{T} = \mathbf{A} + \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 0 \\ 4 \end{pmatrix} \quad (\text{A.2.0.6.3})$$

and

$$\frac{VC}{AC} = k + 1 \quad (\text{A.2.0.6.4})$$

$$\implies \mathbf{A} = \frac{k\mathbf{C} + \mathbf{V}}{k + 1} \quad (\text{A.2.0.6.5})$$

$$\implies \mathbf{V} = (k + 1)\mathbf{A} - k\mathbf{C} \quad (\text{A.2.0.6.6})$$

for  $k = 0.2$ . (A.2.0.6.5) is known as the section formula. The python code for Fig. A.3 is

`codes/triangle/tri_sum_angle.py`

and the equivalent latex-tikz code is

`figs/triangle/tri_sum_angle.tex`

## A.3. Proof of Baudhayana Theorem

Use Fig. A.4 for all problems in this section.

1. Show that

$$\cos \theta = \sin (90^\circ - \theta) \quad (\text{A.3.0.1.1})$$

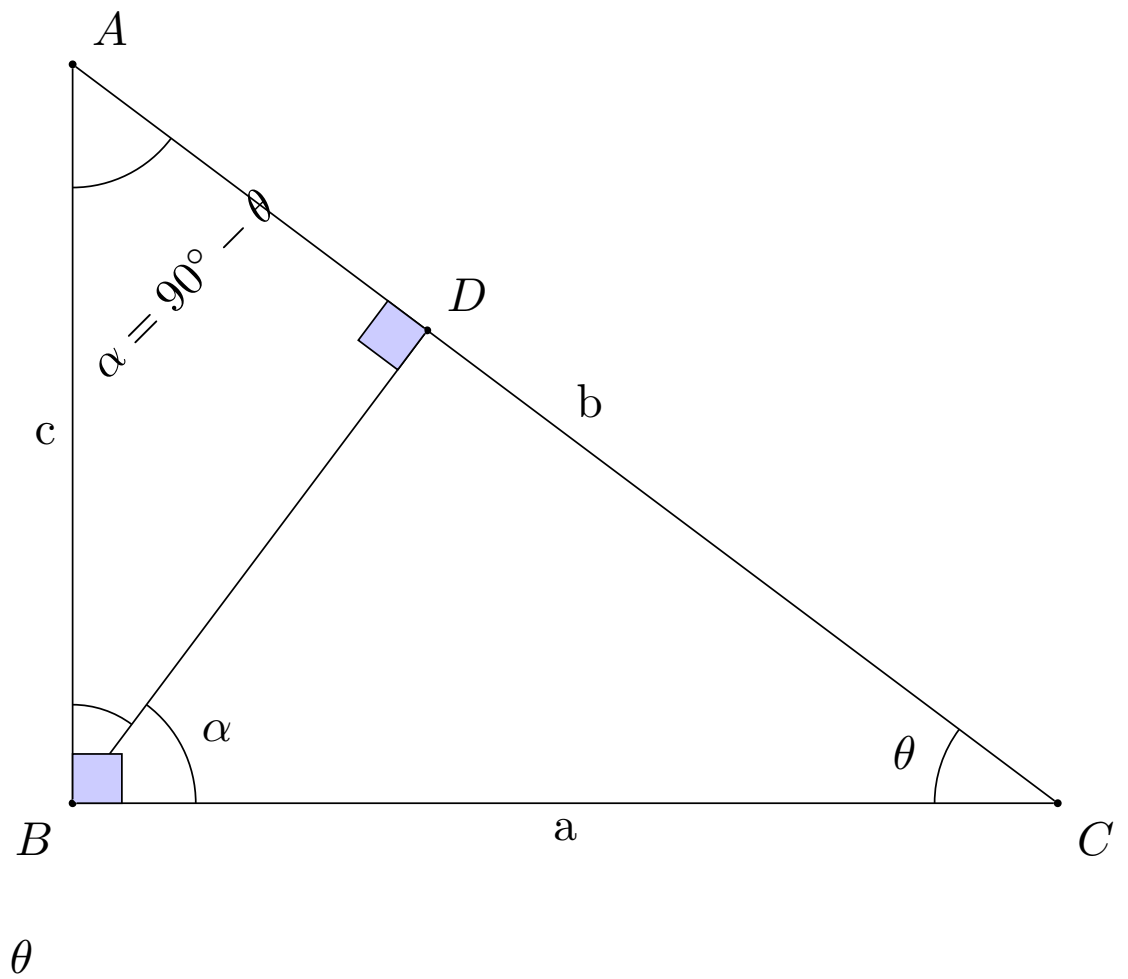


Figure A.4: Baudhayana Theorem

**Solution:** From Problem A.2.0.4 and (A.1.0.2.1)

$$\begin{aligned}\cos \angle BAC = \cos \alpha = \cos (90^\circ - \theta) &= \frac{c}{b} \\ &= \sin \angle ABC = \sin \theta \quad (\text{A.3.0.1.2})\end{aligned}$$

2. Show that

$$b = a \cos \theta + c \sin \theta \quad (\text{A.3.0.2.1})$$

**Solution:** We observe that

$$BD = a \cos \theta \quad (\text{A.3.0.2.2})$$

$$AD = c \cos \alpha = c \sin \theta \quad (\text{From (A.3.0.1.2)}) \quad (\text{A.3.0.2.3})$$

Thus,

$$BD + AD = b = a \cos \theta + c \sin \theta \quad (\text{A.3.0.2.4})$$

3. From (A.3.0.2.1), show that

$$\sin^2 \theta + \cos^2 \theta = 1 \quad (\text{A.3.0.3.1})$$

**Solution:** Dividing both sides of (A.3.0.2.1) by  $b$ ,

$$1 = \frac{a}{b} \cos \theta + \frac{c}{b} \sin \theta \quad (\text{A.3.0.3.2})$$

$$\Rightarrow \sin^2 \theta + \cos^2 \theta = 1 \quad (\text{from (A.1.0.2.1)}) \quad (\text{A.3.0.3.3})$$

4. Using (A.3.0.2.1), show that

$$c^2 = a^2 + b^2 \quad (\text{A.3.0.4.1})$$

(A.3.0.4.1) is known as the Baudhayana theorem. It is also known as the Pythagoras theorem.

**Solution:** From (A.3.0.2.1),

$$c = a\frac{a}{c} + b\frac{b}{c} \quad (\text{from (A.1.0.2.1)}) \quad (\text{A.3.0.4.2})$$

$$\Rightarrow c^2 = a^2 + b^2 \quad (\text{A.3.0.4.3})$$

5. Show that  $c > a, c > b$  **Solution:** From (A.3.0.4.1),

$$c^2 - a^2 = b^2 \quad (\text{A.3.0.5.1})$$

$$\Rightarrow c - a = \frac{b^2}{c + a} > 0 \quad (\text{A.3.0.5.2})$$

$$\Rightarrow c > a \quad (\text{A.3.0.5.3})$$

Similarly, it can be shown that  $c > b$ .

6. In a right angled triangle, the hypotenuse is the longest side.

7. Draw Fig. A.4 for  $a = 4, c = 3$ .

**Solution:** Problem A.1.0.3 is used to draw  $\triangle ABC$ . Using Problem A.1.0.5,

$$\mathbf{D} = BD \begin{pmatrix} \cos \alpha \\ \sin \alpha \end{pmatrix} = a \sin \theta \begin{pmatrix} \sin \theta \\ \cos \theta \end{pmatrix} \quad (\text{A.3.0.7.1})$$

Using (A.3.0.7.1), the python code for Fig. A.4 is

`codes/triangle/tri_baudh.py`

and the equivalent latex-tikz code is

figs/triangle/tri\_baudh.tex

8. Using (A.3.0.4.1), for  $a = 4, c = 3$ ,

$$b = \sqrt{a^2 + c^2} = \sqrt{4^2 + 3^2} = 5 \quad (\text{A.3.0.8.1})$$

9. For point  $\mathbf{D} = \begin{pmatrix} d_1 \\ d_2 \end{pmatrix}$ , its norm is defined as

$$OD = d_1^2 + d_2^2 = \|\mathbf{D}\| \triangleq \sqrt{\mathbf{D}^T \mathbf{D}}, \quad (\text{A.3.0.9.1})$$

where

$$\mathbf{D}^T \triangleq \begin{pmatrix} d_1 & d_2 \end{pmatrix}, \quad (\text{A.3.0.9.2})$$

$$\mathbf{D}^T \mathbf{D} \triangleq \begin{pmatrix} d_1 & d_2 \end{pmatrix} \begin{pmatrix} d_1 \\ d_2 \end{pmatrix} = d_1^2 + d_2^2 \quad (\text{A.3.0.9.3})$$

(A.3.0.9.2) is the definition of transpose.  $\mathbf{D}$  is defined to be a column vector and  $\mathbf{D}^T$  is the corresponding row vector representing the same point.

10. Also, it is easy to verify that

$$AC \triangleq \|\mathbf{A} - \mathbf{C}\| = \left\| \begin{pmatrix} 4 \\ -3 \end{pmatrix} \right\| = \sqrt{3^2 + 4^2} = 5 \quad (\text{A.3.0.10.1})$$

This is known as the distance formula.

11. Prove the distance formula in (A.3.0.10.1) using Baudhayana theorem.

12. Show that

$$(\mathbf{A} - \mathbf{B})^T (\mathbf{B} - \mathbf{C}) = 0 \quad (\text{A.3.0.12.1})$$

**Solution:** From the Baudhayana theorem,

$$a^2 + c^2 = b^2 \quad (\text{A.3.0.12.2})$$

$$\implies \|\mathbf{B} - \mathbf{A}\|^2 + \|\mathbf{C} - \mathbf{A}\|^2 = \|\mathbf{B} - \mathbf{C}\|^2 \quad (\text{A.3.0.12.3})$$

which, from (A.3.0.9.2) can be expressed as

$$\begin{aligned} (\mathbf{B} - \mathbf{A})^T (\mathbf{B} - \mathbf{A}) + (\mathbf{C} - \mathbf{B})^T (\mathbf{C} - \mathbf{B}) \\ = (\mathbf{A} - \mathbf{C})^T (\mathbf{A} - \mathbf{C}) \end{aligned} \quad (\text{A.3.0.12.4})$$

Expanding

$$\begin{aligned} (\mathbf{B} - \mathbf{A})^T (\mathbf{B} - \mathbf{A}) \\ = \mathbf{B}^T \mathbf{B} - \mathbf{B}^T \mathbf{A} - \mathbf{A}^T \mathbf{B} + \mathbf{A}^T \mathbf{A} \end{aligned} \quad (\text{A.3.0.12.5})$$

$\because \mathbf{A}^T \mathbf{B} = \mathbf{B}^T \mathbf{A}$ , the above equation can be expressed as

$$\|\mathbf{B} - \mathbf{A}\|^2 = \|\mathbf{A}\|^2 + \|\mathbf{B}\|^2 - 2\mathbf{A}^T \mathbf{B} \quad (\text{A.3.0.12.6})$$

Thus, (A.3.0.12.3) can be expressed using the above equation as

$$\begin{aligned}
& \|\mathbf{A}\|^2 + \|\mathbf{B}\|^2 - 2\mathbf{A}^T \mathbf{B} \\
& \quad + \|\mathbf{B}\|^2 + \|\mathbf{C}\|^2 - 2\mathbf{B}^T \mathbf{C} \\
& \quad = \|\mathbf{A}\|^2 + \|\mathbf{C}\|^2 - 2\mathbf{A}^T \mathbf{C} \quad (\text{A.3.0.12.7})
\end{aligned}$$

which can be simplified to obtain

$$\begin{aligned}
& 2\|\mathbf{B}\|^2 - 2\mathbf{B}^T \mathbf{C} \\
& \quad - 2\mathbf{A}^T \mathbf{B} + 2\mathbf{A}^T \mathbf{C} = 0 \\
& \text{or, } \mathbf{B}^T (\mathbf{B} - \mathbf{C}) - \mathbf{A}^T (\mathbf{B} - \mathbf{C}) = 0 \\
& \quad \implies (\mathbf{B}^T - \mathbf{A}^T) (\mathbf{B} - \mathbf{C}) = 0 \quad (\text{A.3.0.12.8})
\end{aligned}$$

yielding (A.3.0.12.1).

## Appendix B

# Area of a Triangle

### B.1. From a Rectangle

1. The area of the rectangle  $ACBD$  shown in Fig. B.1 is defined as  $ac$ . Note that all the angles in the rectangle are  $90^\circ$
2. Draw Fig. B.1 for  $a = 4, c = 3$ .

**Solution:** Letting

$$\mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{D} = \begin{pmatrix} 4 \\ 3 \end{pmatrix} \quad (\text{B.1.0.2.1})$$

the python code for Fig. B.1 is

`codes/triangle/tri_rect.py`

and the equivalent latex-tikz code is

`figs/triangle/tri_rect.tex`

3. The area of the two triangles constituting the rectangle is the same.
4. The area of the rectangle is the sum of the areas of the two triangles inside.



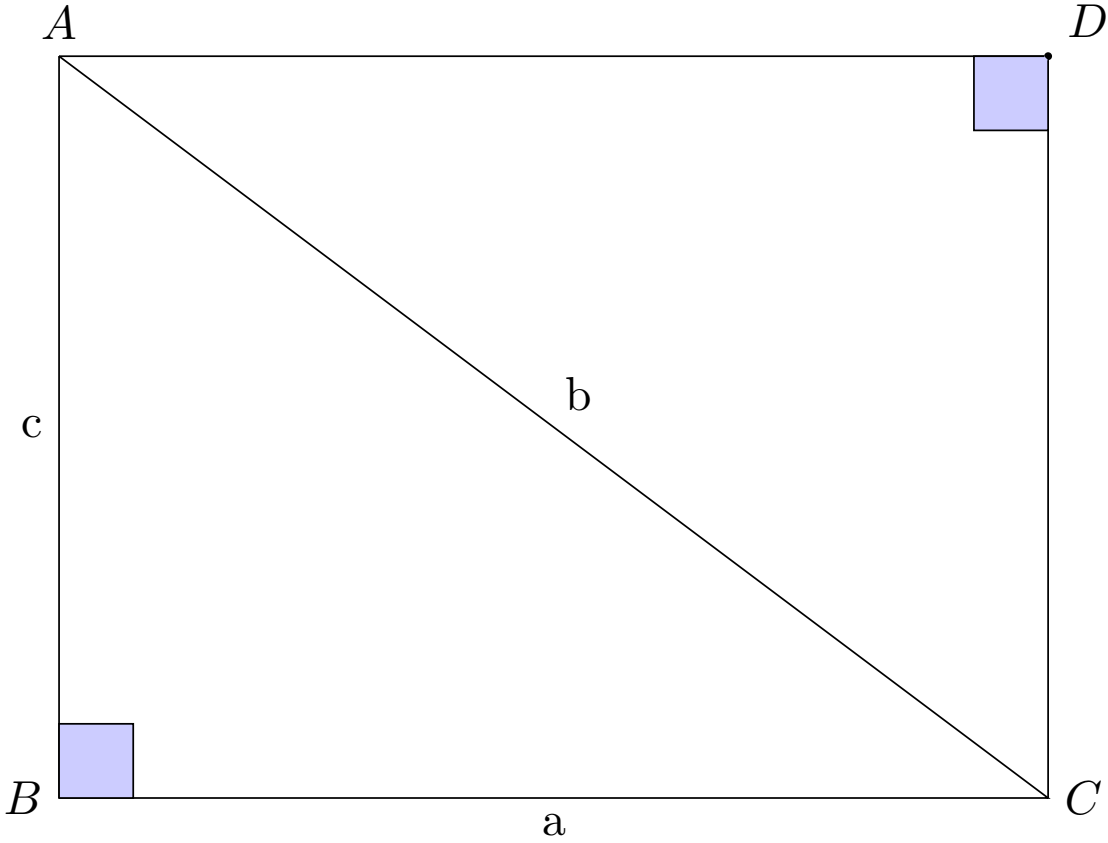


Figure B.1: Area of a Right Triangle

5. Show that the area of  $\triangle ABC$  is  $\frac{ac}{2}$

**Solution:** From (B.1.0.4),

$$ar(ABCD) = ar(ACB) + ar(ADB) \quad (\text{B.1.0.5.1})$$

Also from (B.1.0.3),

$$ar(ACB) = ar(ADB) \quad (\text{B.1.0.5.2})$$

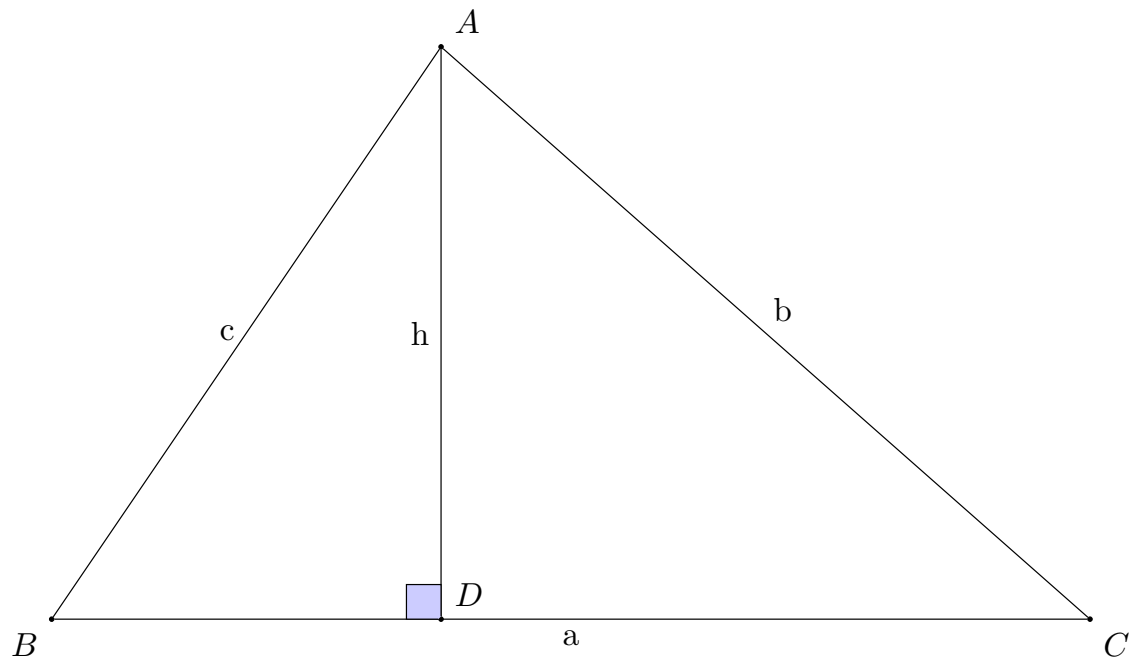


Figure B.2: Area of a Triangle

From (B.1.0.5.1) and (B.1.0.5.2),

$$2ar(ACB) = ar(ABCD) = ac \text{ (from (B.1))} \quad (\text{B.1.0.5.3})$$

$$\Rightarrow ar(ACB) = \frac{ac}{2} \quad (\text{B.1.0.5.4})$$

6. In Fig. B.2,  $AD \perp BC$ .  $AD$  is defined as the altitude.

7. Show that the area of  $\triangle ABC$  in Fig. B.2 is  $\frac{1}{2}ah$ .

**Solution:** In Fig. B.2,

$$ar(\Delta ADC) = \frac{1}{2}hy \quad (\text{B.1.0.7.1})$$

$$ar(\Delta ADB) = \frac{1}{2}hx \quad (\text{B.1.0.7.2})$$

Thus,

$$ar(\Delta ABC) = ar(\Delta ADC) + ar(\Delta ADB) \quad (\text{B.1.0.7.3})$$

$$= \frac{1}{2}hy + \frac{1}{2}hx = \frac{1}{2}h(x + y) \quad (\text{B.1.0.7.4})$$

$$= \frac{1}{2}ah \quad (\text{B.1.0.7.5})$$

8. Draw Fig. B.2 with  $a = 6$ ,  $b = 5$  and  $c = 4$ .

**Solution:** Let the vertices of  $\triangle ABC$  and  $\mathbf{D}$  be

$$\mathbf{A} = \begin{pmatrix} p \\ q \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix}, \mathbf{D} = \begin{pmatrix} p \\ 0 \end{pmatrix} \quad (\text{B.1.0.8.1})$$

Then

$$AB = \|\mathbf{A} - \mathbf{B}\|^2 = \|\mathbf{A}\|^2 = c^2 \quad \because \mathbf{B} = \mathbf{0} \quad (\text{B.1.0.8.2})$$

$$BC = \|\mathbf{C} - \mathbf{B}\|^2 = \|\mathbf{C}\|^2 = a^2 \quad (\text{B.1.0.8.3})$$

$$AC = \|\mathbf{A} - \mathbf{C}\|^2 = b^2 \quad (\text{B.1.0.8.4})$$

From (B.1.0.8.4),

$$b^2 = \|\mathbf{A} - \mathbf{C}\|^2 = \|\mathbf{A} - \mathbf{C}\|^T \|\mathbf{A} - \mathbf{C}\| \quad (\text{B.1.0.8.5})$$

$$= \mathbf{A}^T \mathbf{A} + \mathbf{C}^T \mathbf{C} - \mathbf{A}^T \mathbf{C} - \mathbf{C}^T \mathbf{A} \quad (\text{B.1.0.8.6})$$

$$= \|\mathbf{A}\|^2 + \|\mathbf{C}\|^2 - 2\mathbf{A}^T \mathbf{C} \quad (\because \mathbf{A}^T \mathbf{C} = \mathbf{C}^T \mathbf{A}) \quad (\text{B.1.0.8.7})$$

$$= a^2 + c^2 - 2ap \quad (\text{B.1.0.8.8})$$

yielding

$$p = \frac{a^2 + c^2 - b^2}{2a} \quad (\text{B.1.0.8.9})$$

From (B.1.0.8.2),

$$\|\mathbf{A}\|^2 = c^2 = p^2 + q^2 \quad (\text{B.1.0.8.10})$$

$$\implies q = \pm \sqrt{c^2 - p^2} \quad (\text{B.1.0.8.11})$$

The python code for Fig. B.2 is

`codes/triangle/tri-sss.py`

and the equivalent latex-tikz code is

`figs/triangle/tri-sss.tex`

## B.2. Sine and Cosine formula

1. Show that the area of  $\triangle ABC$  in Fig. B.2 is  $\frac{1}{2}ab \sin C$ .

**Solution:** We have

$$ar(\Delta ABC) = \frac{1}{2}ah = \frac{1}{2}ab \sin C \quad (\because h = b \sin C). \quad (\text{B.2.0.1.1})$$

2. Show that

$$\sin 90^\circ = 1 \quad (\text{B.2.0.2.1})$$

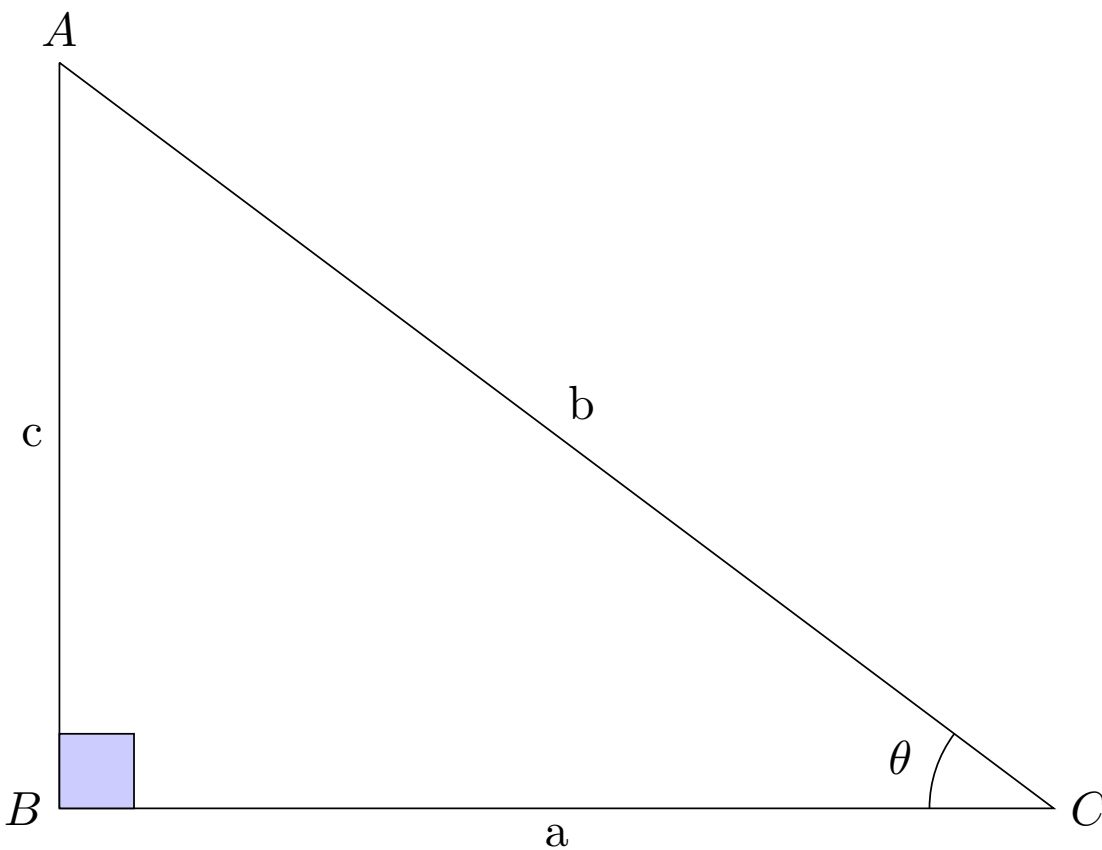


Figure B.3:  $\sin 90^\circ = 1$

**Solution:** In Fig. B.3, using (B.2.0.1.1) and (B.1.0.5.4)

$$ar(\triangle ABC) = \frac{1}{2}ac \sin B = \frac{1}{2}ac \quad (\text{B.2.0.2.2})$$

$$\implies \sin B = \sin 90^\circ = 1 \quad (\text{B.2.0.2.3})$$

3. Show that

$$\cos 90^\circ = 1 \quad (\text{B.2.0.3.1})$$

**Solution:** Trivial using (A.3.0.3.1).

4. Show that

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c} \quad (\text{B.2.0.4.1})$$

**Solution:** Fig. B.2 can be suitably modified to obtain

$$ar(\triangle ABC) = \frac{1}{2}ab \sin C = \frac{1}{2}bc \sin A = \frac{1}{2}ca \sin B \quad (\text{B.2.0.4.2})$$

Dividing the above by  $abc$ , we obtain

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c} \quad (\text{B.2.0.4.3})$$

This is known as the sine formula.

5. In Fig. B.4, show that

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc} \quad (\text{B.2.0.5.1})$$

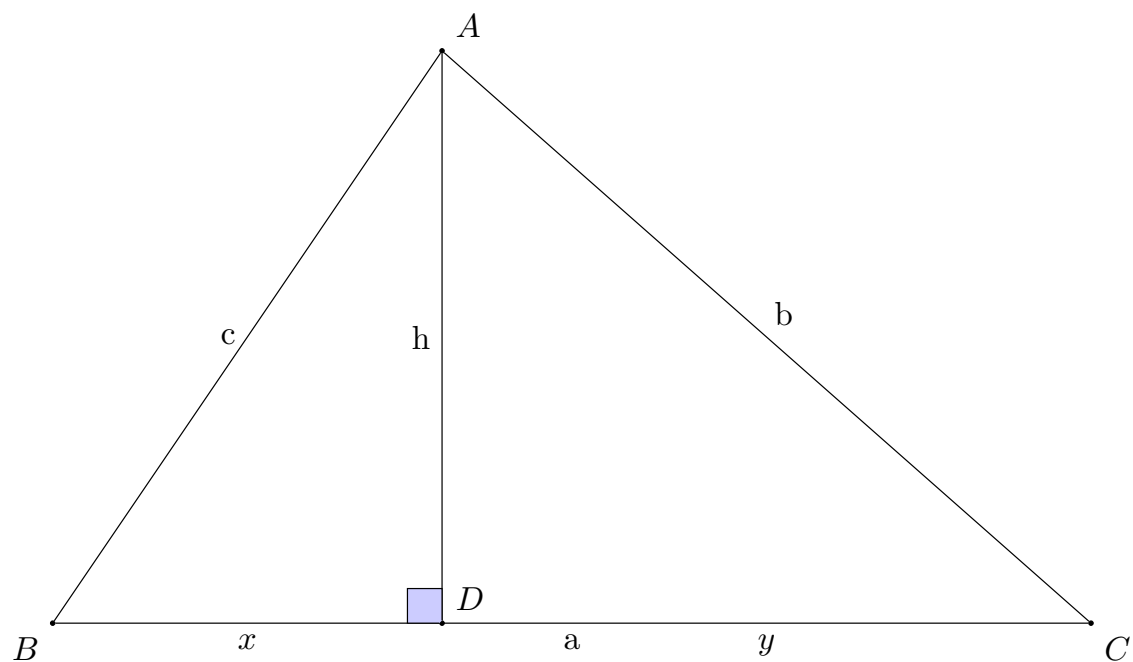


Figure B.4: The cosine formula

**Solution:** From Fig. B.4,

$$a = x + y = b \cos C + c \cos B. \quad (\text{B.2.0.5.2})$$

Similarly,

$$b = c \cos A + a \cos C \quad (\text{B.2.0.5.3})$$

$$c = b \cos A + a \cos B \quad (\text{B.2.0.5.4})$$

The above equations can be expressed in matrix form as

$$\begin{pmatrix} 0 & c & b \\ c & 0 & a \\ b & a & 0 \end{pmatrix} \begin{pmatrix} \cos A \\ \cos B \\ \cos C \end{pmatrix} = \begin{pmatrix} a \\ b \\ c \end{pmatrix} \quad (\text{B.2.0.5.5})$$

Using the properties of determinants,

$$\cos A = \frac{\begin{vmatrix} a & c & b \\ b & 0 & a \\ c & a & 0 \end{vmatrix}}{\begin{vmatrix} 0 & c & b \\ c & 0 & a \\ b & a & 0 \end{vmatrix}} = \frac{ab^2 + ac^2 - a^3}{abc + abc} \quad (\text{B.2.0.5.6})$$

$$= \frac{b^2 + c^2 - a^2}{2abc} \quad (\text{B.2.0.5.7})$$

6. Show that

$$\alpha > \beta \implies \sin \alpha > \sin \beta \quad (\text{B.2.0.6.1})$$



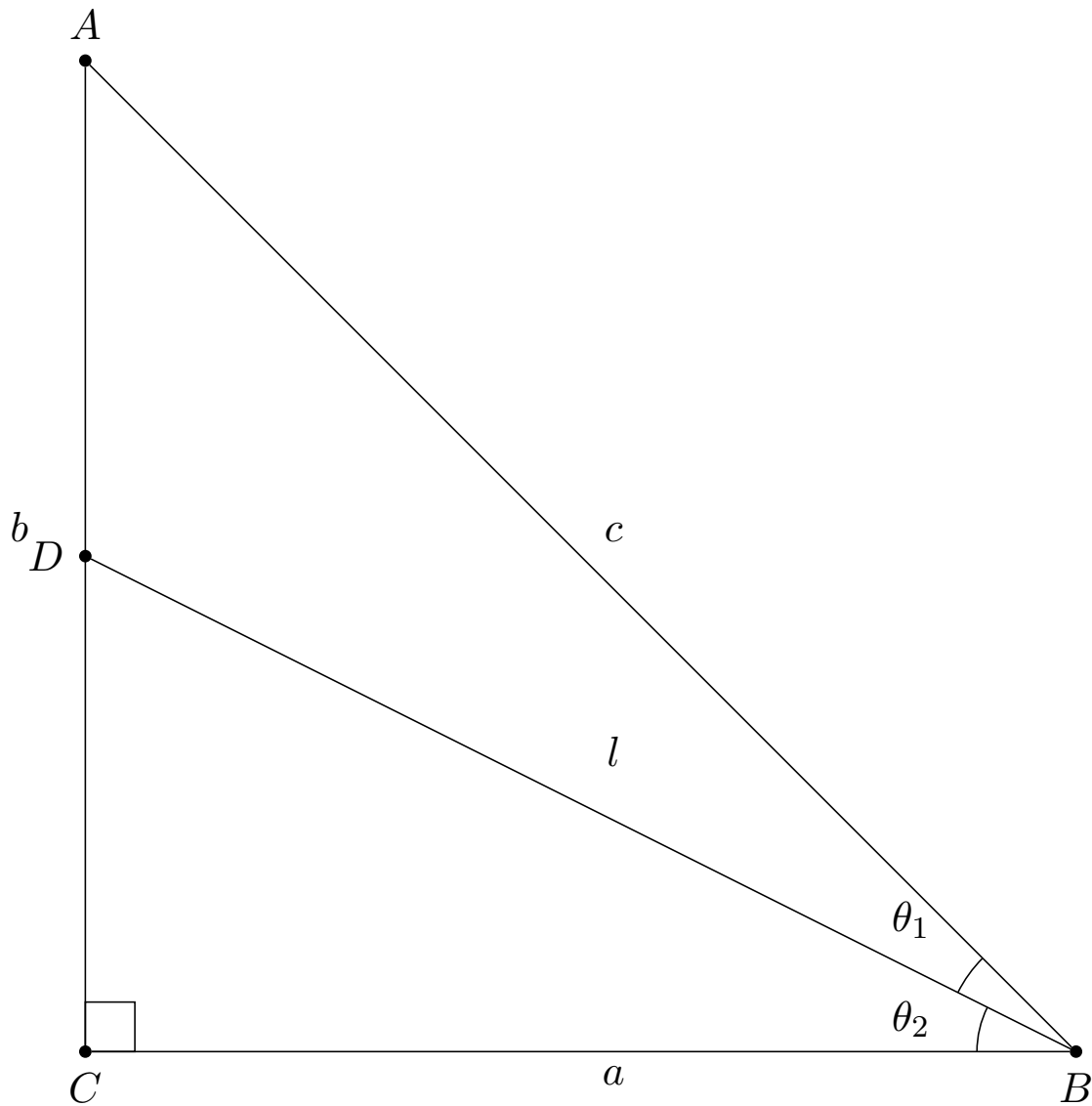


Figure B.5:  $\sin (\theta_1 + \theta_2) = \sin \theta_1 \cos \theta_2 + \cos \theta_1 \sin \theta_2$

**Solution:** In Fig. B.5,

$$ar (\triangle ABD) < ar (\triangle ABC) \quad (\text{B.2.0.6.2})$$

$$\implies \frac{1}{2} l c \sin \theta_1 < \frac{1}{2} a c \sin (\theta_1 + \theta_2) \quad (\text{B.2.0.6.3})$$

$$\implies \frac{130}{2} \frac{l}{c} < \frac{\sin (\theta_1 + \theta_2)}{\sin \theta_1} \quad (\text{B.2.0.6.4})$$

from Theorem A.3.0.6. This proves (B.2.0.6.1).

7. In a triangle, the side opposite the greater angle is greater.

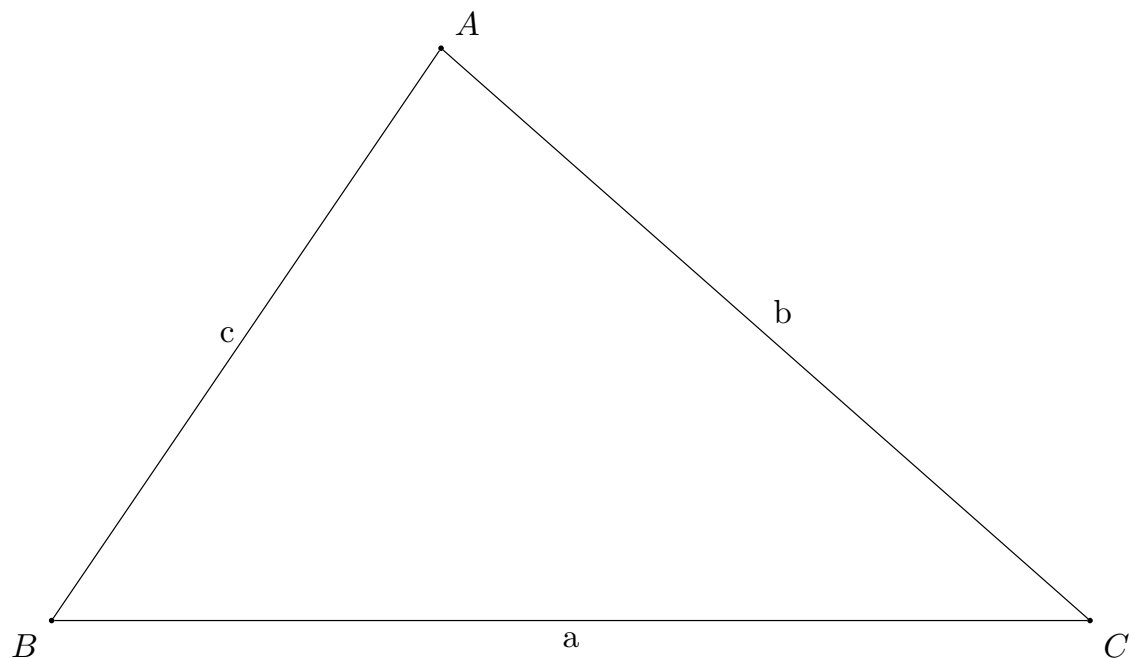


Figure B.6: Side opposite the greater angle is greater

**Solution:** In Fig. B.6, let

$$\angle B > \angle C \quad (\text{B.2.0.7.1})$$

Then, using the sine formula,

$$\frac{\sin B}{b} = \frac{\sin C}{c} \quad (\text{B.2.0.7.2})$$

$$\implies \frac{\sin B}{\sin C} = \frac{b}{c} > 1 \quad (\text{B.2.0.7.3})$$

using (B.2.0.6.1).

## B.3. Hero's formula

1. Find Hero's formula for the area of a triangle.

**Solution:** From (B.2.0.1), the area of  $\triangle ABC$  is

$$\frac{1}{2}ab \sin C = \frac{1}{2}ab \sqrt{1 - \cos^2 C} \quad (\text{from (A.3.0.3.1)}) \quad (\text{B.3.0.1.1})$$

$$= \frac{1}{2}ab \sqrt{1 - \left( \frac{a^2 + b^2 - c^2}{2ab} \right)^2} \quad (\text{from (B.2.0.5.1)}) \quad (\text{B.3.0.1.2})$$

$$= \frac{1}{4} \sqrt{(2ab)^2 - (a^2 + b^2 - c^2)} \quad (\text{B.3.0.1.3})$$

$$= \frac{1}{4} \sqrt{(2ab + a^2 + b^2 - c^2)(2ab - a^2 - b^2 + c^2)} \quad (\text{B.3.0.1.4})$$

$$= \frac{1}{4} \sqrt{\{(a+b)^2 - c^2\} \{c^2 - (a-b)^2\}} \quad (\text{B.3.0.1.5})$$

$$= \frac{1}{4} \sqrt{(a+b+c)(a+b-c)(a+c-b)(b+c-a)} \quad (\text{B.3.0.1.6})$$

Substituting

$$s = \frac{a+b+c}{2} \quad (\text{B.3.0.1.7})$$

in (B.3.0.1.6), the area of  $\triangle ABC$  is

$$\sqrt{s(s-a)(s-b)(s-c)} \quad (\text{B.3.0.1.8})$$

This is known as Hero's formula.

2. Find the area of  $\triangle ABC$  in Fig. B.1.

**Solution:** The desired area is computed using (B.3.0.1.8) by the following the python code.

`codes/triangle/tri_area_hero.py`

3. Show that the sum of two sides of a triangle is always greater than the third side.

**Solution:** In (B.3.0.1.8), all terms under the square roots should be positive. Hence,

$$s - a > 0$$

$$s - b > 0 \tag{B.3.0.3.1}$$

$$s - c > 0$$

resulting in

$$b + c > a$$

$$c + a > b \tag{B.3.0.3.2}$$

$$a + b > c$$



## Appendix C

# Circumcentre

### C.1. Locating the Circumcentre

1. Find a point  $\mathbf{O}$  that is equidistant from the vertices of  $\triangle ABC$  for  $a = 5, b = 6, c = 4$ .

**Solution:** Let  $\mathbf{O}$  be the desired point. Then,

$$\|\mathbf{A} - \mathbf{O}\| = \|\mathbf{B} - \mathbf{O}\| = \|\mathbf{C} - \mathbf{O}\| = R \quad (\text{C.1.0.1.1})$$

From (C.1.0.1.1),

$$\|\mathbf{A} - \mathbf{O}\|^2 - \|\mathbf{B} - \mathbf{O}\|^2 = 0 \quad (\text{C.1.0.1.2})$$

$$\begin{aligned} \implies (\mathbf{A} - \mathbf{O})^T (\mathbf{A} - \mathbf{O}) \\ - (\mathbf{B} - \mathbf{O})^T (\mathbf{B} - \mathbf{O}) = 0 \end{aligned} \quad (\text{C.1.0.1.3})$$

which can be simplified as

$$(\mathbf{A} - \mathbf{B})^T \mathbf{O} = \frac{\|\mathbf{A}\|^2 - \|\mathbf{B}\|^2}{2} \quad (\text{C.1.0.1.4})$$

Similarly,

$$(\mathbf{B} - \mathbf{C})^T \mathbf{O} = \frac{\|\mathbf{B}\|^2 - \|\mathbf{C}\|^2}{2} \quad (\text{C.1.0.1.5})$$

(C.1.0.1.4) and (C.1.0.1.4), can be combined to form the matrix equation

$$\mathbf{N}^T \mathbf{O} = \mathbf{c} \quad (\text{C.1.0.1.6})$$

$$\implies \mathbf{O} = \mathbf{N}^{-T} \mathbf{c} \quad (\text{C.1.0.1.7})$$

where

$$\mathbf{N} = \begin{pmatrix} \mathbf{A} - \mathbf{B} & \mathbf{B} - \mathbf{C} \end{pmatrix} \quad (\text{C.1.0.1.8})$$

$$\mathbf{c} = \frac{1}{2} \begin{pmatrix} \|\mathbf{A}\|^2 - \|\mathbf{B}\|^2 \\ \|\mathbf{B}\|^2 - \|\mathbf{C}\|^2 \end{pmatrix} \quad (\text{C.1.0.1.9})$$

$\mathbf{O}$  can be computed using the python code below

`codes/circle/tri_centre.py`

and the equivalent latex-tikz code to draw Fig. C.1 is

`figs/triangle/tri_centre.tex`

2. In  $\triangle OBC$ ,  $OB = OC = R$ . Such a triangle is known as an isocles triangle.
3. Show that  $\angle OBC = \angle OCB$ . In an isocles triangle, opposite sides and corresponding opposite angles are equal.

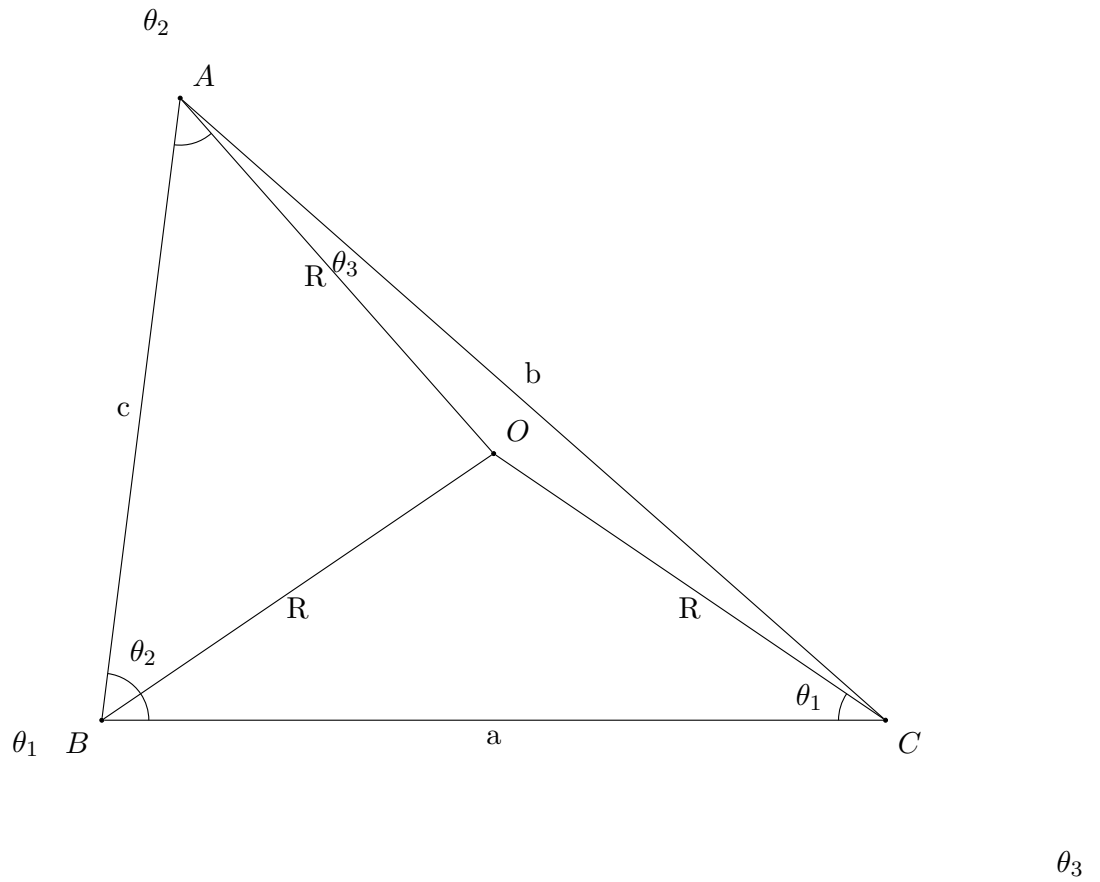


Figure C.1: Circumcentre  $O$  of  $\triangle ABC$

**Solution:** Using the sine formula in (B.2.0.4.3),

$$\frac{\sin \angle OBC}{R} = \frac{\sin \angle OCB}{R} \quad (\text{C.1.0.3.1})$$

$$\implies \sin \angle OBC = \sin \angle OCB \quad (\text{C.1.0.3.2})$$

4. Show that  $\angle BOC = 2\angle A$ .



**Solution:** In Fig. C.1,

$$A = \theta_2 + \theta_3 \quad (\text{C.1.0.4.1})$$

$$B = \theta_1 + \theta_2 \quad (\text{C.1.0.4.2})$$

$$C = \theta_3 + \theta_1 \quad (\text{C.1.0.4.3})$$

$$\implies 2(\theta_1 + \theta_2 + \theta_3) = A + B + C = 180^\circ \quad (\text{C.1.0.4.4})$$

$$\implies \theta_1 + \theta_2 + \theta_3 = 90^\circ \quad (\text{C.1.0.4.5})$$

From (C.1.0.4.1) and (C.1.0.4.5),

$$A = 90^\circ - \theta_1 \quad (\text{C.1.0.4.6})$$

Also, in  $\triangle OBC$ , all angles add up to  $180^\circ$ . Hence,

$$\angle BOC + 2\theta_1 = 180^\circ \quad (\text{C.1.0.4.7})$$

$$\implies \angle BOC = 180^\circ - 2\theta_1 = 2(90^\circ - \theta_1) = 2\angle A \quad (\text{C.1.0.4.8})$$

upon substituting from (C.1.0.4.6).

5. Let  $\mathbf{D}$  be the mid point of  $BC$ . Show that  $OD \perp BC$ .

**Solution:** From (C.1.0.1.5),

$$(\mathbf{B} - \mathbf{C})^T \mathbf{O} = \frac{\|\mathbf{B}\|^2 - \|\mathbf{C}\|^2}{2} \quad (\text{C.1.0.5.1})$$

$$\implies (\mathbf{B} - \mathbf{C})^T \mathbf{O} = \frac{1}{2} (\mathbf{B} - \mathbf{C})^T (\mathbf{B} + \mathbf{C}) \quad (\text{C.1.0.5.2})$$

$$\implies (\mathbf{B} - \mathbf{C})^T \left( \mathbf{O} - \frac{\mathbf{B} + \mathbf{C}}{2} \right) = 0 \quad (\text{C.1.0.5.3})$$

$$\text{or, } (\mathbf{B} - \mathbf{C})^T (\mathbf{O} - \mathbf{D}) = 0 \quad (\text{C.1.0.5.4})$$

$\therefore \mathbf{D} = \frac{\mathbf{B}+\mathbf{C}}{2}$  is the mid point of  $BC$ . From (A.3.0.12.1) we then conclude that  $OD \perp BC$ .

6. Perpendicular bisectors of a triangle meet at the circumcentre.

7. In the isosceles  $\triangle OBC$ , if  $BD = DC$ ,  $OD \perp BC$ .

## C.2. Finding the Circumradius

1. Show that

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C} = 2R. \quad (\text{C.2.0.1.1})$$

**Solution:** In  $\triangle OBC$ , using the cosine formula,

$$\cos 2A = \frac{R^2 + R^2 - a^2}{2R^2} = 1 - \frac{a^2}{2R^2} \quad (\text{C.2.0.1.2})$$

Using the sine formula,

$$\frac{\sin 2A}{a} = \frac{\sin \theta_1}{R} = \frac{\sin (90^\circ - A)}{R} \quad (\text{C.2.0.1.3})$$

$$\implies \sin 2A = \frac{a \cos A}{R} \quad (\text{C.2.0.1.4})$$

from (C.1.0.4.6) and (A.3.0.1.1). Using (A.3.0.3.1),

$$\cos^2 2A + \sin^2 2A = 1 \quad (\text{C.2.0.1.5})$$

$$\implies \left(1 - \frac{a^2}{2R^2}\right)^2 + \left(\frac{a \cos A}{R}\right)^2 = 1 \quad (\text{C.2.0.1.6})$$

upon substituting from (C.2.0.1.2) and (C.2.0.1.4). Letting

$$x = \left(\frac{a}{R}\right)^2, \quad (\text{C.2.0.1.7})$$

in the previous equation yields

$$\left(1 - \frac{x}{2}\right)^2 + x \cos^2 A = 1 \quad (\text{C.2.0.1.8})$$

$$\implies 1 - \frac{x^2}{4} - x + x \cos^2 A = 1 \quad (\text{C.2.0.1.9})$$

$$\implies x(1 - \cos^2 A) - \frac{x^2}{4} = 0 \quad (\text{C.2.0.1.10})$$

From (A.3.0.3.1), the above equation can be expressed as

$$x \sin^2 A - \frac{x^2}{4} = 0 \quad (\text{C.2.0.1.11})$$

$$\implies x \left( \sin^2 A - \frac{x}{4} \right) = 0 \quad (\text{C.2.0.1.12})$$

$$\text{or, } \frac{x}{4} - \sin^2 A = 0 \quad (\text{C.2.0.1.13})$$

$\therefore x \neq 0$ . Thus, substituting from (C.2.0.1.7),

$$x = \left(\frac{a}{R}\right)^2 = 4 \sin^2 A \quad (\text{C.2.0.1.14})$$

$$\implies \frac{a}{R} = 2 \sin A, \quad (\text{C.2.0.1.15})$$

$$\text{or, } \frac{a}{\sin A} = 2R \quad (\text{C.2.0.1.16})$$

2. Show that

$$\cos 2A = 1 - 2 \sin^2 A = 2 \cos^2 A - 1 \quad (\text{C.2.0.2.1})$$

$$= \cos^2 A - \sin^2 A \quad \text{and} \quad (\text{C.2.0.2.2})$$

$$\sin 2A = 2 \sin A \cos A \quad (\text{C.2.0.2.3})$$

3. Find  $R$ .

**Solution:** From (B.2.0.1.1),

$$\text{ar}(\triangle ABC) = \frac{1}{2}bc \sin A = \frac{abc}{4R} \quad (\text{C.2.0.3.1})$$

$$\implies R = \frac{abc}{4s\sqrt{(s-a)(s-b)(s-c)}} \quad (\text{C.2.0.3.2})$$

upon substituting from (C.2.0.1.1) and using Hero's formula.

4. Show that

$$\text{ar}(\triangle OBC) = \frac{1}{2}R^2 \sin 2A \quad (\text{C.2.0.4.1})$$

5. Find the circumradius of  $\triangle ABC$  for  $a = 5, b = 6, c = 4$ .

**Solution:** The following python code calculates the circumradius

`codes/circle/tri_radius.py`

## C.3. Drawing the Circumcircle

1. In Fig. C.1, points **A**, **B**, **C** are at a distance  $R$  from **O**. Trace all such points. The locus of such points is defined as a circle.

**Solution:** This is done by the following python code

```
codes/circle/tri_ccircle.py
```

and the equivalent latex-tikz code to draw Fig. C.2 is

```
figs/triangle/tri_ccircle.tex
```

2. Line segments joining any two points on the circle are defined to be chords. The sides of  $\triangle ABC$  are chords of the circle in (C.2)
3. From (C.1.0.5), it is established that the line segment joining the centre of a circle to the mid point of a chord bisects the chord.
4. From (C.1.0.4), it is clear that the angle subtended by a chord at the centre of the circle is twice the angle subtended at any point on the circle.

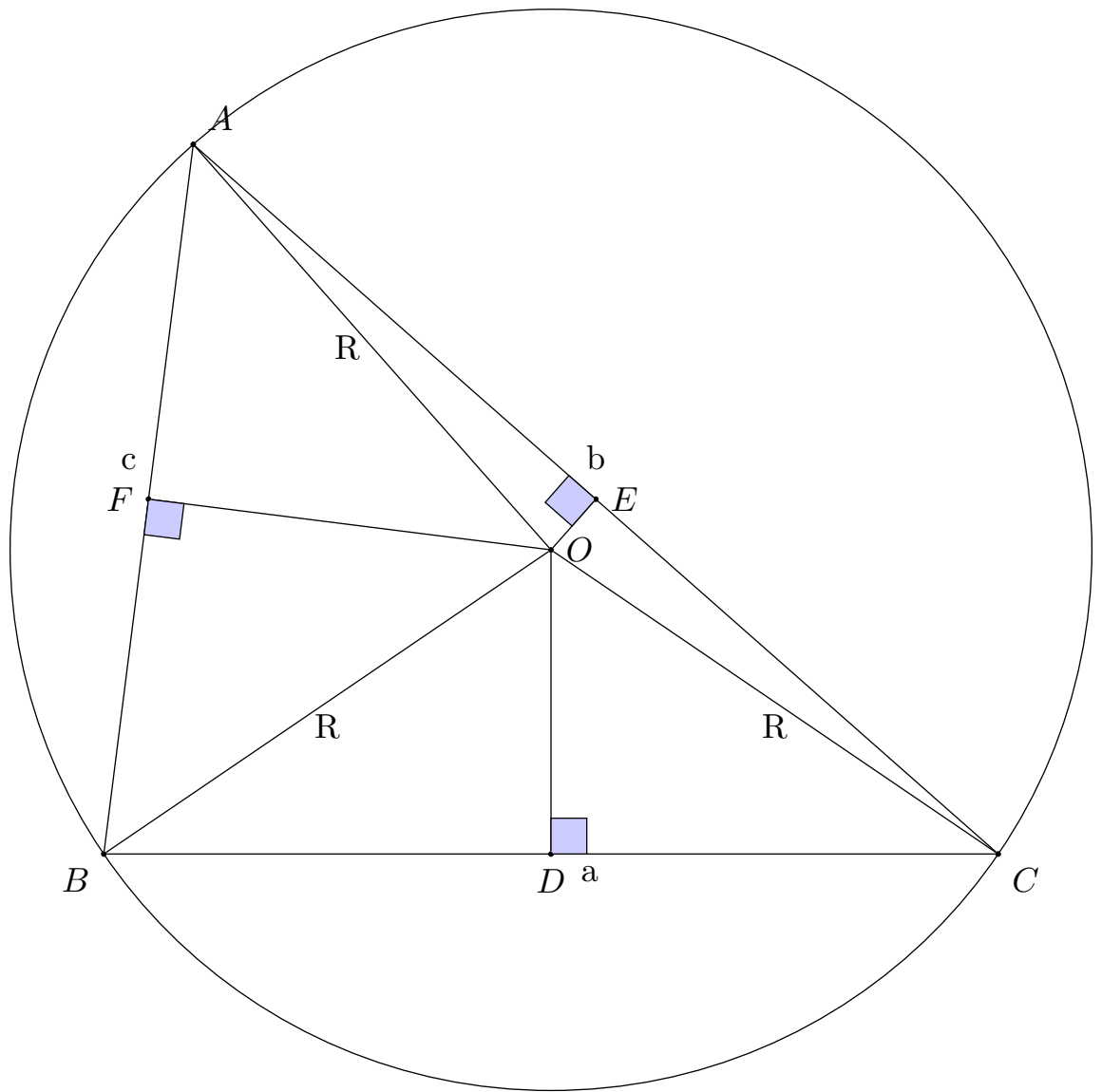


Figure C.2: Circumcircle of  $\triangle ABC$



## Appendix D

### Incentre

#### D.1. Locating the Incentre

1. Find a point **O** that is equidistant from the sides of  $\triangle ABC$  for  $a = 5, b = 6, c = 4$ .

Here, distance means the perpendicular distance. **Solution:** Let **I** be the desired point and **D, E, F** are on  $BC, CA, AB$  such that  $ID \perp BC, IE \perp CA, IF \perp AB$  and  $ID = IE = IF = r$ , then, applying (A.3.0.4.1) in  $\triangle IDB$  and  $IEB$ ,

$$\begin{aligned} IB^2 &= ID^2 + BD^2 = r^2 + BD^2 \\ IB^2 &= IF^2 + BF^2 = r^2 + BF^2 \end{aligned} \tag{D.1.0.1.1}$$

From the above, it is obvious that  $BD = BF$ . Similarly,  $AE = AF, CD = CF$ . Denoting these lengths as  $x, y$  and  $z$ , as shown in Fig. D.1,

$$x + y = ay + z = bx + z = c \tag{D.1.0.1.2}$$



which can be expressed as the matrix equation

$$\begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} a \\ b \\ c \end{pmatrix} \quad (\text{D.1.0.1.3})$$

Section formula can be used to compute

$$\mathbf{D} = \frac{x\mathbf{C} + y\mathbf{B}}{x + y} \quad (\text{D.1.0.1.4})$$

$$\mathbf{E} = \frac{y\mathbf{A} + z\mathbf{C}}{y + z} \quad (\text{D.1.0.1.5})$$

$$\mathbf{F} = \frac{z\mathbf{B} + x\mathbf{A}}{z + x} \quad (\text{D.1.0.1.6})$$

Note that  $\mathbf{I}$  is the circumcentre of  $\triangle DEF$ . Thus, (C.1.0.1.7) can be used to compute

$\mathbf{I}$ . This is done by the python code below

`codes/circle/tri_icentre.py`

and the equivalent latex-tikz code to draw Fig. D.1 is

`figs/circle/tri_icentre.tex`

2.  $r$  is known as the inradius of  $\triangle ABC$ . Find  $r$  for the given values of  $a, b, c$ .

**Solution:** From Fig. D.1

$$\therefore ar(ABC) = ar(IBC) + ar(ICA) + ar(IAB) \quad (\text{D.1.0.2.1})$$

$$= \frac{1}{2}ra + \frac{1}{2}rb + \frac{1}{2}rc = \frac{a + b + c}{2}r, \quad (\text{D.1.0.2.2})$$

$$r = \frac{\sqrt{s(s-a)(s-b)(s-c)}}{s} \quad (\text{D.1.0.2.3})$$

using Hero's formula. The following python code computes the inradius

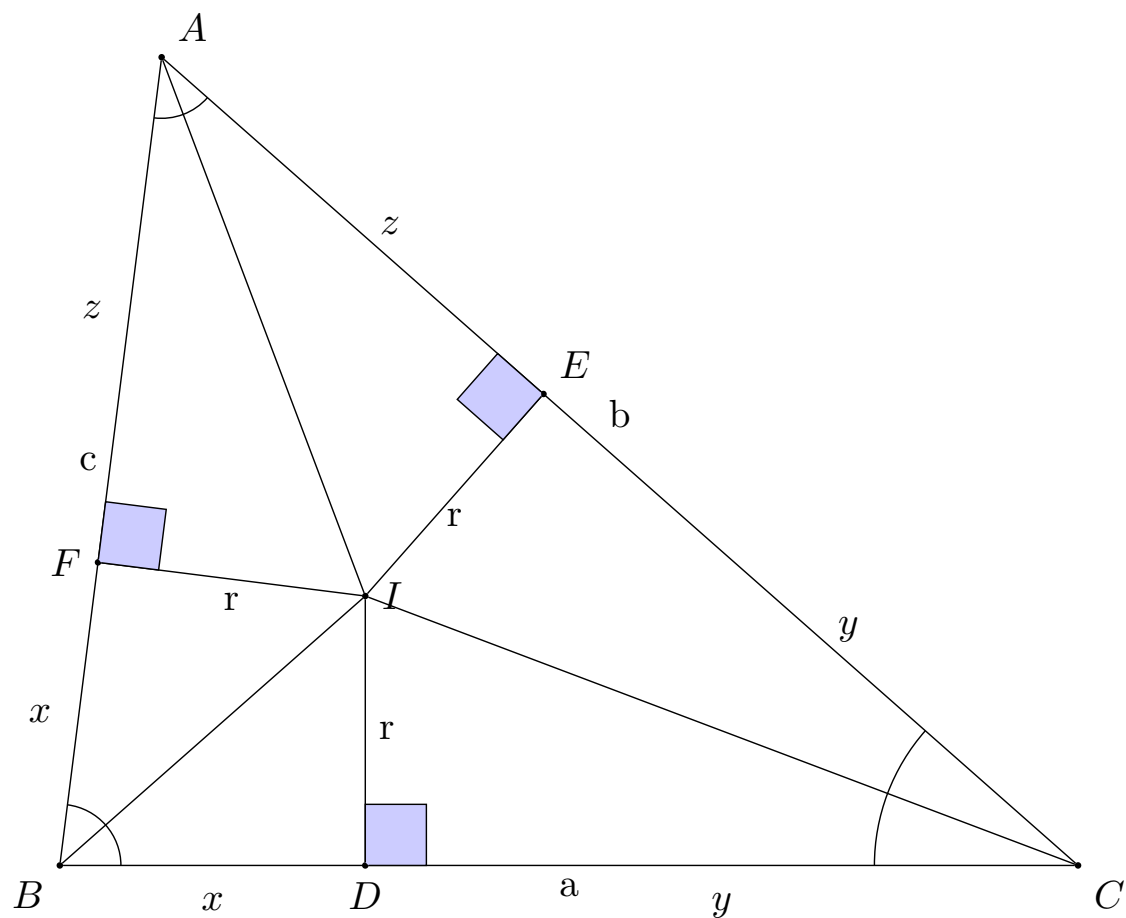


Figure D.1: Incentre  $I$  of  $\triangle ABC$

`codes/circle/tri_iradius.py`

## D.2. Drawing the Incircle

1. In Fig. D.1, points  $D$ ,  $E$ ,  $F$  are at a distance  $r$  from  $I$ . The circle with centre  $I$  through these points is known as the incircle. Draw the incircle of  $\triangle ABC$ .

**Solution:** This is done by the following python code

```
codes/circle/tri_icircle.py
```

and the equivalent latex-tikz code to draw Fig. D.2 is

```
figs/triangle/tri_icircle.tex
```

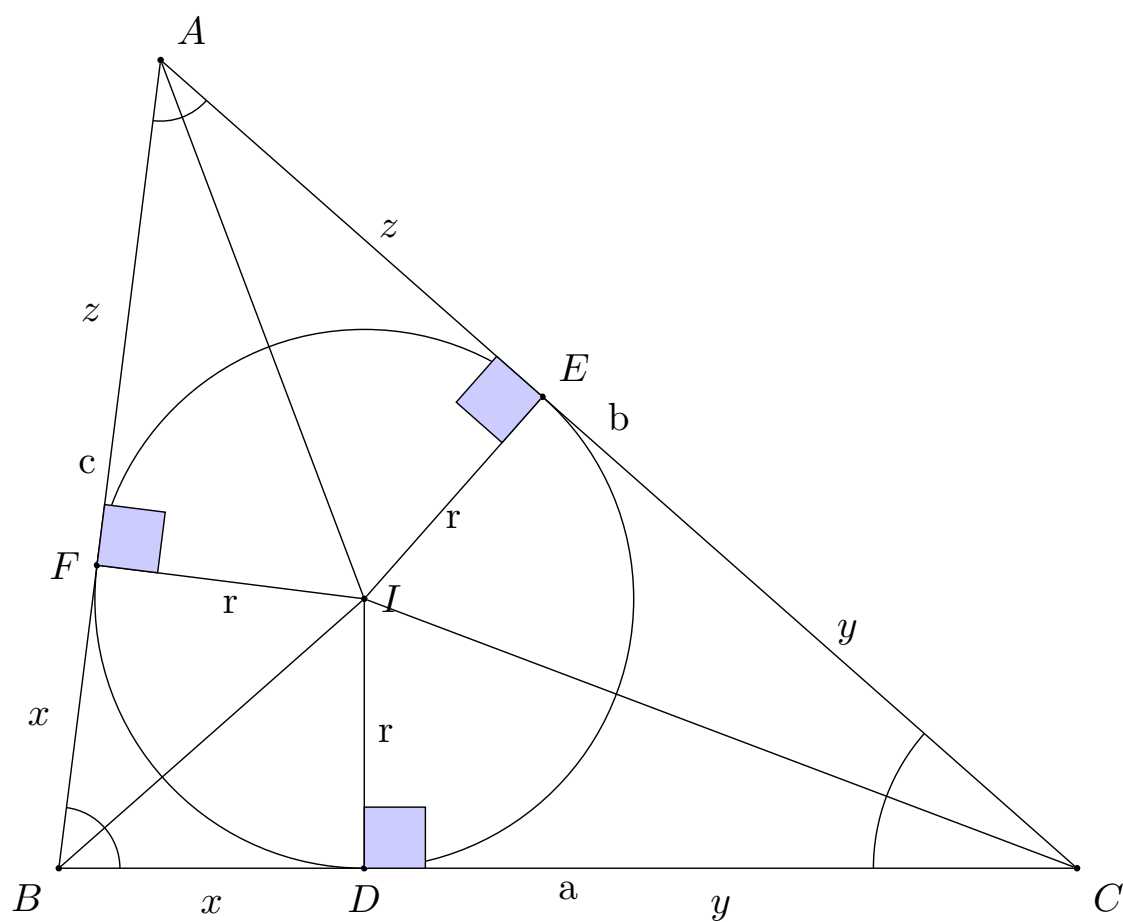


Figure D.2: Circumcircle of  $\triangle ABC$

2. Sides  $AB$ ,  $BC$  and  $CA$  touch the circle at exactly one point. Such lines are known as tangents to the circle.

3. Tangents to the circle are perpendicular to the radius at the point of contact.
4. From (D.1.0.1.1), it is obvious that tangents to the circle from a given point are equal.

## D.3. Congruent Triangles

1. RHS: For two right angled triangles, if the hypotenuse and one of the sides are equal, show that the triangles are congruent.

**Solution:** In  $\triangle IDB$  and  $IFB$  in Fig. D.1,  $ID \perp BC, IF \perp AB, IB$  is a common side and  $ID = IF$ , i.e. both triangles are right angled, have the same hypotenuse and one equal leg. This information was sufficient to show that  $BD = BF$ . Similarly, it can be shown that all angles of both triangles are equal. Such triangles are known as congruent triangles and denoted by  $\triangle IDB \cong \triangle IEB$ .

2. Show that  $IA, IB, IC$  bisect the angles  $A, B$  and  $C$  respectively.
3. Angle bisectors of  $\triangle ABC$  meet at the incentre **I**.
4. To show that two triangles are congruent, it is sufficient to show that some corresponding angles and sides are equal. Sine and cosine formulae are sufficient to show that two triangles are congruent.
5. SSS: Show that if the corresponding sides of three triangles are equal, the triangles are congruent.
6. ASA: Show that if two angles and any one side are equal in corresponding triangles, the triangles are congruent.
7. SAS: Show that if two sides and the angle between them are equal in corresponding triangles, the triangles are congruent.



## Appendix E

# Medians of a Triangle

## E.1. Basic Proportionality Theorem

1. Draw Fig. E.1 with  $a = 5$ ,  $b = 6$  and  $c = 4$ . **E** and **F** are the mid points of  $AC$  and  $AB$  respectively. **Solution:** Using (A.2.0.6.5),

$$\mathbf{E} = \frac{\mathbf{A} + \mathbf{C}}{2} \quad (\text{E.1.0.1.1})$$

$$\mathbf{F} = \frac{\mathbf{A} + \mathbf{B}}{2} \quad (\text{E.1.0.1.2})$$

The latex-tikz code is

`figs/triangle/tri_med_sim.tex`

2. In Fig. E.1,  $BE$  and  $CF$  are the medians. show that  $EF = \frac{a}{2}$ .

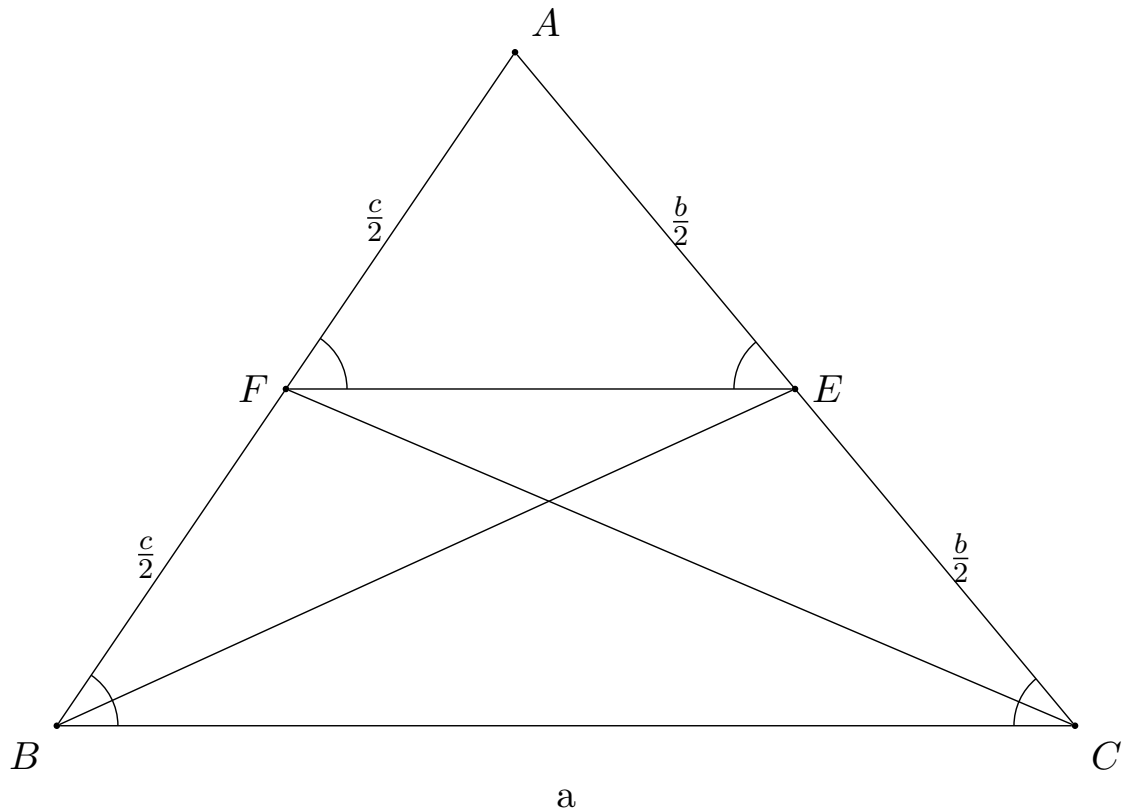


Figure E.1: Similar Triangles

**Solution:** Using the cosine formula for  $\triangle AEF$ ,

$$EF^2 = \left(\frac{b}{2}\right)^2 + \left(\frac{c}{2}\right)^2 - 2\left(\frac{b}{2}\right)\left(\frac{c}{2}\right)\cos A \quad (\text{E.1.0.2.1})$$

$$= \frac{b^2 + c^2 - 2bc \cos A}{4} \quad (\text{E.1.0.2.2})$$

$$= \frac{a^2}{4} \quad (\text{E.1.0.2.3})$$

$$\Rightarrow EF = \frac{a}{2} \quad (\text{E.1.0.2.4})$$

3. The ratio of sides of triangles  $AEF$  and  $ABC$  is the same. Such triangles are known

as similar triangles.

4. Show that similar triangles have the same angles.

**Solution:** Use cosine formula and the proof is trivial.

5. Show that in Fig. E.1,  $EF \parallel BC$ .

**Solution:** Since  $\triangle AEF \sim \triangle ABC$ ,  $\angle AEF = \angle ACB$ . Hence the line  $EF \parallel BC$

6. The line joining the mid points of two sides of a triangle is parallel to the third side.

This is known as the basic proportionality theorem.

## E.2. Similar Triangles

Use the sine and cosine formulae to show that triangles are similar if

1. AAA: all angles are equal
2. SAS: two corresponding sides are in the same ratio and the common angle is equal.
3. SSS: all sides have the same ratio.

## E.3. Centroid

1. In Fig. E.2,  $BE$  and  $CF$  are the medians. Show that  $\triangle GEF \sim \triangle GBC$ .

**Solution:**  $\because EF \parallel BC$ , alternate interior angles are equal. Hence, corresponding angles of both triangles are equal and the triangles are similar.

2. Show that



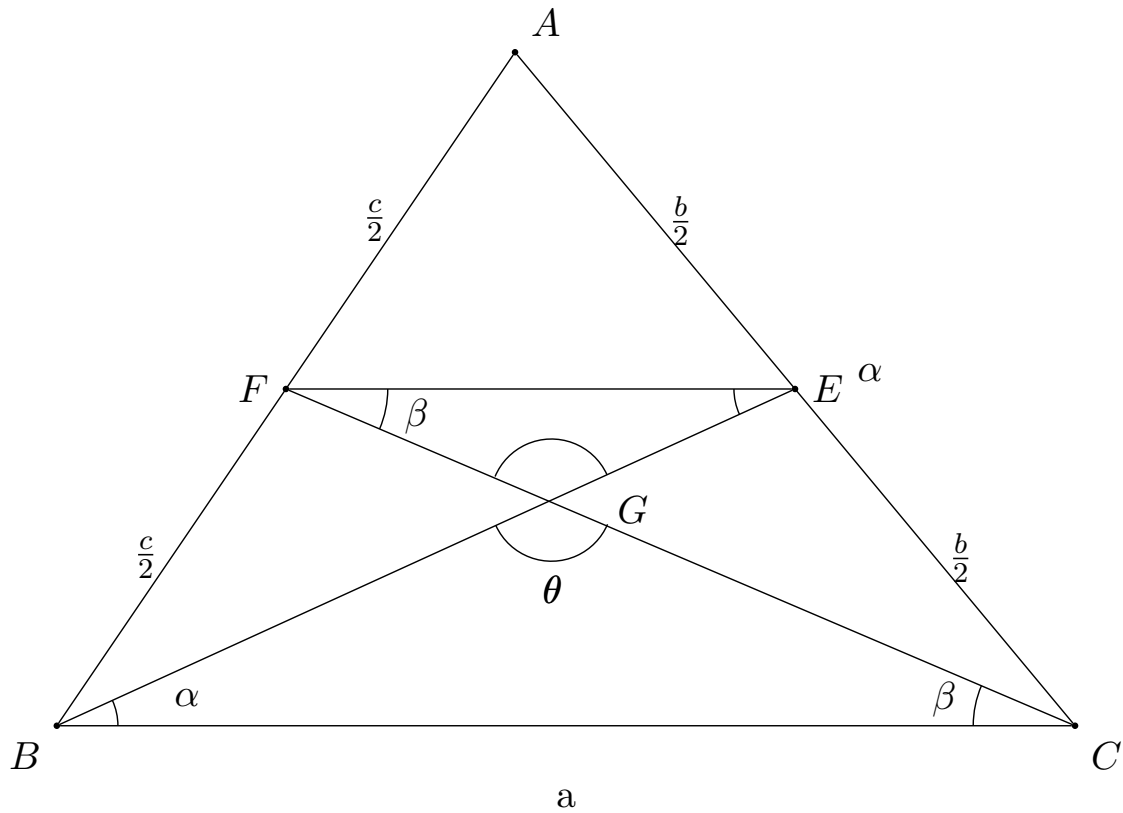


Figure E.2:  $\frac{GB}{GE} = \frac{GC}{GF} = 2$

$$\frac{GB}{GE} = \frac{GC}{GF} = 2 \quad (\text{E.3.0.2.1})$$

**Solution:**  $\because \triangle GEF \sim \triangle GBC$  and  $\frac{EF}{BC} = 2$ , (E.3.0.2.1) follows.

3. In Fig. E.3, AG is extended to meet BC at D. Show that

$$\frac{GA}{GD} = 2 \quad (\text{E.3.0.3.1})$$

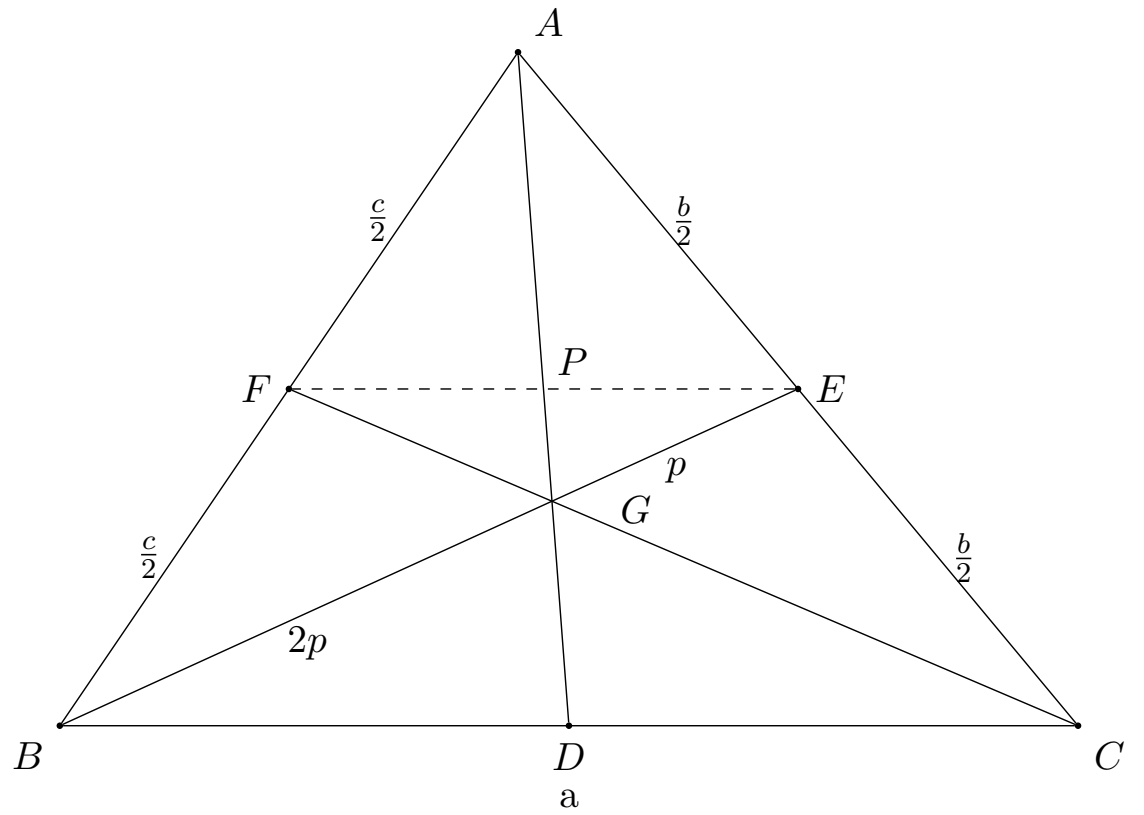


Figure E.3:  $\frac{GA}{GD} = 2$

**Solution:** From Theorem E.1.0.6,  $EF \parallel BC$ . Hence,

$$\triangle APE \sim \triangle ADC \quad (\text{AAA}) \quad (\text{E.3.0.3.2})$$

$$\implies AP = PD = \frac{AD}{2} \quad (\text{E.3.0.3.3})$$

$$\implies AG - GP = GP + GD \quad (\text{E.3.0.3.4})$$

$$\text{or, } GP = \frac{AG - GD}{2} \quad (\text{E.3.0.3.5})$$

Similarly,

$$\triangle PGE \sim \triangle BGD \quad (AAA) \quad (E.3.0.3.6)$$

$$\implies \frac{GP}{GD} = \frac{GE}{GB} = \frac{1}{2} \quad (E.3.0.3.7)$$

$$\text{or, } GP = \frac{GD}{2} \quad (E.3.0.3.8)$$

using (E.3.0.2.1). From (E.3.0.3.5) and (E.3.0.3.8),

$$GP = \frac{GA - GD}{2} = \frac{GD}{2} \quad (E.3.0.3.9)$$

$$\implies \frac{GA}{GD} = 2 \quad (E.3.0.3.10)$$

4. In Fig. E.4,  $BE$  is a median and

$$\frac{GA}{GD} = 2 \quad (E.3.0.4.1)$$

Show that

$$BD = DC \quad (E.3.0.4.2)$$

**Solution:** In Fig. E.4,

$$\triangle GDE \sim \triangle GAB \quad (SAS) \quad (E.3.0.4.3)$$

Hence, all angles of both the above triangles are equal resulting in  $DE \parallel AB$ . As a

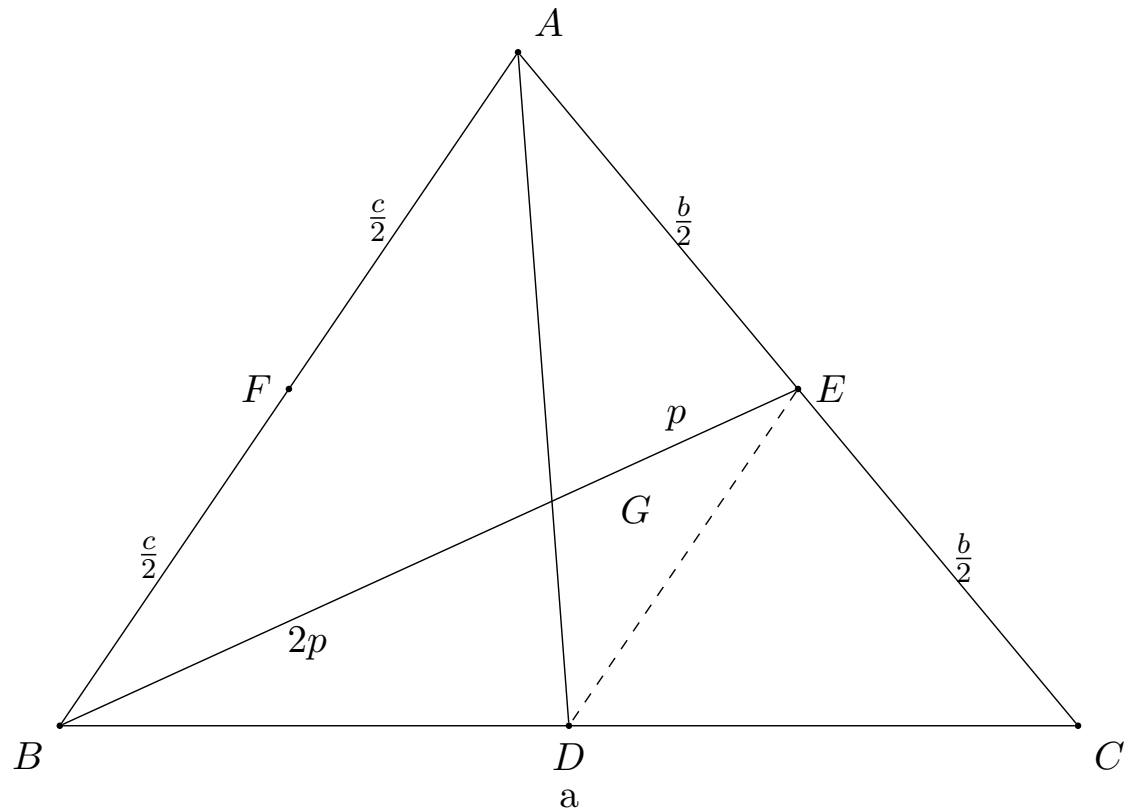


Figure E.4:  $AD$  is also a median.

consequence,

$$\triangle DDE \sim \triangle CAB \quad (AAA) \quad (E.3.0.4.4)$$

resulting in (E.3.0.4.2)

5. Medians of a triangle meet at a point.

6. The centroid divides the median in the ratio  $2 : 1$ .

7. Show that

$$\mathbf{G} = \frac{\mathbf{A} + \mathbf{B} + \mathbf{C}}{3} \quad (\text{E.3.0.7.1})$$

## E.4. Median and Area

1. In Fig. E.2, show that

$$ar(\triangle ABE) = ar(\triangle EBC)$$

$$ar(\triangle AFC) = ar(\triangle BFC) \quad (\text{E.4.0.1.1})$$

$$ar(\triangle BCF) = ar(\triangle EBC)$$

**Solution:** We have

$$ar(\triangle EBC) = \frac{1}{2} \left( \frac{b}{2} \right) a \sin C = \frac{1}{4} ab \sin C \quad (\text{E.4.0.1.2})$$

$$= \frac{1}{2} ar(\triangle ABC) \quad (\text{E.4.0.1.3})$$

$$ar(\triangle BCF) = \frac{1}{2} \left( \frac{c}{2} \right) a \sin B = \frac{1}{4} ac \sin B \quad (\text{E.4.0.1.4})$$

$$= \frac{1}{2} ar(\triangle ABC) \quad (\text{E.4.0.1.5})$$

Using the sine formula,  $b \sin C = c \sin B$  we obtain E.4.0.1.1

2. The median divides a triangle into two triangles that have equal area.

3. Triangles on the same base between two parallel lines have the same area.

## E.5. Parallelogram

1. In Fig. E.5,  $BDEF$  is defined as a parallelogram. Based on the properties of medians and similar triangles, we know that

$$BD \parallel EF, BD = EF \quad (\text{E.5.0.1.1})$$

$$BF \parallel DE, BF = DE \quad (\text{E.5.0.1.2})$$

$$OD = OF, OB = OE \quad (\text{E.5.0.1.3})$$

Hence,

- (a) opposite sides are equal
- (b) opposite angles are equal
- (c) diagonals bisect each other
- (d) Adjacent angles of a parallelogram are supplementary.

2. In Fig. E.5,  $BFEC$  is a quadrilateral with  $EF \parallel BC$  and is known as a trapezium.

3. Sum of the angles of a quadrilateral is  $360^\circ$ .

4. Construct parallelogram  $ABCD$  in Fig. E.6 given that  $BC = 5, AB = 6, \angle C = 85^\circ$ .

**Solution:**  $BD$  is found using the cosine formula and  $\triangle BDC$  is drawn using the approach in Construction B.1.0.8 with

$$\mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 5 \\ 0 \end{pmatrix}, \quad (\text{E.5.0.4.1})$$

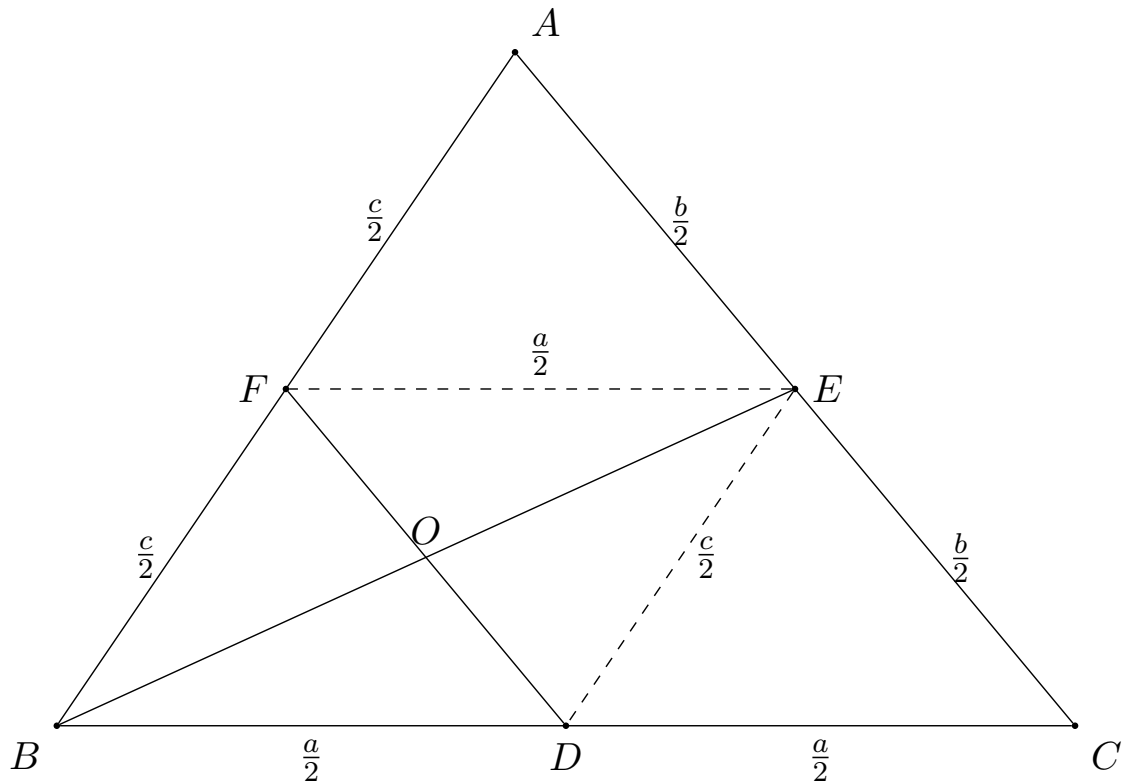


Figure E.5: Parallelogram

Since the diagonals bisect each other,

$$\mathbf{O} = \frac{\mathbf{B} + \mathbf{D}}{2} \quad (\text{E.5.0.4.2})$$

$$\mathbf{A} = 2\mathbf{O} - \mathbf{C}. \quad (\text{E.5.0.4.3})$$

$AB$  and  $AD$  are then joined to complete the ||gm. The python code for Fig. E.6 is

`codes/quad/pgm_sas.py`

and The equivalent latex-tikz code is

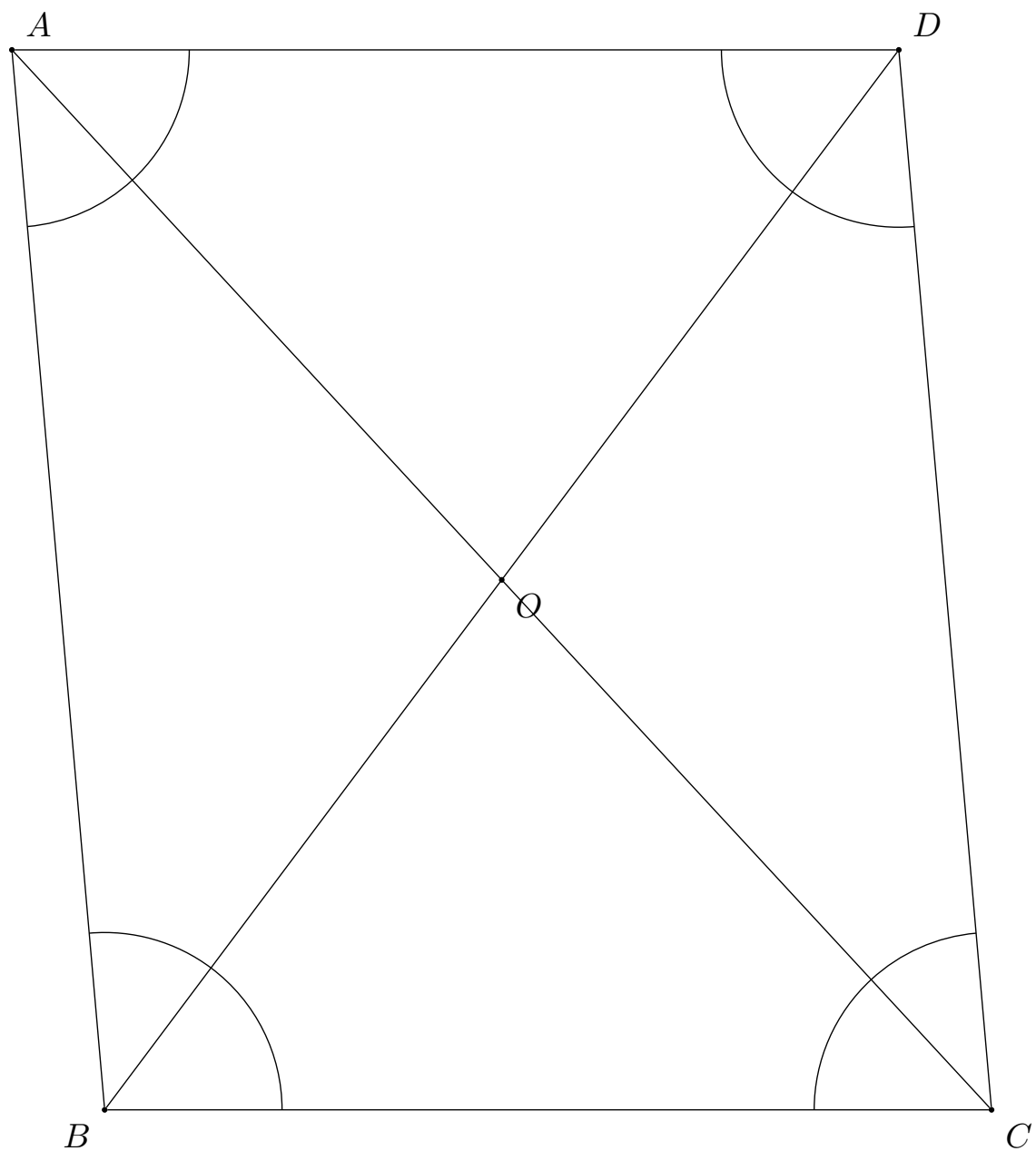


Figure E.6: Parallelogram Properties



figs/quad/pgm\_sas.tex

5. A rectangle is a parallelogram with one right angle.
6. Draw the  $\parallel\text{gm } ABCD$  in Fig. E.7 with  $BC = 6$ ,  $CD = 4.5$  and  $BD = 7.5$ . Show that it is a rectangle.

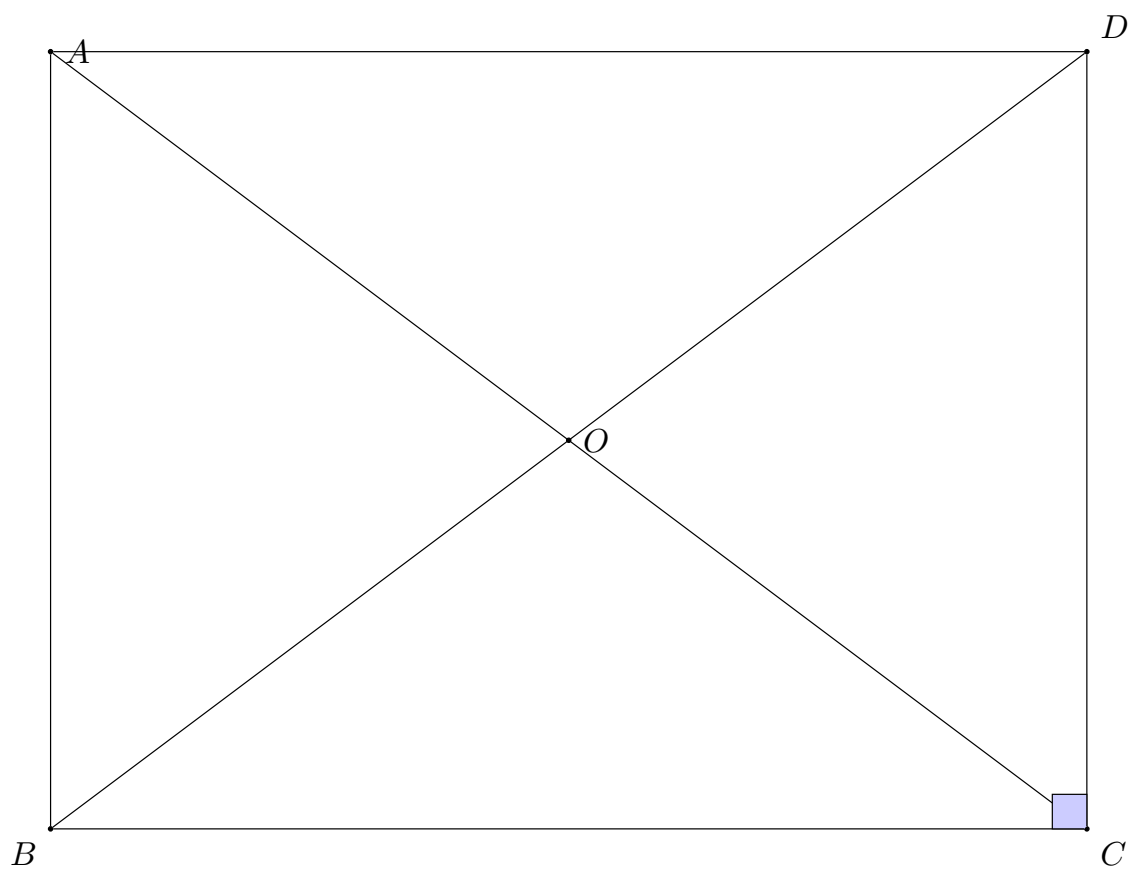


Figure E.7: Rectangle

**Solution:** It is easy to verify that

$$BD^2 = BC^2 + CD^2 \quad (\text{E.5.0.6.1})$$

Hence, using Baudhayana theorem,

$$\angle BCD = 90^\circ \quad (\text{E.5.0.6.2})$$

and  $ABCD$  is a rectangle.

$$\mathbf{A} = \begin{pmatrix} 0 \\ 4.5 \end{pmatrix} \mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \mathbf{C} = \begin{pmatrix} 6 \\ 0 \end{pmatrix} \mathbf{D} = \begin{pmatrix} 6 \\ 4 \end{pmatrix} \quad (\text{E.5.0.6.3})$$

The python code for Fig. E.7 is

`codes/quad/pgm_sss.py`

and the equivalent latex-tikz code is

`figs/quad/pgm_sss.tex`

7. Diagonals of a rectangle are equal and vice-versa.

**Solution:** Follows from the fact that  $\triangle BCD \cong \triangle ABC$ .

8. A rhombus, shown in Fig. E.8 is a parallelogram with equal sides.

9. Diagonals of a rhombus bisect each other at right angles.

**Solution:** In Fig. E.8, from Theorem E.5.0.1,  $OB = OS$ . From Theorem C.1.0.7,  $OE \perp BS$ .

10. Draw the rhombus  $BEST$  with  $BE = 4.5$  and  $ET = 6$ .

**Solution:** The coordinates of the various points in Fig. E.8 are obtained as

$$\mathbf{O} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 0 \\ -4.5 \end{pmatrix} \quad (\text{E.5.0.10.1})$$

$$\mathbf{E} = \begin{pmatrix} 3 \\ 0 \end{pmatrix}, \mathbf{S} = \begin{pmatrix} 4.5 \\ 0 \end{pmatrix}, \mathbf{T} = \begin{pmatrix} 0 \\ -3 \end{pmatrix} \quad (\text{E.5.0.10.2})$$

11. A square is a rectangle whose sides are equal. Draw a square of side 4.5.

**Solution:** The coordinates of the various points in Fig. E.9 are obtained as

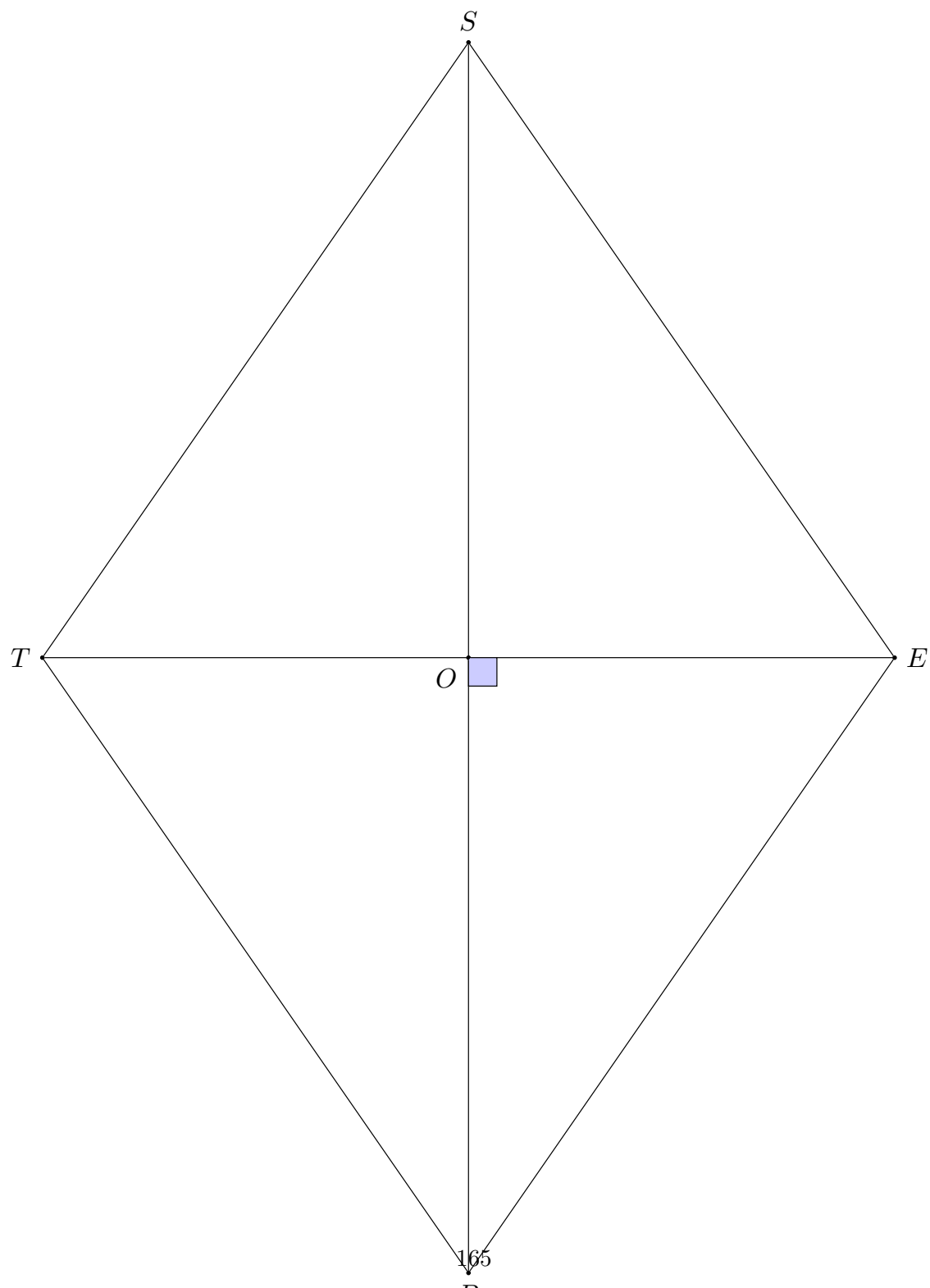
$$\mathbf{A} = \begin{pmatrix} 0 \\ 4.5 \end{pmatrix} \quad (\text{E.5.0.11.1})$$

$$\mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 4.5 \\ 0 \end{pmatrix}, \mathbf{D} = \begin{pmatrix} 4.5 \\ 4.5 \end{pmatrix}, \mathbf{O} = \frac{\mathbf{B} + \mathbf{C}}{2} \quad (\text{E.5.0.11.2})$$

12. Diagonals of a square bisect each other at right angles and are equal, and vice-versa.

**Solution:** A square has the properties of a rectangle as well as a rhombus.

13. Area of a parallelogram is the product of its base and the corresponding altitude.



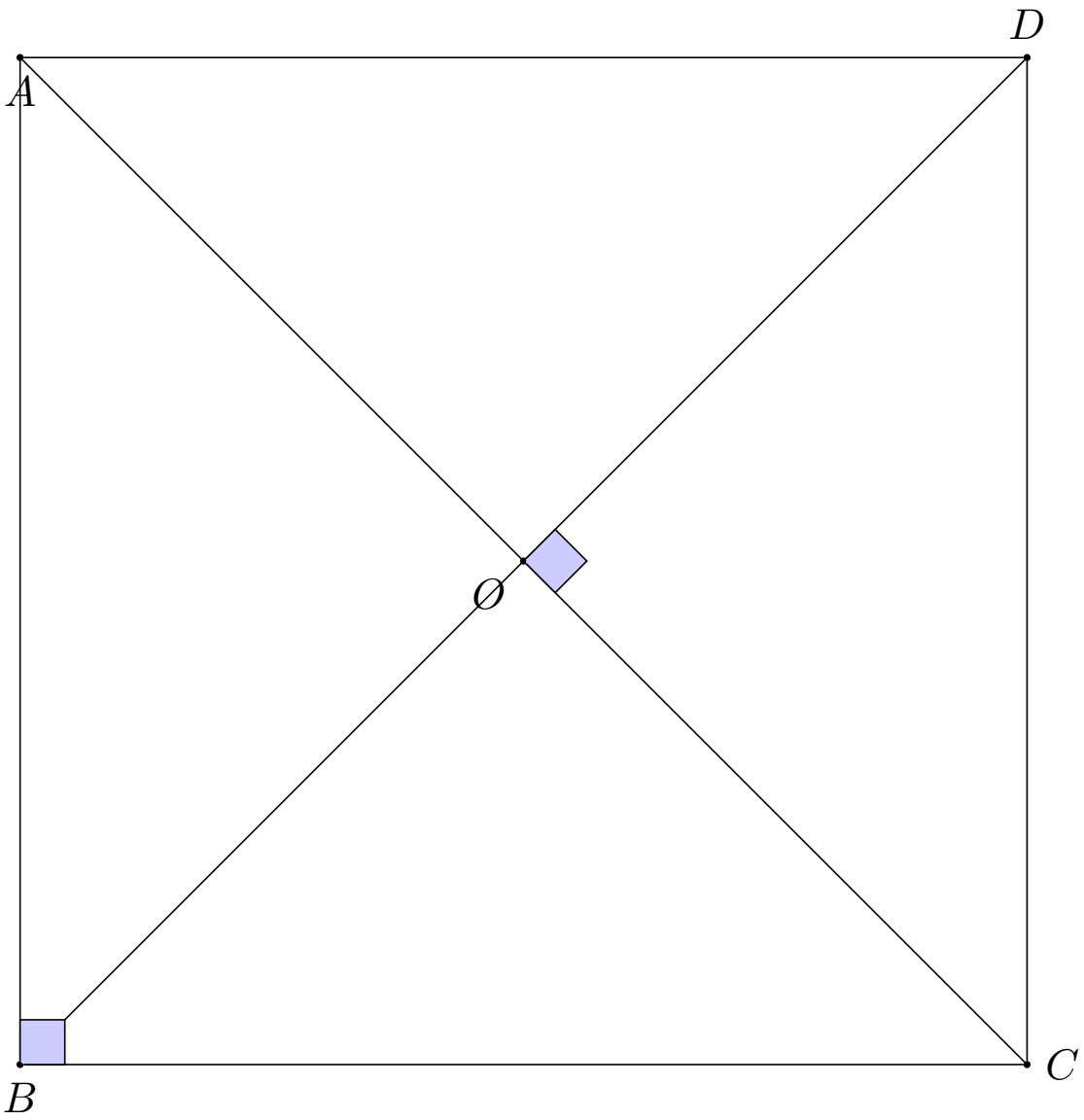


Figure E.9: Square

# Appendix F

## Circles

### F.1. Area of a Circle

1. The diameter of a circle is the chord that divides the circle into two equal parts. The diameter is equal to twice the radius
2. The ratio of the perimeter of a circle to its diameter is  $\pi$ .
3. Radian is a another unit of the angle defined by

$$\pi \text{ radians} = 180^\circ \quad (\text{F.1.0.3.1})$$

4. In Fig. F.1, 6 congruent triangles are arranged in a circular fashion. Such a figure is known as a regular hexagon. In general,  $n$  number of traingles can be arranged to form a regular polygon.
5. The angle formed by each of the congruent triangles at the centre of a regular polygon of  $n$  sides is  $\frac{2\pi}{n} = \frac{2\pi}{n}$  rad.
6. The triangle that forms a polygon of  $n$  sides is given in Fig. F.2. Show that

$$BC = 2r \sin \frac{\pi}{n} \quad (\text{F.1.0.6.1})$$

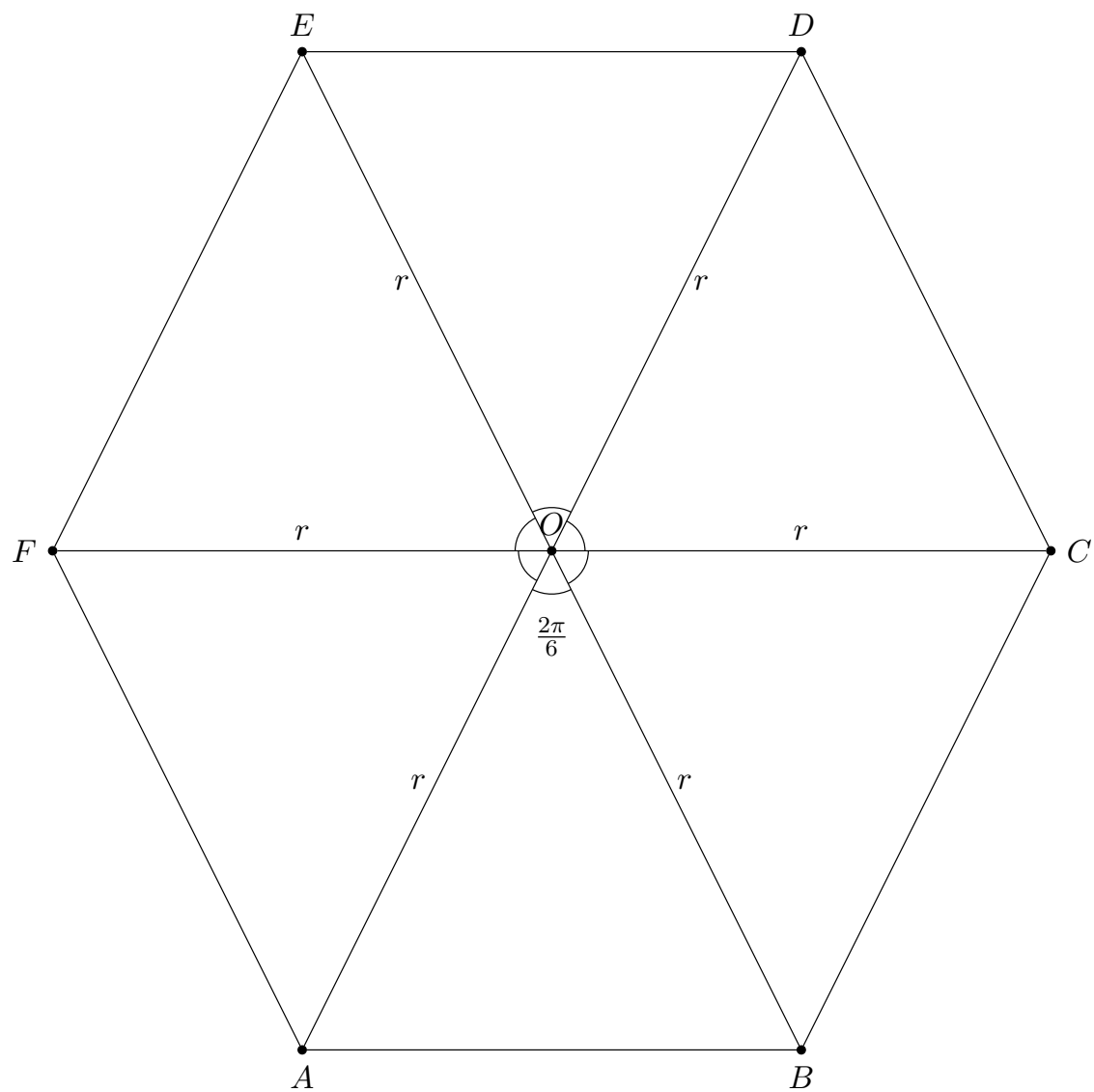


Figure F.1: Polygon Definition

**Solution:** From (C.2.0.1.1).

$$BC = 2r \sin \frac{A}{2} = 2r \sin \frac{\pi}{n} \quad (\text{F.1.0.6.2})$$

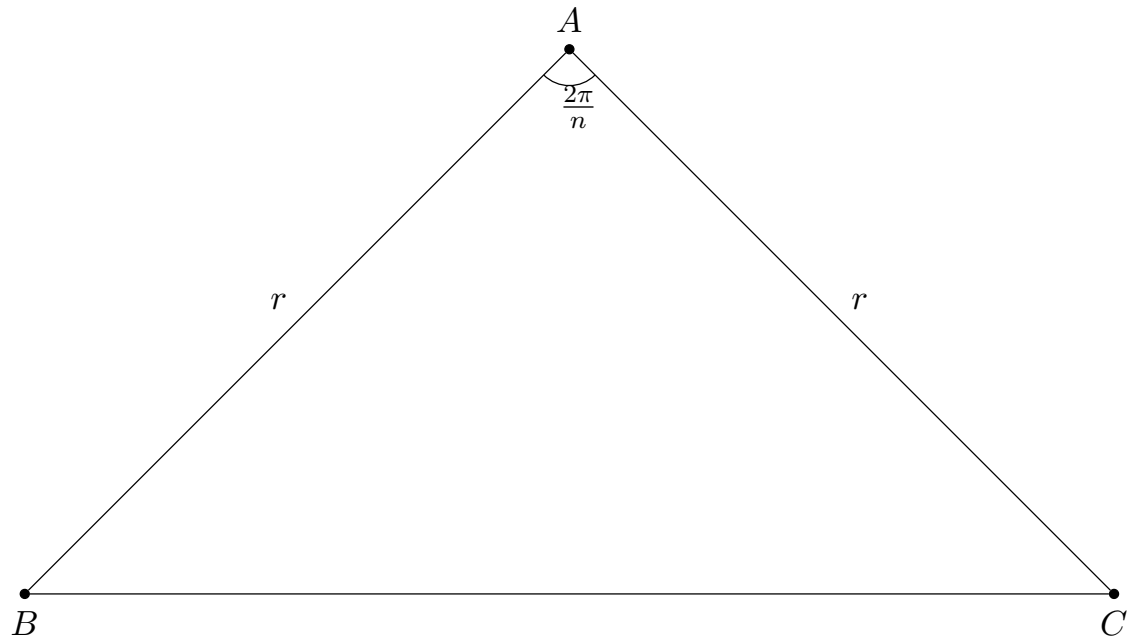


Figure F.2: Triangle that forms a polygon

7. Show that the perimeter of a regular polygon is given by

$$2rn \sin \frac{\pi}{n} \quad (\text{F.1.0.7.1})$$

8. Show that the area of a regular polygon is given by

$$\frac{n}{2} r^2 \sin \frac{2\pi}{n} \quad (\text{F.1.0.8.1})$$

**Solution:** From Fig. F.2



$$\begin{aligned}
ar(\text{polygon}) &= n \times ar(\Delta ABC) \\
&= \frac{n}{2} r^2 \sin \frac{2\pi}{n}
\end{aligned} \tag{F.1.0.8.2}$$

using (C.2.0.4.1)

9. Using Fig. F.3, show that

$$\frac{n}{2} r^2 \sin \frac{2\pi}{n} < \text{area of circle} < nr^2 \tan \frac{\pi}{n} \tag{F.1.0.9.1}$$

The portion of the circle visible in Fig. F.3 is defined to be a sector of the circle.

**Solution:** Note that the circle is squeezed between the inner and outer regular polygons. As we can see from Fig. F.3, the area of the circle should be in between the areas of the inner and outer polygons. Since

$$ar(\Delta OAB) = \frac{1}{2} r^2 \sin \frac{2\pi}{n} \tag{F.1.0.9.2}$$

$$ar(\Delta OPQ) = 2 \times \frac{1}{2} \times r \tan \frac{2\pi/n}{2} \times r \tag{F.1.0.9.3}$$

$$= r^2 \tan \frac{\pi}{n}, \tag{F.1.0.9.4}$$

we obtain (F.1.0.9.1).

10. Show that

$$\cos^2 \frac{\pi}{n} < \frac{\text{area of circle}}{nr^2 \tan \frac{\pi}{n}} < 1 \tag{F.1.0.10.1}$$

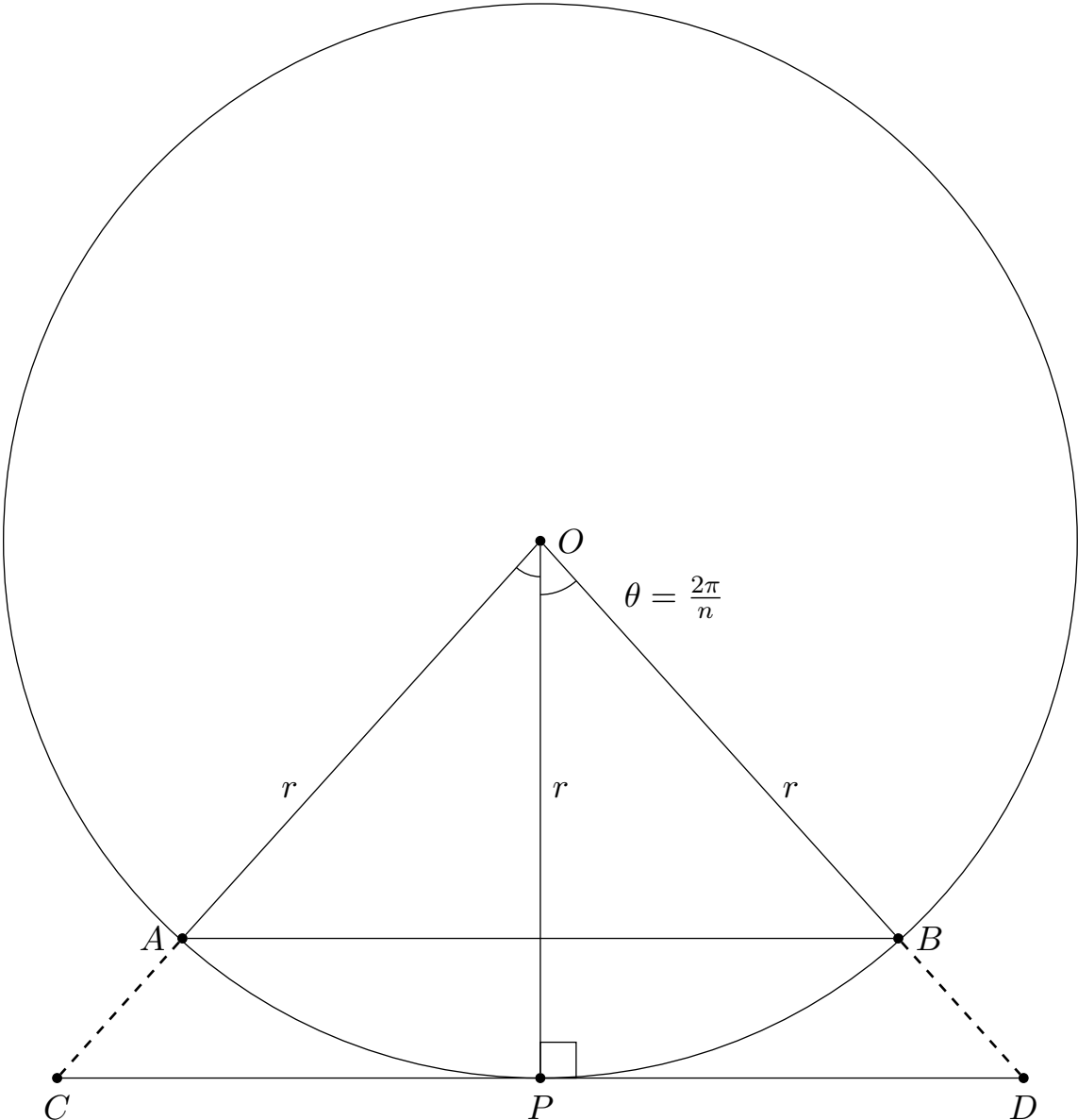


Figure F.3: Circle Area in between Area of Two Polygons

**Solution:** From (F.1.0.9.1) and (C.2.0.2.3).

$$\frac{n}{2}r^2 \sin \frac{2\pi}{n} < \text{area of circle} < nr^2 \tan \frac{\pi}{n} \quad (\text{F.1.0.10.2})$$

$$\Rightarrow nr^2 \sin \frac{\pi}{n} \cos \frac{\pi}{n} < \text{area of circle} < nr^2 \tan \frac{\pi}{n} \quad (\text{F.1.0.10.3})$$

which yields (F.1.0.10.1) upon making use of the fact that

$$\frac{\sin \theta}{\cos \theta} = \tan \theta \quad (\text{F.1.0.10.4})$$

11. Show that

$$\cos 0^\circ = 1 \quad (\text{F.1.0.11.1})$$

**Solution:** Follows from the fact that  $\cos 0^\circ = \sin(90^\circ - 0^\circ) = \sin(90^\circ) = 1$  using (B.2.0.2.1) and (A.3.0.1.2).

12. Show that

$$\sin 0^\circ = 0 \quad (\text{F.1.0.12.1})$$

13. Show that for large values of  $n$

$$\cos^2 \frac{\pi}{n} = 1 \quad (\text{F.1.0.13.1})$$

**Solution:** As  $n \rightarrow \infty$ ,  $\frac{\pi}{n} \rightarrow 0$ . From (F.1.0.11.1), this yields (F.1.0.13.1).

14. (F.1.0.13.1) is a limit and expressed as

$$\lim_{n \rightarrow \infty} \cos^2 \frac{\pi}{n} = 1 \quad (\text{F.1.0.14.1})$$

15. Show that

$$\text{area of circle} = r^2 \lim_{n \rightarrow \infty} n \tan \frac{\pi}{n} \quad (\text{F.1.0.15.1})$$

**Solution:** From (F.1.0.10.1) and (F.1.0.14.1),

$$\lim_{n \rightarrow \infty} \cos^2 \frac{\pi}{n} < \lim_{n \rightarrow \infty} \frac{\text{area of circle}}{nr^2 \tan \frac{\pi}{n}} < 1 \quad (\text{F.1.0.15.2})$$

$$1 = \lim_{n \rightarrow \infty} \frac{\text{area of circle}}{nr^2 \tan \frac{\pi}{n}} < 1 \quad (\text{F.1.0.15.3})$$

resulting in (F.1.0.15.1).

16. Show that

$$\lim_{n \rightarrow \infty} n \sin \frac{\pi}{n} = \pi \quad (\text{F.1.0.16.1})$$

**Solution:** From (F.1.0.2) and (F.1.0.7.1), the perimeter of the circle is

$$\lim_{n \rightarrow \infty} 2rn \sin \frac{\pi}{n} = 2\pi r \implies \lim_{n \rightarrow \infty} n \sin \frac{\pi}{n} = \pi \quad (\text{F.1.0.16.2})$$

17. Show that

$$\pi = \lim_{n \rightarrow \infty} n \tan \frac{\pi}{n} \quad (\text{F.1.0.17.1})$$

**Solution:** From Fig. (F.3), using the fact that the inner and outer polygons converge into a circle for large  $n$ ,

$$\lim_{n \rightarrow \infty} nCD - nAB = 0 \quad (\text{F.1.0.17.2})$$

$$\implies \lim_{n \rightarrow \infty} 2rn \tan \frac{\pi}{n} - 2rn \sin \frac{\pi}{n} = 0 \quad (\text{F.1.0.17.3})$$

from which, we obtain (F.1.0.17.1) by substituting from (F.1.0.16.1).

18. Show that the area of a circle is  $\pi r^2$ .

**Solution:** Use (F.1.0.17.1) in (F.1.0.15.1).

19. Show that

$$\lim_{\theta \rightarrow 0} \frac{\sin \theta}{\theta} = \lim_{\theta \rightarrow 0} \frac{\tan \theta}{\theta} = 1 \quad (\text{F.1.0.19.1})$$

20. Show that the area of a sector with angle  $\theta$  in radians is  $\frac{1}{2}r^2\theta$ .

## F.2. Miscellaneous Properties

1. In Fig. F.4,  $AB$  is the diameter and passes through the centre  $O$ . show that  $\angle APB = 90^\circ$ .

**Solution:** From Theorem C.3.0.4,

$$\angle APB = \frac{1}{2}\angle AOB = 90^\circ \quad (\text{F.2.0.1.1})$$

2. In right  $\triangle APB$ , right angled at  $\mathbf{P}$ , the median

$$PO = AO = OB \quad (\text{F.2.0.2.1})$$

**Solution:** See Fig. F.4. The median  $PO$  is a radius of the circle.

3. In Fig. F.5, show that

$$PA.PB = PC.PD \quad (\text{F.2.0.3.1})$$

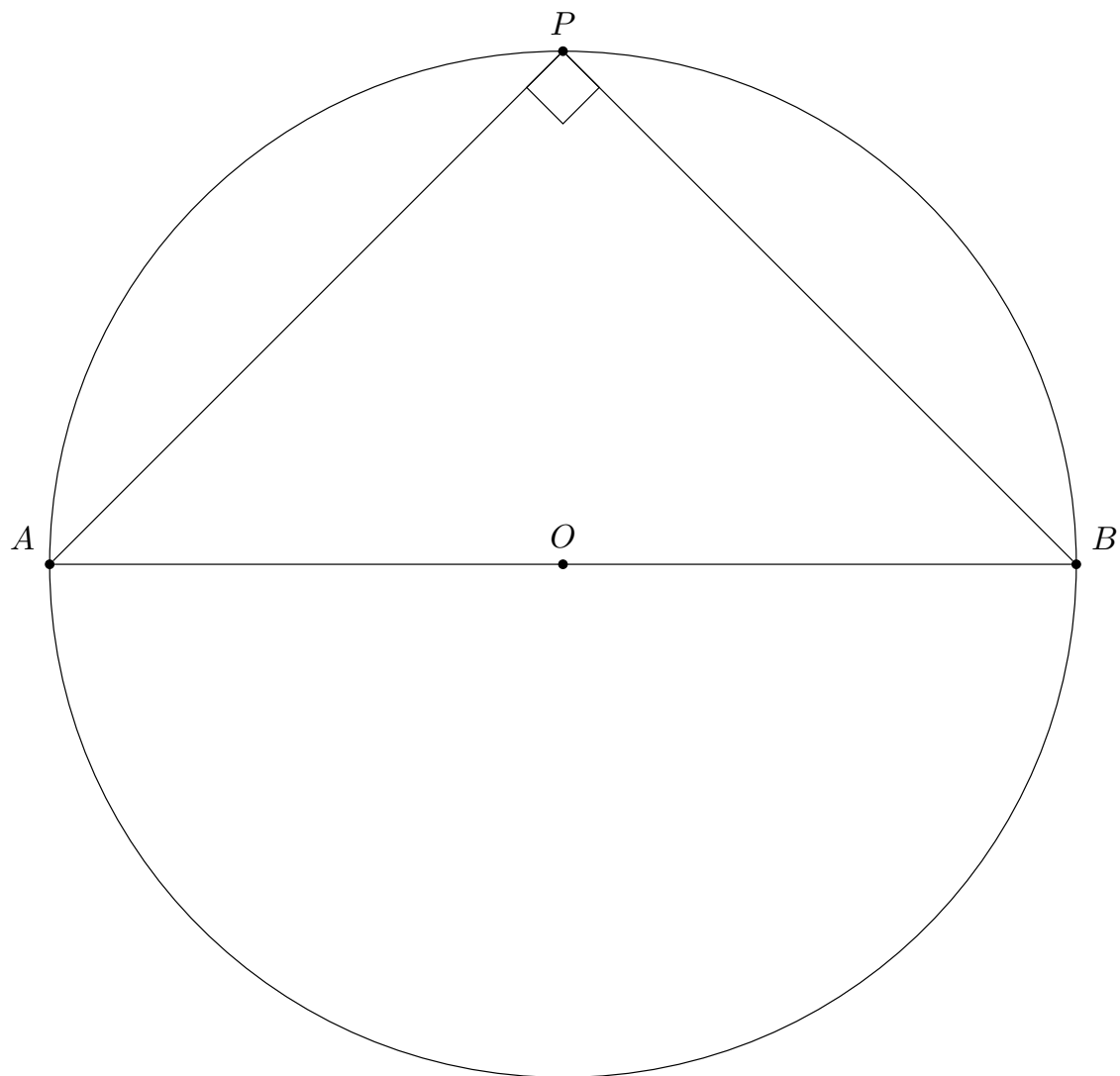


Figure F.4: Diameter of a circle.

**Solution:** From Theorem C.3.0.4,

$$\angle ABD = \angle ACD$$

$$\angle CAB = \angle CDB$$

(F.2.0.3.2)

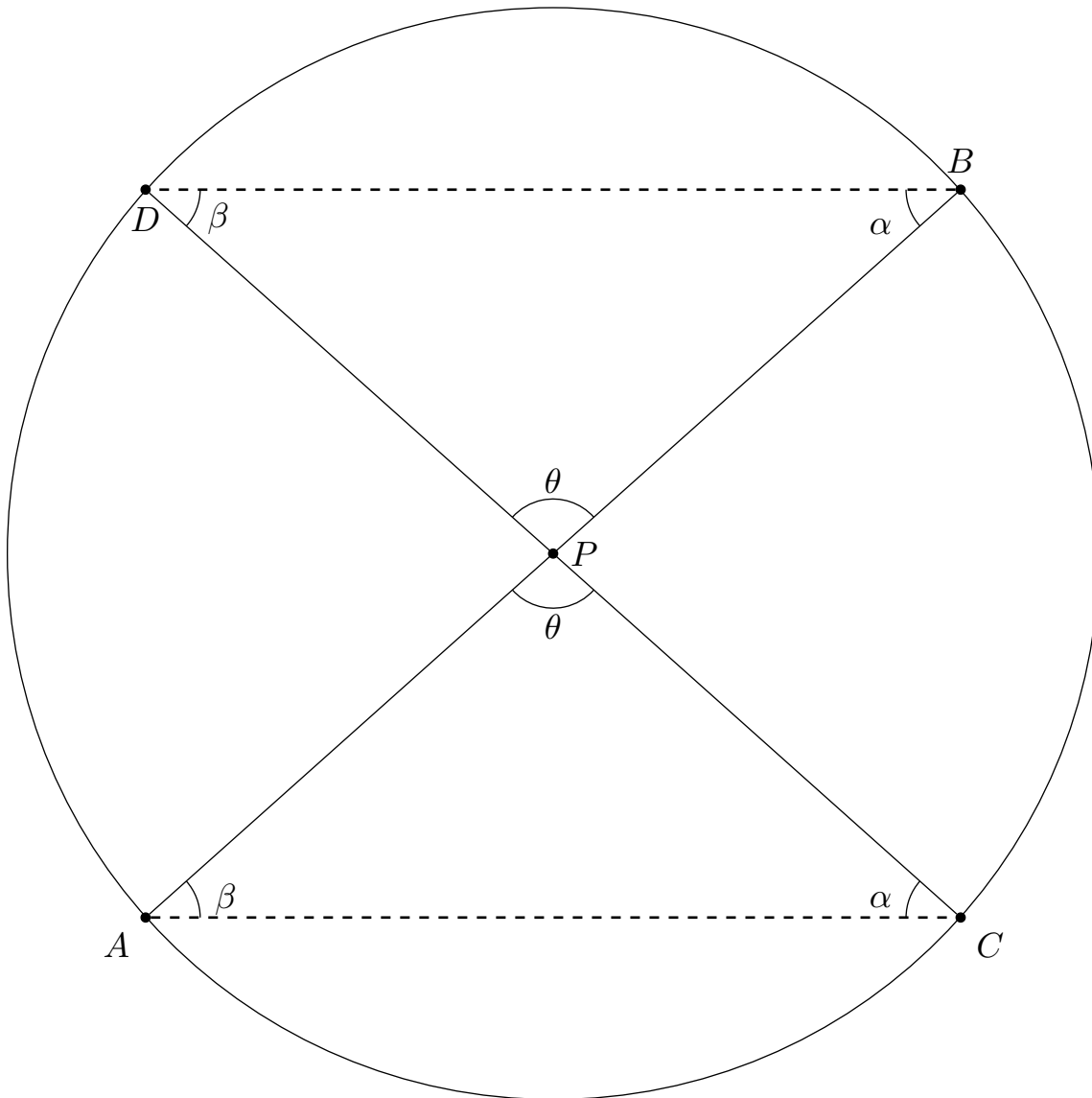


Figure F.5:  $PA.PB = PC.PD$

Hence,

$$\triangle PAC \sim \triangle PBD \quad (AAA) \qquad (F.2.0.3.3)$$

and

$$\frac{PA}{PD} = \frac{PC}{PB} \quad (\text{F.2.0.3.4})$$

$$\implies PA.PB = PC.PD \quad (\text{F.2.0.3.5})$$

4. In Fig. F.6 show that

$$\angle PCA = \angle PBC \quad (\text{F.2.0.4.1})$$

$O$  is the centre of the circle and  $PC$  is the tangent.

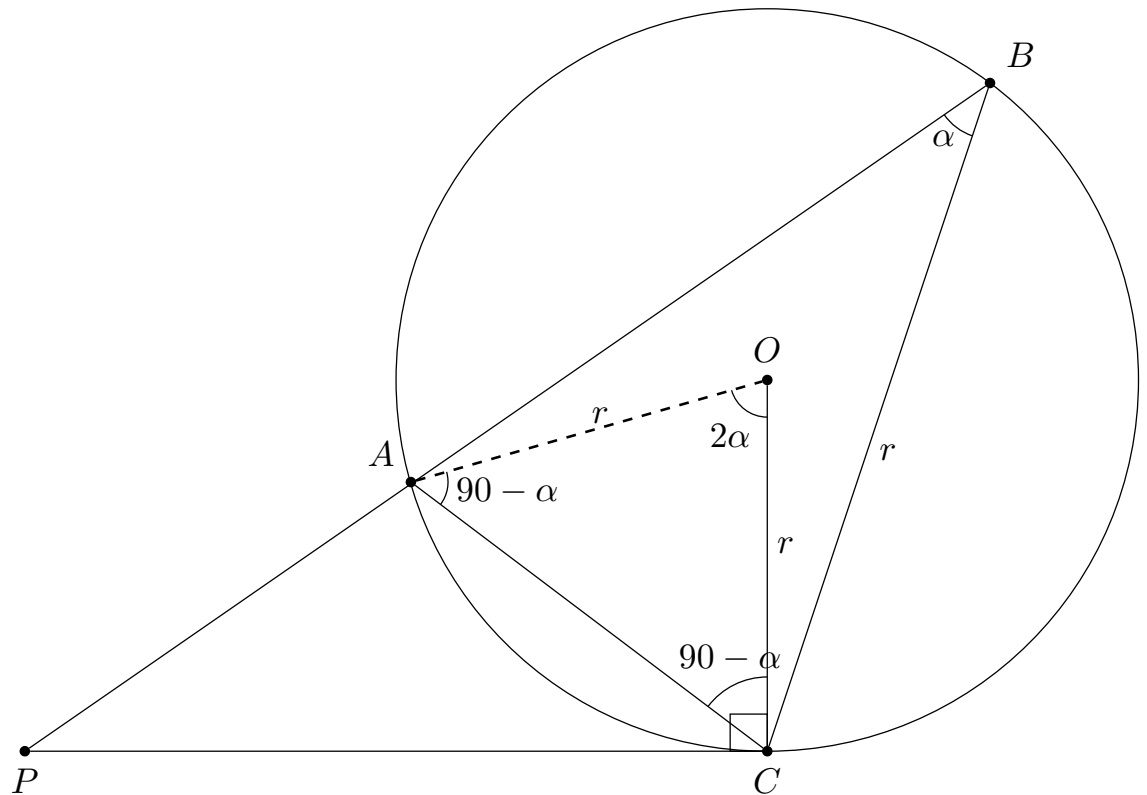


Figure F.6:  $PA.PB = PC^2$ .

**Solution:** Obvious from the figure once we observe that  $\triangle OAC$  is isosceles.



5. In Fig. F.6, show that  $PA.PB = PC^2$ . **Solution:** Using Theorem F.2.0.4,

$$\triangle PAC \sim \triangle PBC \quad (AAA) \quad (F.2.0.5.1)$$

Hence,

$$\frac{PA}{PC} = \frac{PC}{PB} \quad (F.2.0.5.2)$$

$$\implies PA.PB = PC^2 \quad (F.2.0.5.3)$$

6. In Fig. F.7, show that

$$PA.PB = PC.PD \quad (F.2.0.6.1)$$

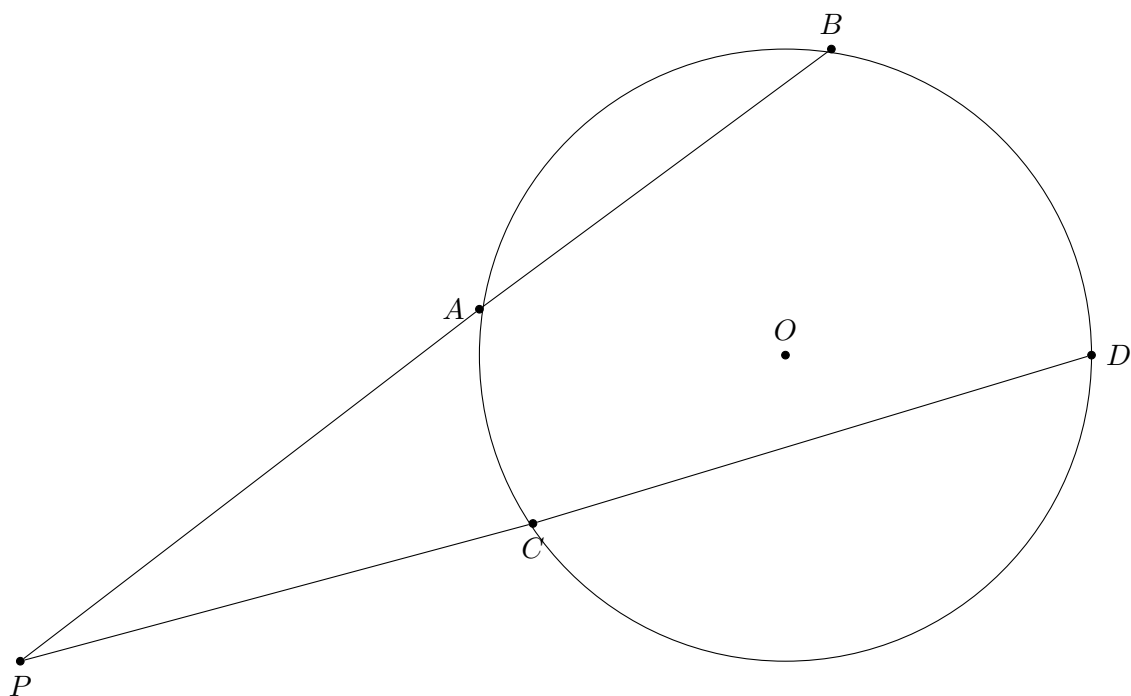


Figure F.7:  $PA.PB = PC^2$ .

**Solution:** From Theorem F.2.0.5, if  $PT$  be a tangent to the circle,

$$PA.PB = PT^2 = PC.PD \quad (\text{F.2.0.6.2})$$



# Appendix G

## Miscellaneous

### G.1. Trigonometric Identities

1. Using Fig. G.1, show that

$$\sin \theta_1 = \sin (\theta_1 + \theta_2) \cos \theta_2 - \cos (\theta_1 + \theta_2) \sin \theta_2 \quad (\text{G.1.0.1.1})$$

**Solution:** The following equations can be obtained from the figure using the formula for the area of a triangle

$$ar(\Delta ABC) = \frac{1}{2}ac \sin (\theta_1 + \theta_2) \quad (\text{G.1.0.1.2})$$

$$= ar(\Delta BDC) + ar(\Delta ADB) \quad (\text{G.1.0.1.3})$$

$$= \frac{1}{2}cl \sin \theta_1 + \frac{1}{2}al \sin \theta_2 \quad (\text{G.1.0.1.4})$$

$$= \frac{1}{2}ac \sin \theta_1 \sec \theta_2 + \frac{1}{2}a^2 \tan \theta_2 \quad (\text{G.1.0.1.5})$$

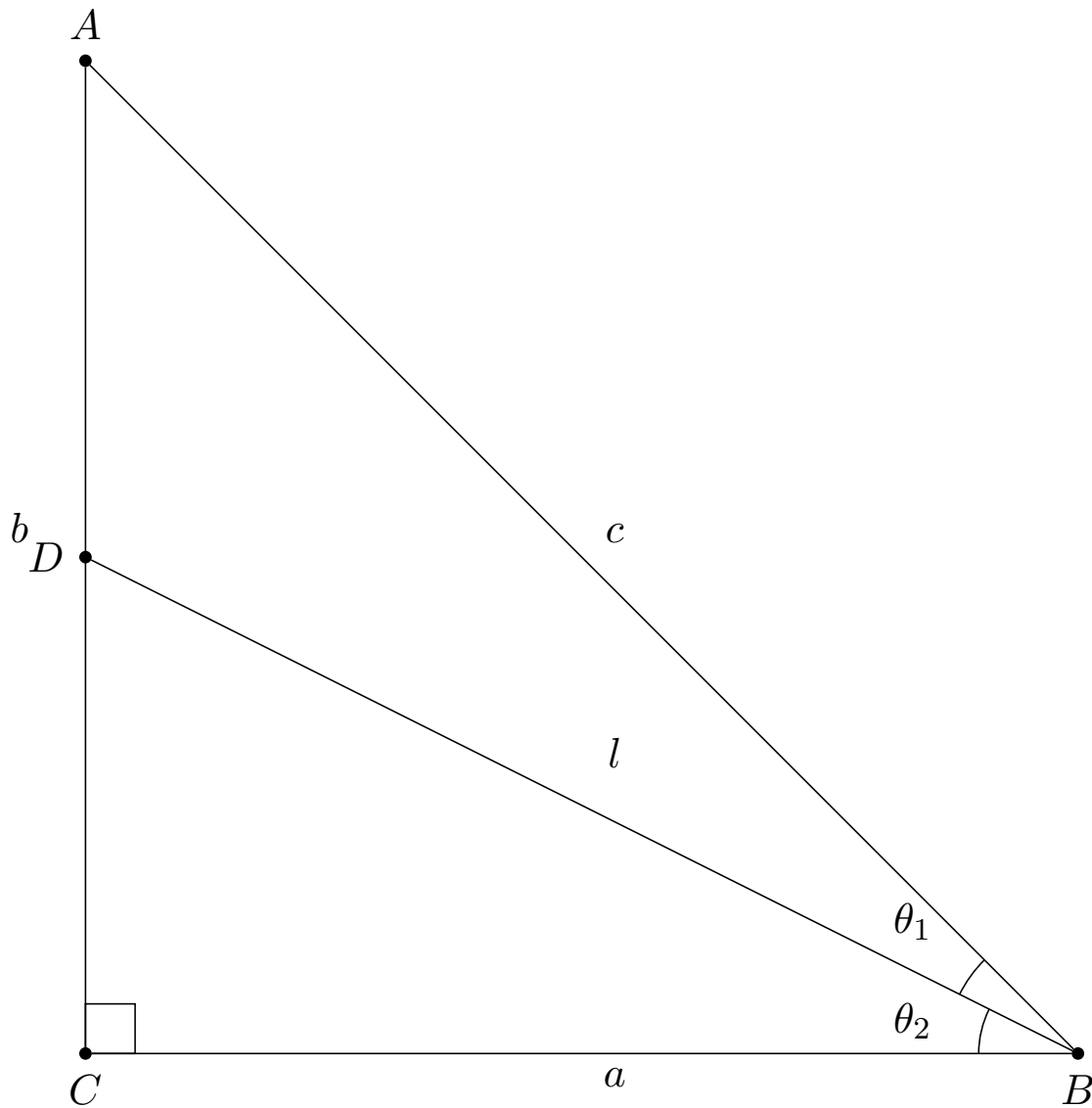


Figure G.1:  $\sin(\theta_1 + \theta_2) = \sin \theta_1 \cos \theta_2 + \cos \theta_1 \sin \theta_2$

( $\because l = a \sec \theta_2$ ). From the above,

$$\implies \sin(\theta_1 + \theta_2) = \sin \theta_1 \sec \theta_2 + \frac{a}{c} \tan \theta_2 \quad (\text{G.1.0.1.6})$$

$$(\text{G.1.0.1.7})$$

$$\begin{aligned}\implies \sin(\theta_1 + \theta_2) &= \sin \theta_1 \sec \theta_2 \\ &\quad + \cos(\theta_1 + \theta_2) \tan \theta_2 \quad (\text{G.1.0.1.8})\end{aligned}$$

Multiplying both sides by  $\cos \theta_2$ ,

$$\begin{aligned}\implies \sin(\theta_1 + \theta_2) \cos \theta_2 &= \sin \theta_1 \\ &\quad + \cos(\theta_1 + \theta_2) \sin \theta_2 \quad (\text{G.1.0.1.9})\end{aligned}$$

resulting in

$$\begin{aligned}\implies \sin \theta_1 &= \sin(\theta_1 + \theta_2) \cos \theta_2 \\ &\quad - \cos(\theta_1 + \theta_2) \sin \theta_2 \quad (\text{G.1.0.1.10})\end{aligned}$$

2. Prove the following identities

(a)

$$\sin(\alpha - \beta) = \sin \alpha \cos \beta - \cos \alpha \sin \beta. \quad (\text{G.1.0.2.1})$$

(b)

$$\cos(\alpha + \beta) = \cos \alpha \cos \beta - \sin \alpha \sin \beta. \quad (\text{G.1.0.2.2})$$

**Solution:** In (G.1.0.1.1), let

$$\begin{aligned}\theta_1 + \theta_2 &= \alpha \\ \theta_2 &= \beta\end{aligned} \quad (\text{G.1.0.2.3})$$

This gives (G.1.0.2.1). In (G.1.0.2.1), replace  $\alpha$  by  $90^\circ - \alpha$ . This results in

$$\begin{aligned}\sin(90^\circ - \alpha - \beta) \\ &= \sin(90^\circ - \alpha) \cos \beta - \cos(90^\circ - \alpha) \sin \beta \\ &\implies \cos(\alpha + \beta) = \cos \alpha \cos \beta - \sin \alpha \sin \beta \quad (\text{G.1.0.2.4})\end{aligned}$$

3. Using (G.1.0.1.1) and (G.1.0.2.2), show that

$$\sin(\theta_1 + \theta_2) = \sin \theta_1 \cos \theta_2 + \cos \theta_1 \sin \theta_2 \quad (\text{G.1.0.3.1})$$

$$\cos(\theta_1 - \theta_2) = \cos \theta_1 \cos \theta_2 + \sin \theta_1 \sin \theta_2 \quad (\text{G.1.0.3.2})$$

**Solution:** From (G.1.0.1.1),

$$\sin(\theta_1 + \theta_2) \cos \theta_2 = \sin \theta_1 \cos \theta_2 + \cos(\theta_1 + \theta_2) \sin \theta_2 \quad (\text{G.1.0.3.3})$$

Using (G.1.0.2.2) in the above,

$$\begin{aligned}\sin(\theta_1 + \theta_2) \cos \theta_2 &= \sin \theta_1 \cos \theta_2 + (\cos \theta_1 \cos \theta_2 \\ &\quad - \sin \theta_1 \sin \theta_2) \sin \theta_2 \quad (\text{G.1.0.3.4})\end{aligned}$$

which can be expressed as

$$\begin{aligned}\sin(\theta_1 + \theta_2) \cos \theta_2 &= \sin \theta_1 \cos \theta_2 \\ &\quad + \cos \theta_1 \cos \theta_2 \sin \theta_2 - \sin \theta_1 \sin^2 \theta_2 \quad (\text{G.1.0.3.5})\end{aligned}$$

Since

$$\sin^2 \theta_2 = 1 - \cos^2 \theta_2, \quad (\text{G.1.0.3.6})$$

we obtain

$$\begin{aligned} \sin(\theta_1 + \theta_2) \cos \theta_2 &= \cos \theta_1 \cos \theta_2 \sin \theta_2 \\ &\quad + \sin \theta_1 \cos^2 \theta_2 \end{aligned} \quad (\text{G.1.0.3.7})$$

resulting in

$$\sin(\theta_1 + \theta_2) = \cos \theta_1 \sin \theta_2 + \sin \theta_1 \cos \theta_2 \quad (\text{G.1.0.3.8})$$

after factoring out  $\cos \theta_2$ . Using a similar approach, (G.1.0.3.2) can also be proved.

4. Show that

$$\sin \theta_1 + \sin \theta_2 = 2 \sin \left( \frac{\theta_1 + \theta_2}{2} \right) \cos \left( \frac{\theta_1 - \theta_2}{2} \right) \quad (\text{G.1.0.4.1})$$

$$\cos \theta_1 + \cos \theta_2 = 2 \cos \left( \frac{\theta_1 + \theta_2}{2} \right) \cos \left( \frac{\theta_1 - \theta_2}{2} \right) \quad (\text{G.1.0.4.2})$$

$$\sin \theta_1 - \sin \theta_2 = 2 \sin \left( \frac{\theta_1 - \theta_2}{2} \right) \cos \left( \frac{\theta_1 + \theta_2}{2} \right) \quad (\text{G.1.0.4.3})$$

$$\cos \theta_1 - \cos \theta_2 = 2 \sin \left( \frac{\theta_1 + \theta_2}{2} \right) \cos \left( \frac{\theta_2 - \theta_1}{2} \right) \quad (\text{G.1.0.4.4})$$

**Solution:** Let

$$\begin{aligned} \theta_1 &= \alpha + \beta \\ \theta_2 &= \alpha - \beta \end{aligned} \quad (\text{G.1.0.4.5})$$



From (G.1.0.3.1),

$$\sin \theta_1 + \sin \theta_2 = \sin (\alpha + \beta) + \sin (\alpha - \beta) \quad (\text{G.1.0.4.6})$$

$$= \sin \alpha \cos \beta + \cos \alpha \sin \beta \quad (\text{G.1.0.4.7})$$

$$+ \sin \alpha \cos \beta - \cos \alpha \sin \beta \quad (\text{G.1.0.4.8})$$

$$= 2 \sin \alpha \cos \beta \quad (\text{G.1.0.4.9})$$

resulting in (G.1.0.4.1)

$$\therefore \alpha = \frac{\theta_1 + \theta_2}{2} \quad (\text{G.1.0.4.10})$$

$$\beta = \frac{\theta_1 - \theta_2}{2} \quad (\text{G.1.0.4.11})$$

from (G.1.0.4.5). Other identities may be proved similarly.

## G.2. Constructions

1. Draw quadrilateral  $ABCD$  with

$$BC = a = 4.5, CD = b = 5.5, AD = c = 4, \quad (\text{G.2.0.1.1})$$

$$AB = d = 6, BD = e = 7 \quad (\text{G.2.0.1.2})$$

**Solution:** The angles  $\theta_1$  and  $\theta_2$  in Fig. G.2 are calculated using the cosine formula as

$$\cos \theta_1 = \frac{a^2 + e^2 - b^2}{2ae} \quad (\text{G.2.0.1.3})$$

$$\cos \theta_2 = \frac{d^2 + e^2 - c^2}{2de} \quad (\text{G.2.0.1.4})$$

The coordinates are then obtained as

$$\mathbf{A} = d \begin{pmatrix} \cos(\theta_1 + \theta_2) \\ \sin(\theta_1 + \theta_2) \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix}, \quad \mathbf{D} = e \begin{pmatrix} \cos \theta_1 \\ \sin \theta_1 \end{pmatrix} \quad (\text{G.2.0.1.5})$$

The python code for Fig. G.2 is available in

`codes/quad/quad_sss.py`

and the equivalent latex-tikz code is

`figs/quad/quad_sss.tex`

2. Fig. G.3 shows that the quadrilateral  $ABCD$  can also be drawn by drawing  $\triangle A_1BD_1$  and rotating it by  $\theta_2$ . Show that

$$\mathbf{D} = \mathbf{PD}_1 \quad (\text{G.2.0.2.1})$$

$$\mathbf{A} = \mathbf{PA}_1 \quad (\text{G.2.0.2.2})$$

where

$$\mathbf{P} = \begin{pmatrix} \cos \theta_2 & -\sin \theta_2 \\ \sin \theta_2 & \cos \theta_2 \end{pmatrix} \quad (\text{G.2.0.2.3})$$

is known as the rotation matrix.

3. Draw  $\triangle ABC$  if  $AB = 3$ ,  $AC = 5$  and  $\angle C = 30^\circ$ .

**Solution:** From the cosine formula,

$$\cos C = \frac{a^2 + b^2 - c^2}{2ab} \quad (\text{G.2.0.3.1})$$

which can be expressed as

$$a^2 - 2ab \cos C + b^2 - c^2 = 0. \quad (\text{G.2.0.3.2})$$

$$\therefore (a - b \cos C)^2 = a^2 + b^2 \cos^2 C - 2ab \cos C, \quad (\text{G.2.0.3.3})$$

(G.2.0.3.2) can be expressed as

$$(a - b \cos C)^2 - b^2 \cos^2 C + b^2 - c^2 = 0 \quad (\text{G.2.0.3.4})$$

$$\implies (a - b \cos C)^2 = b^2 (1 - \cos^2 C) - c^2 \quad (\text{G.2.0.3.5})$$

$$\text{or, } a = b \cos C \pm \sqrt{b^2 (1 - \cos^2 C) - c^2} \quad (\text{G.2.0.3.6})$$

Choose the value(s) for which  $a > 0$ .

4. The solution of a quadratic equation

$$\alpha x^2 + \beta x + \gamma = 0 \quad (\text{G.2.0.4.1})$$

is given by

$$x = \frac{-\beta \pm \sqrt{\beta^2 - 4\alpha\gamma}}{2\alpha}. \quad (\text{G.2.0.4.2})$$

Verify (G.2.0.3.6) using (G.2.0.4.2).

## G.3. Altitudes of a Triangle

1. Draw Fig. G.4, where  $AD$  is the altitude, given that  $a = 6, b = 5, c = 4$ .

**Solution:** Let  $\mathbf{x}$  be any point on  $BC$ . Using section formula, for some  $k$ ,

$$\mathbf{x} = \frac{k\mathbf{C} + \mathbf{B}}{k + 1} = \frac{(k + 1)\mathbf{C} + (\mathbf{B} - \mathbf{C})}{k + 1} \quad (\text{G.3.0.1.1})$$

$$\implies \mathbf{x} = \mathbf{C} + \lambda \mathbf{m} \quad (\text{G.3.0.1.2})$$

where

$$\mathbf{m} = (\mathbf{B} - \mathbf{C}) \lambda = \frac{1}{k + 1} \quad (\text{G.3.0.1.3})$$

Define

$$\mathbf{n} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} \mathbf{m} \quad (\text{G.3.0.1.4})$$

It can be verified that

$$\mathbf{n}^T \mathbf{m} = 0 \quad (\text{G.3.0.1.5})$$

From (G.3.0.1.5) and (G.3.0.1.2),

$$\mathbf{n}^T \mathbf{x} = \mathbf{n}^T \text{vec}C + \lambda \mathbf{n}^T \mathbf{m} \quad (\text{G.3.0.1.6})$$

$$\implies \mathbf{n}^T \mathbf{x} = \mathbf{n}^T \mathbf{C} \quad (\text{G.3.0.1.7})$$

(G.3.0.1.2) and (G.3.0.1.7) are two different representations of the line  $BC$ .  $\mathbf{m}$  is defined to be the direction vector and  $\mathbf{n}$  is the normal vector. Similarly, the equation of the line  $AD$  is obtained as

$$\mathbf{m}^T \mathbf{x} = \mathbf{m}^T \mathbf{A} \quad (\text{G.3.0.1.8})$$

$\therefore \mathbf{D}$  is the intersection of  $AD$  and  $BC$ , from (G.3.0.1.7) and (G.3.0.1.8)

$$\begin{pmatrix} \mathbf{m} & \mathbf{n} \end{pmatrix}^T \mathbf{D} = \begin{pmatrix} \mathbf{m}^T \mathbf{A} \\ \mathbf{n}^T \mathbf{C} \end{pmatrix} \quad (\text{G.3.0.1.9})$$

which can be solved to obtain  $\mathbf{D}$ . The python code for Fig. G.4 is

`codes/triangle/tri_alt.py`

and the equivalent latex-tikz code is

`figs/triangle/tri_alt.tex`

- Let  $\mathbf{H}$  be the intersection of the altitudes  $AD$  and  $BE$  as shown in Fig. G.5.  $CH$  is extended to meet  $AB$  at  $\mathbf{F}$ . Show that  $CF \perp AB$ .

**Solution:** The equations of  $AD$  and  $BE$  are

$$(\mathbf{B} - \mathbf{C})^T (\mathbf{x} - \mathbf{A}) = 0 \quad (\text{G.3.0.2.1})$$

$$(\mathbf{C} - \mathbf{A})^T (\mathbf{x} - \mathbf{B}) = 0 \quad (\text{G.3.0.2.2})$$

$\therefore \mathbf{H}$  lies on both  $AD$  and  $BE$ , it satisfies the above equations, and

$$(\mathbf{B} - \mathbf{C})^T (\mathbf{H} - \mathbf{A}) = 0 \quad (\text{G.3.0.2.3})$$

$$(\mathbf{C} - \mathbf{A})^T (\mathbf{H} - \mathbf{B}) = 0 \quad (\text{G.3.0.2.4})$$

Adding both the above and simplifying,

$$(\mathbf{B} - \mathbf{A})^T (\mathbf{H} - \mathbf{C}) = 0 \quad (\text{G.3.0.2.5})$$

$\implies CH \perp AB$  from Theorem A.3.0.12, or  $CF \perp AB$ . The python code for Fig. G.5 is

`codes/triangle/tri_alt_h.py`

and the equivalent latex-tikz code is

`figs/triangle/tri_alt_h.tex`

3. Altitudes of a  $\triangle$  meet at the orthocentre  $H$ .
4. Find  $\mathbf{H}$ .

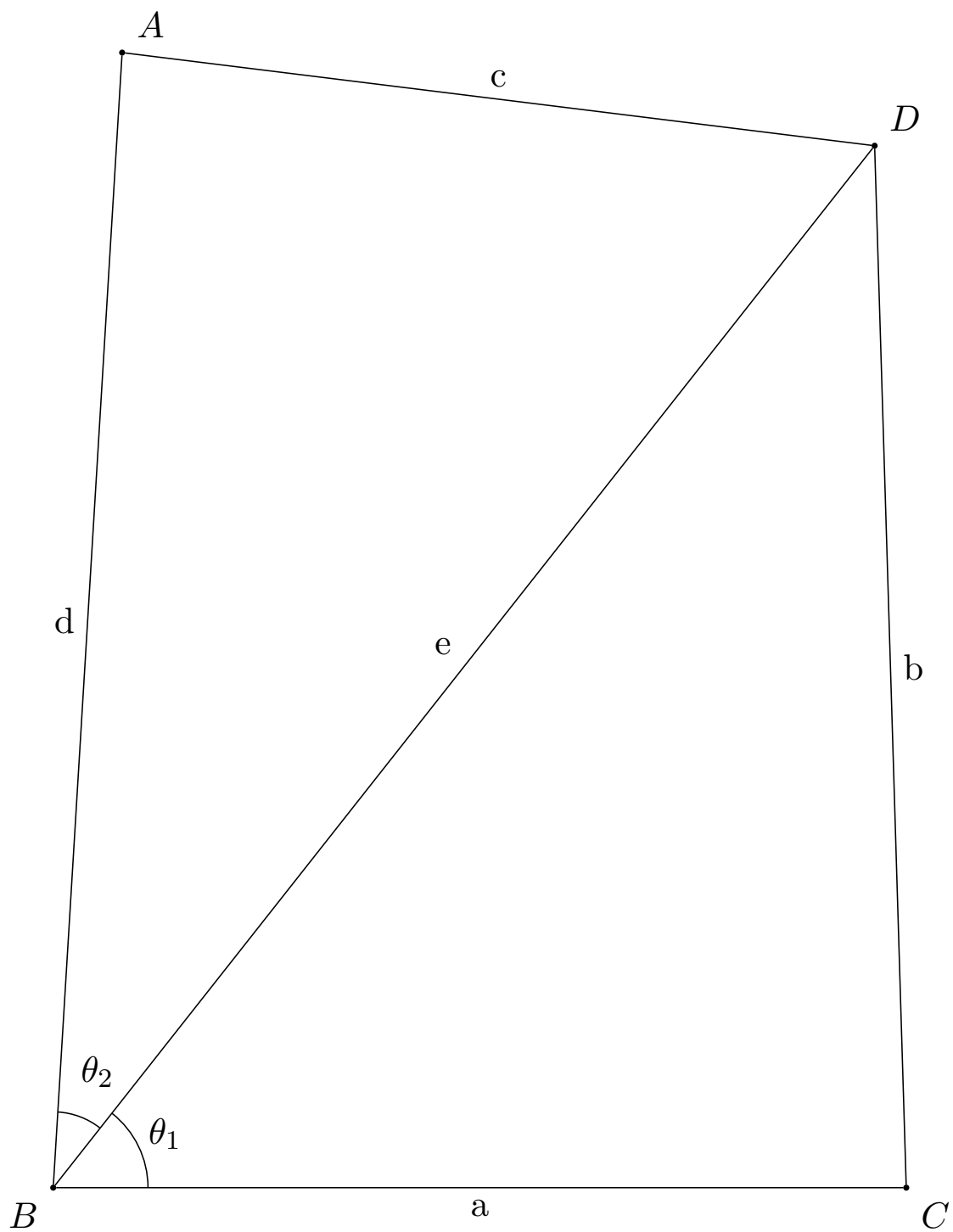


Figure G.2: Drawing a quadrilateral given 4 sides and a diagonal

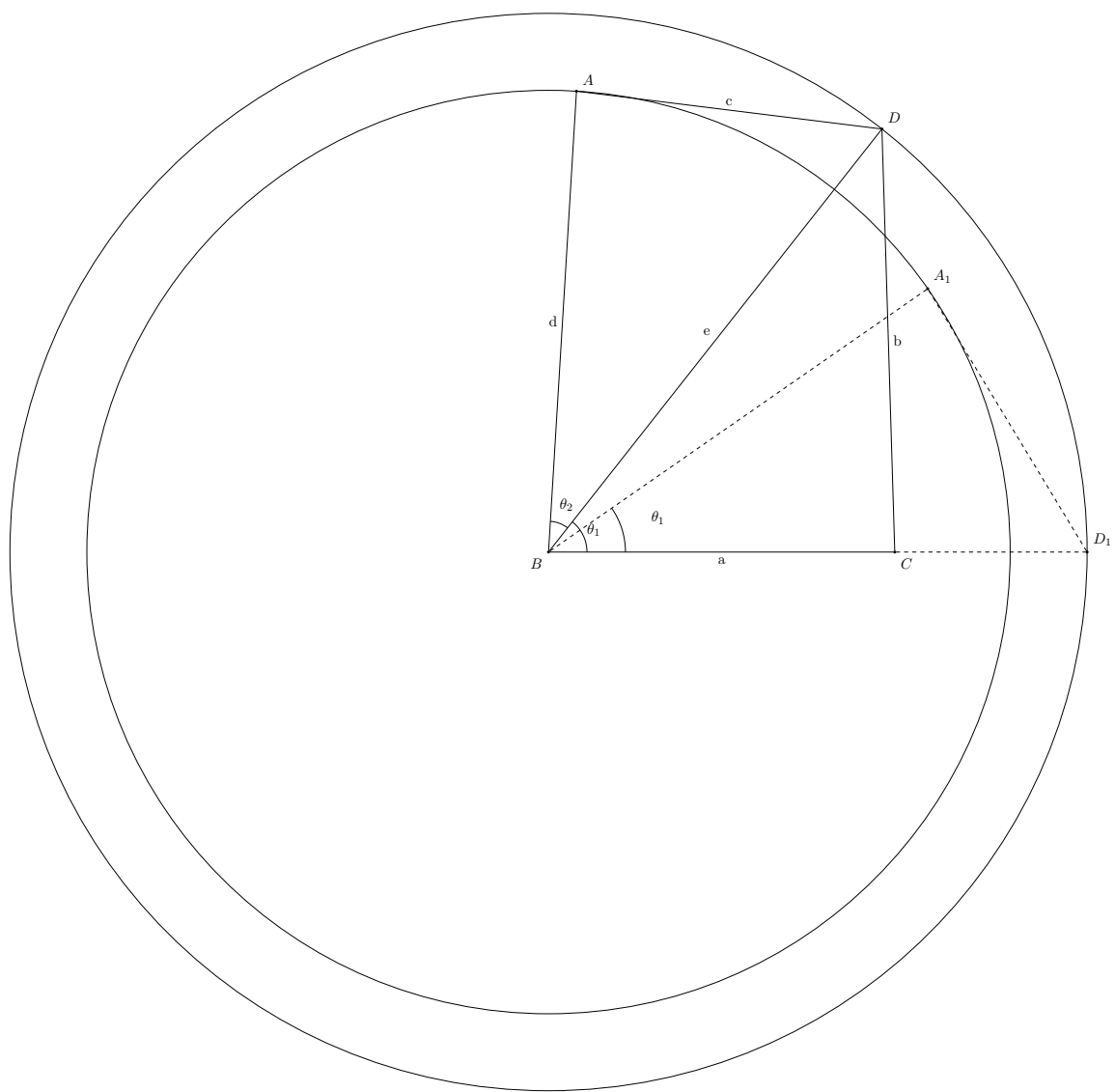


Figure G.3: Drawing a quadrilateral given 4 sides and a diagonal



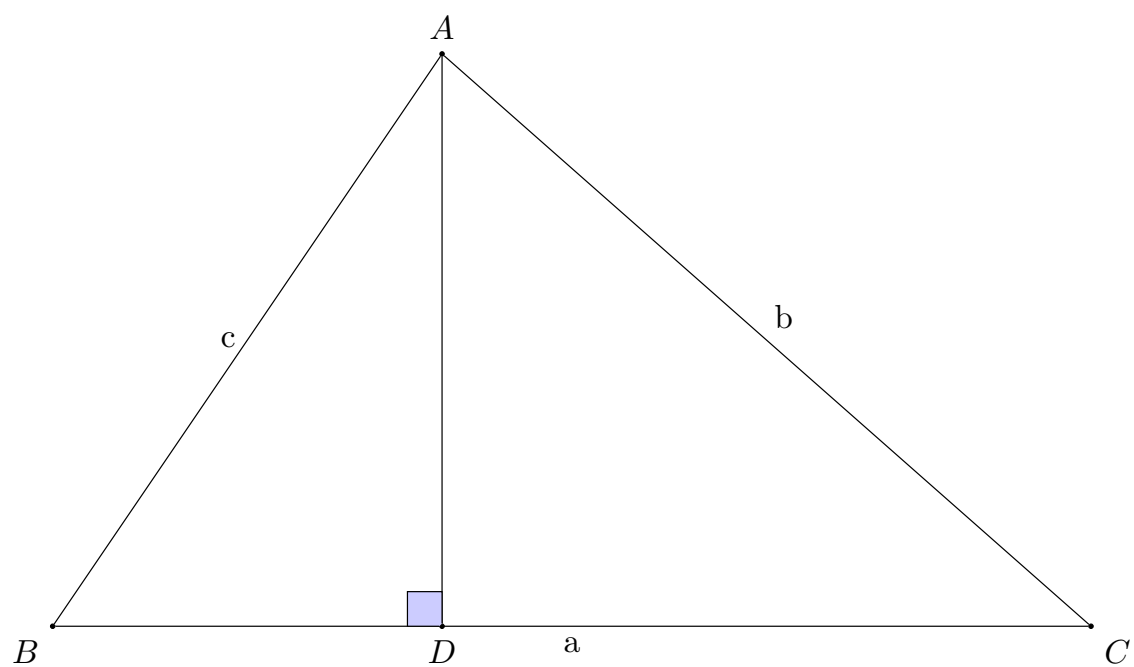


Figure G.4: Drawing the altitude

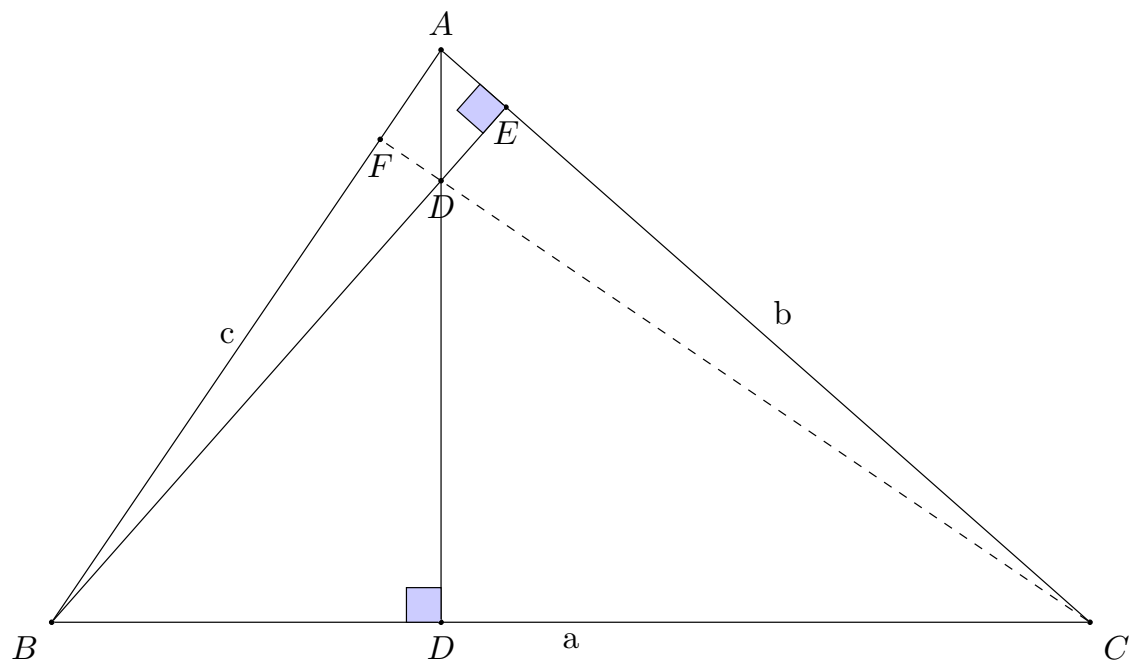


Figure G.5: Altitudes of a triangle meet at the orthocentre  $H$

