Computational Approach to School Mathematics

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Contents

***Abstract*—This book provides a computational approach to school mathematics based on the NCERT textbooks from Class 6-12. Links to sample Python codes are available in the text.**

Download python codes using

```
svn co https://github.com/gadepall/school/trunk/
    ncert/codes
```

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1 Triangle

1.1 Construction Examples

1. Draw $\triangle ABC$ where $\angle B = 90°, a = 4$ and $b = 3$.
   Solution: The vertices of $\triangle ABC$ are

$$\mathbf{A} = \begin{pmatrix} 0 \\ 3 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 4 \\ 0 \end{pmatrix} \tag{1.1.1.1}$$

   The following code plots Fig. 1.1.1

```
codes/triangle/rt_triangle.py
```

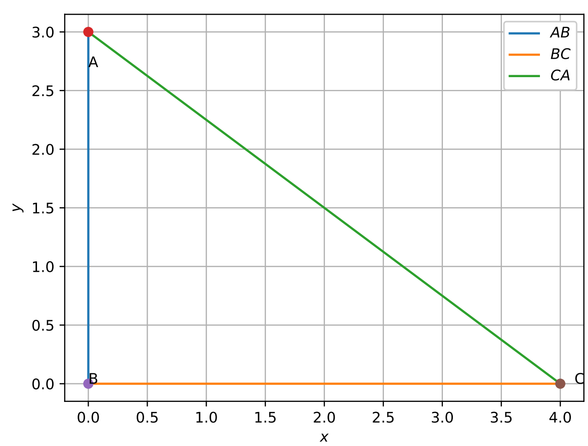

Fig. 1.1.1

2. Construct a triangle of sides $a = 4$, $b = 5$ and $c = 6$.
   Solution: Let the vertices of $\triangle ABC$ be

$$\mathbf{A} = \begin{pmatrix} p \\ q \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} a \\ 0 \end{pmatrix} \tag{1.1.2.1}$$

$$\mathbf{A}^T \triangleq \begin{pmatrix} p & q \end{pmatrix} \tag{1.1.2.2}$$

$$\|\mathbf{A}\|^2 = \mathbf{A}^T\mathbf{A} = \begin{pmatrix} p & q \end{pmatrix}\begin{pmatrix} p \\ q \end{pmatrix} \tag{1.1.2.3}$$

$$= p \times p + q \times q = p^2 + q^2 \tag{1.1.2.4}$$

Then

$$AB \triangleq \|\mathbf{A}-\mathbf{B}\|^2 = \|\mathbf{A}\|^2 = c^2 \quad \because \mathbf{B} = \mathbf{0} \tag{1.1.2.5}$$

$$BC = \|\mathbf{C}-\mathbf{B}\|^2 = \|\mathbf{C}\|^2 = a^2 \tag{1.1.2.6}$$

$$AC = \|\mathbf{A}-\mathbf{C}\|^2 = b^2 \tag{1.1.2.7}$$

From (1.1.2.7),

$$b^2 = \|\mathbf{A}-\mathbf{C}\|^2 = \|\mathbf{A}-\mathbf{C}\|^T \|\mathbf{A}-\mathbf{C}\| \tag{1.1.2.8}$$

$$= \mathbf{A}^T\mathbf{A} + \mathbf{C}^T\mathbf{C} - \mathbf{A}^T\mathbf{C} - \mathbf{C}^T\mathbf{A} \tag{1.1.2.9}$$

$$= \|\mathbf{A}\|^2 + \|\mathbf{C}\|^2 - 2\mathbf{A}^T\mathbf{C} \quad \left(\because \mathbf{A}^T\mathbf{C} = \mathbf{C}^T\mathbf{A}\right) \tag{1.1.2.10}$$

$$= a^2 + c^2 - 2ap \tag{1.1.2.11}$$

yielding

$$p = \frac{a^2 + c^2 - b^2}{2a} \tag{1.1.2.12}$$

From (1.1.2.5),

$$\|\mathbf{A}\|^2 = c^2 = p^2 + q^2 \tag{1.1.2.13}$$

$$\implies q = \pm\sqrt{c^2 - p^2} \tag{1.1.2.14}$$

The following code plots Fig. 1.1.2

```
codes/triangle/draw_triangle.py
```

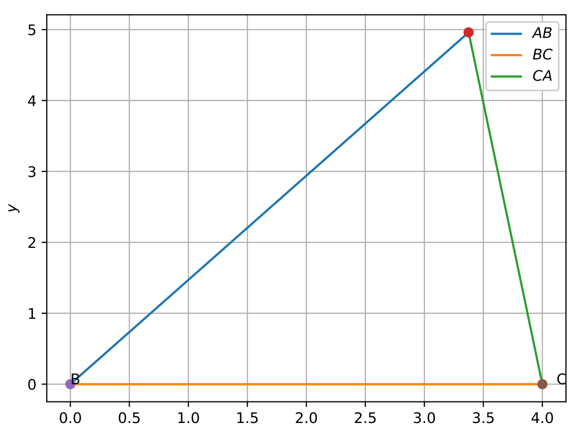

Fig. 1.1.2

3. Construct a triangle of sides $a = 5$, $b = 6$ and $c = 7$. Construct a similar triangle whose sides are $\frac{7}{5}$ times the corresponding sides of the first triangle.
Solution: The sides of the similar triangle are $\frac{7}{5}a, \frac{7}{5}b$ and $\frac{7}{5}c$.

4. Construct an isosceles triangle whose base is $a = 8$cm and altitude $AD = h = 4$cm
Solution: Using Baudhayana's theorem,

$$b = c = \sqrt{h^2 + \left(\frac{a}{2}\right)^2} \tag{1.1.4.1}$$

5. In $\triangle ABC$, given that $a+b+c = 11$, $\angle B = 45^{\circ}$ and $\angle C = 45^{\circ}$, find a, b, c and sketch the triangle.
Solution: From the given information,

$$a + b + c = 11 \tag{1.1.5.1}$$

$$b = c \quad (\because B = C = 45^{\circ}) \tag{1.1.5.2}$$

$$a^2 = b^2 + c^2 \quad (\because A = 90^{\circ}) \tag{1.1.5.3}$$

From (1.1.5.1) and (1.1.5.2),

$$a + 2b = 11 \tag{1.1.5.4}$$

From (1.1.5.2) and (1.1.5.3),

$$a^2 = 2b^2 \implies a - b\sqrt{2} = 0 \tag{1.1.5.5}$$

(1.1.5.4) and (1.1.5.5) can be summarized as the matrix equation

$$\begin{pmatrix} 1 & 2 \\ 1 & -\sqrt{2} \end{pmatrix} \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} 11 \\ 0 \end{pmatrix} \tag{1.1.5.6}$$

which can be solved using Cramer's rule as

$$a = \frac{\begin{vmatrix} 11 & 2 \\ 0 & -\sqrt{2} \end{vmatrix}}{\begin{vmatrix} 1 & 2 \\ 1 & -\sqrt{2} \end{vmatrix}} = \frac{11 \times \left(-\sqrt{2}\right) - 2 \times 0}{1 \times \left(-\sqrt{2}\right) - 2 \times 1} \tag{1.1.5.7}$$

$$= \frac{11\sqrt{2}}{2 + \sqrt{2}} \tag{1.1.5.8}$$

$$b = \frac{\begin{vmatrix} 1 & 11 \\ 1 & 0 \end{vmatrix}}{\begin{vmatrix} 1 & 2 \\ 1 & -\sqrt{2} \end{vmatrix}} = \frac{11}{2 + \sqrt{2}} \tag{1.1.5.9}$$

by expanding the determinants. The following code may be used to compute a, b and c.

```
codes/triangle/triangle_det.py
```

6. Repeat Problem 1.1.5 using a single matrix equation.

Solution: The equations

$$a + 2b = 11 \tag{1.1.6.1}$$
$$a - b\sqrt{2} = 0 \tag{1.1.6.2}$$
$$b - c = 0 \tag{1.1.6.3}$$

can be expressed as a single matrix equation

$$\begin{pmatrix} 1 & 2 & 0 \\ 1 & -\sqrt{2} & 0 \\ 0 & 1 & -1 \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} 11 \\ 0 \\ 0 \end{pmatrix} \tag{1.1.6.4}$$

and can be solved using Cramer's rule as

$$a = \frac{\begin{vmatrix} 11 & 2 & 0 \\ 1 & -\sqrt{2} & 0 \\ 0 & 1 & -1 \end{vmatrix}}{\begin{vmatrix} 0 & 2 & 0 \\ 1 & -\sqrt{2} & 0 \\ 0 & 1 & -1 \end{vmatrix}} \tag{1.1.6.5}$$

$$b = \frac{\begin{vmatrix} 0 & 11 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{vmatrix}}{\begin{vmatrix} 0 & 2 & 0 \\ 1 & -\sqrt{2} & 0 \\ 0 & 1 & -1 \end{vmatrix}} \tag{1.1.6.6}$$

$$c = \frac{\begin{vmatrix} 0 & 2 & 11 \\ 1 & -\sqrt{2} & 0 \\ 0 & 1 & 0 \end{vmatrix}}{\begin{vmatrix} 0 & 2 & 0 \\ 1 & -\sqrt{2} & 0 \\ 0 & 1 & -1 \end{vmatrix}} \tag{1.1.6.7}$$

The determinant

$$\begin{vmatrix} 0 & 2 & 0 \\ 1 & -\sqrt{2} & 0 \\ 0 & 1 & -1 \end{vmatrix} = 0 \times \begin{vmatrix} -\sqrt{2} & 0 \\ 1 & -1 \end{vmatrix} - 2 \times \begin{vmatrix} 1 & 0 \\ 0 & -1 \end{vmatrix} + 0 \times \begin{vmatrix} 1 & -\sqrt{2} \\ 0 & 1 \end{vmatrix} \tag{1.1.6.8}$$

The determinant can also be expressed as

$$\begin{vmatrix} 0 & 2 & 0 \\ 1 & -\sqrt{2} & 0 \\ 0 & 1 & -1 \end{vmatrix} = 0 \times \begin{vmatrix} -\sqrt{2} & 0 \\ 1 & -1 \end{vmatrix} - 1 \times \begin{vmatrix} 2 & 0 \\ 1 & -1 \end{vmatrix} + 0 \times \begin{vmatrix} 2 & 0 \\ -\sqrt{2} & 0 \end{vmatrix} \tag{1.1.6.9}$$

The determinants of larger matrices can be expressed similarly.

7. Draw $\triangle ABC$ with $a = 6, c = 5$ and $\angle B = 60°$.
Solution: In Fig. 1.1.7, $AD \perp BC$.

$$\cos C = \frac{y}{b}, \tag{1.1.7.1}$$
$$\cos B = \frac{x}{b}, \tag{1.1.7.2}$$

Thus,

$$a = x + y = b\cos C + c\cos B, \tag{1.1.7.3}$$
$$b = c\cos A + a\cos C \tag{1.1.7.4}$$
$$c = b\cos A + a\cos B \tag{1.1.7.5}$$

The above equations can be expressed in matrix form as

$$\begin{pmatrix} 0 & c & b \\ c & 0 & a \\ b & a & 0 \end{pmatrix} \begin{pmatrix} \cos A \\ \cos B \\ \cos C \end{pmatrix} = \begin{pmatrix} a \\ b \\ c \end{pmatrix} \tag{1.1.7.6}$$

Using Cramer's rule and determinants,

$$\cos A = \frac{\begin{vmatrix} a & c & b \\ b & 0 & a \\ c & a & 0 \end{vmatrix}}{\begin{vmatrix} 0 & c & b \\ c & 0 & a \\ b & a & 0 \end{vmatrix}} = \frac{ab^2 + ac^2 - a^3}{abc + abc} \tag{1.1.7.7}$$

$$= \frac{b^2 + c^2 - a^2}{2bc} \tag{1.1.7.8}$$

From (1.1.7.8)

$$b^2 = c^2 + a^2 - 2ca\cos B \tag{1.1.7.9}$$

which is computed by the following code

```
codes/triangle/cos_form.py
```

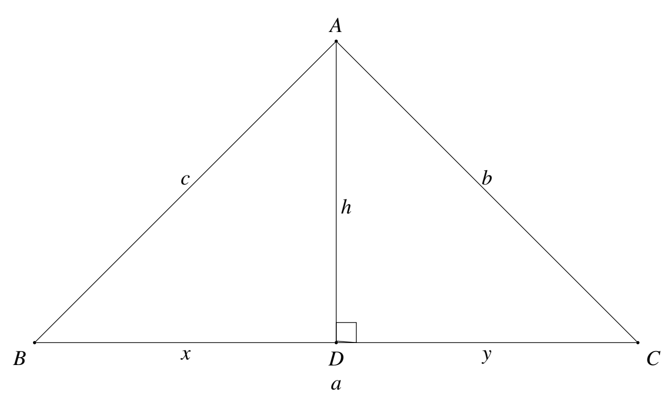

Fig. 1.1.7: The cosine formula

8. Draw $\triangle ABC$ with $a = 7, \angle B = 45°$ and $\angle A = 105°$.
Solution: In Fig. (1.1.7),

$$\sin B = \frac{h}{c} \tag{1.1.8.1}$$

$$\sin C = \frac{h}{b} \tag{1.1.8.2}$$

which can be used to show that

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c} \tag{1.1.8.3}$$

Thus,

$$c = \frac{a \sin C}{\sin A} \tag{1.1.8.4}$$

where

$$C = 180 - A - B \tag{1.1.8.5}$$

9. Draw $\triangle ABC$ if $AB = 3, AC = 5$ and $\angle C = 30°$.
Solution: From (1.1.7.9),

$$\cos C = \frac{a^2 + b^2 - c^2}{2ab} \tag{1.1.9.1}$$

which can be expressed as

$$a^2 - 2ab \cos C + b^2 - c^2 = 0. \tag{1.1.9.2}$$

$$\because (a - b\cos C)^2 = a^2 + b^2 \cos^2 C - 2ab \cos C, \tag{1.1.9.3}$$

(1.1.9.2) can be expressed as

$$(a - b\cos C)^2 - b^2 \cos^2 C + b^2 - c^2 = 0 \tag{1.1.9.4}$$

$$\implies (a - b\cos C)^2 = b^2 \left(1 - \cos^2 C\right) - c^2 \tag{1.1.9.5}$$

$$\text{or}, a = b\cos C \pm \sqrt{b^2 \left(1 - \cos^2 C\right) - c^2} \tag{1.1.9.6}$$

Choose the value(s) for which $a > 0$.

10. The solution of a quadratic equation

$$\alpha x^2 + \beta x + \gamma = 0 \tag{1.1.10.1}$$

is given by

$$x = \frac{-\beta \pm \sqrt{\beta^2 - 4\alpha\gamma}}{2\alpha}. \tag{1.1.10.2}$$

Verify (1.1.9.6) using (1.1.10.2).

11. $\triangle ABC$ is right angled at **B**. If $a = 12$ and $b+c = 18$, find b, c and draw the triangle.
Solution: From Baudhayana's theorem,

$$b^2 = a^2 + c^2 \tag{1.1.11.1}$$

$$\implies (18 - c)^2 = 12^2 + c^2 \tag{1.1.11.2}$$

which can be simplified to obtain

$$36c - 180 = 0 \tag{1.1.11.3}$$

$$\implies c = 5 \tag{1.1.11.4}$$

and $b = 13$

12. Find a simpler solution for Problem 1.1.5
Solution: Use cosine formula.

13. In $\triangle ABC$, $a = 7, \angle B = 75^{\circ}$ and $b + c = 13$. Alternatively,

$$a = b\cos C + c\cos B \tag{1.1.13.1}$$

$$b \sin C = c \sin B \tag{1.1.13.2}$$

$$a + b + c = 11 \tag{1.1.13.3}$$

resulting in the matrix equation

$$\begin{pmatrix} 1 & -\cos C & -\cos B \\ 0 & \sin C & -\sin B \\ 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 11 \end{pmatrix} \tag{1.1.13.4}$$

Solving the equivalent matrix equation gives the desired answer.

1.2 Construction Exercises

1. In $\triangle ABC$, $a = 8, \angle B = 45^{\circ}$ and $c - b = 3.5$. Sketch $\triangle ABC$.
2. In $\triangle ABC$, $a = 6, \angle B = 60^{\circ}$ and $b - c = 2$. Sketch $\triangle ABC$.
3. Draw $\triangle ABC$, given that $a + b + c = 11, \angle B = 30^{\circ}$ and $\angle C = 90^{\circ}$.
4. Construct $\triangle xyz$ where $xy = 4.5, yz = 5$ and $zx = 6$.
5. Draw an equilateral triangle of side 5.5.
6. Draw $\triangle PQR$ with $PQ = 4, QR = 3.5$ and $PR = 4$. What type of triangle is this?
7. Construct $\triangle ABC$ such that $AB = 2.5, BC = 6$ and $AC = 6.5$. Find $\angle B$.
8. Construct $\triangle PQR$, given that $PQ = 3, QR = 5.5$ and $\angle PQR = 60°$.
9. Construct $\triangle DEF$ such that $DE = 5, DF = 3$ and $\angle D = 90°$.
10. Construct an isosceles triangle in which the lengths of the equal sides is 6.5 and the angle between them is 110°.
11. Construct $\triangle ABC$ with $BC = 7.5, AC = 5$ and $\angle C = 60°$.

12. Construct $\triangle XYZ$ if $XY = 6, \angle X = 30°$ and $\angle Y = 100°$.
13. If $AC = 7, \angle A = 60°$ and $\angle B = 50°$, can you draw the triangle?
14. Construct $\triangle ABC$ given that $\angle A = 60°, \angle B = 30°$ and $AB = 5.8$.
15. Construct $\triangle PQR$ if $PQ = 5, \angle Q = 105°$ and $\angle R = 40°$.
16. Can you construct $\triangle DEF$ such that $EF = 7.2, \angle E = 110°$ and $\angle F = 180°$?
17. Construct $\triangle LMN$ right angled at M such that $LN = 5$ and $MN = 3$.
18. Construct $\triangle PQR$ right angled at Q such that $QR = 8$ and $PR = 10$.
19. Construct right angled $\triangle$ whose hypotenuse is 6 and one of the legs is 4.
20. Construct an isosceles right angled $\triangle ABC$ right angled at C such $AC = 6$.
21. Construct the triangles in Table 1.2.21.

S.No	**Triangle**	**Given Measurements**		
1	$\triangle$ABC	$\angle A = 85°$	$\angle B = 115°$	AB = 5
2	$\triangle$PQR	$\angle Q = 30°$	$\angle R = 60°$	QR = 4.7
3	$\triangle$ABC	$\angle A = 70°$	$\angle B = 50°$	AC = 3
4	$\triangle$LMN	$\angle L = 60°$	$\angle N = 120°$	LM = 5
5	$\triangle$ABC	BC = 2	AB = 4	AC = 2
6	$\triangle$PQR	PQ = 2.5	QR = 4	PR = 3.5
7	$\triangle$XYZ	XY = 3	YZ = 4	XZ = 5
8	$\triangle$DEF	DE = 4.5	EF = 5.5	DF = 4

TABLE 1.2.21

1.3 Triangle Examples

1. Do the points $\mathbf{A} = \begin{pmatrix} 3 \\ 2 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} -2 \\ -3 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 2 \\ 3 \end{pmatrix}$ form a triangle? If so, name the type of triangle formed.

   Solution: The direction vectors of AB and BC are

$$\mathbf{B} - \mathbf{A} = \begin{pmatrix} -5 \\ -5 \end{pmatrix} \tag{1.3.1.1}$$

$$\mathbf{C} - \mathbf{A} = \begin{pmatrix} -1 \\ 1 \end{pmatrix} \tag{1.3.1.2}$$

Since

$$\mathbf{B} - \mathbf{A} \neq k(\mathbf{C} - \mathbf{A}), \tag{1.3.1.3}$$

the points are not collinear and form a triangle. An alternative method is to create the matrix

$$\mathbf{M} = \begin{pmatrix} \mathbf{B} - \mathbf{A} & \mathbf{B} - \mathbf{A} \end{pmatrix} \tag{1.3.1.4}$$

If $rank(\mathbf{M}) = 1$, the points are collinear. In this problem,

$$\mathbf{M} = \begin{pmatrix} -5 & -1 \\ -5 & 1 \end{pmatrix} \xleftrightarrow{R_2 \leftarrow R_2 - R_1} \begin{pmatrix} -5 & -1 \\ 0 & 2 \end{pmatrix} \tag{1.3.1.5}$$

$$\implies rank(\mathbf{M}) = 2 \tag{1.3.1.6}$$

as the number of non zero rows is 2. The following code plots Fig. 1.3.1

```
codes/triangle/check_tri.py
```

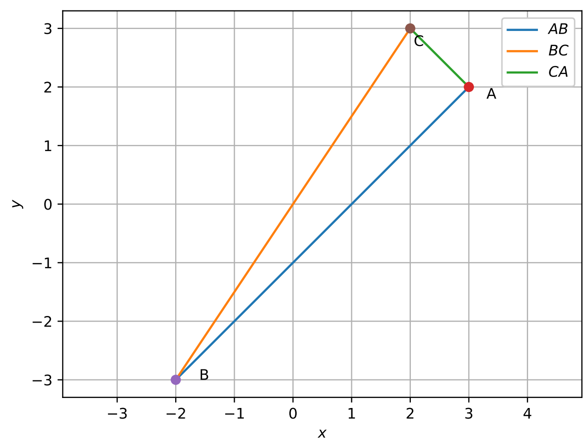

Fig. 1.3.1

From the figure, it appears that $\triangle ABC$ is right angled, with BC as the hypotenuse. From Baudhayana's theorem, this would be true if

$$\|\mathbf{B} - \mathbf{A}\|^2 + \|\mathbf{C} - \mathbf{A}\|^2 = \|\mathbf{B} - \mathbf{C}\|^2 \tag{1.3.1.7}$$

which, from (1.1.2.10) can be expressed as

$$\|\mathbf{A}\|^2 + \|\mathbf{C}\|^2 - 2\mathbf{A}^T\mathbf{C} + \|\mathbf{A}\|^2 + \|\mathbf{B}\|^2 - 2\mathbf{A}^T\mathbf{B} = \|\mathbf{B}\|^2 + \|\mathbf{C}\|^2 - 2\mathbf{B}^T\mathbf{C} \tag{1.3.1.8}$$

to obtain

$$(\mathbf{B} - \mathbf{A})^T(\mathbf{C} - \mathbf{A}) = 0 \tag{1.3.1.9}$$

after simplification. From (1.3.1.1) and (1.3.1.2), it is easy to verify that

$$(\mathbf{B} - \mathbf{A})^T(\mathbf{C} - \mathbf{A}) = \begin{pmatrix} -5 & -5 \end{pmatrix}\begin{pmatrix} -1 \\ 1 \end{pmatrix} = 0 \tag{1.3.1.10}$$

satisfying (1.3.1.9). Thus, $\triangle ABC$ is right angled at $\mathbf{A}$.

2. Find the area of a triangle whose vertices are $\mathbf{A} = \begin{pmatrix} 1 \\ -1 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} -4 \\ 6 \end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix} -3 \\ -5 \end{pmatrix}$.
Solution: In Fig. 1.1.1, from Baudhayana's theorem,
$$b^2 = a^2 + c^2 \tag{1.3.2.1}$$
$$= b^2 \cos^2 C + b^2 \sin^2 C \tag{1.3.2.2}$$
$$\implies \cos^2 C + \sin^2 C = 1 \tag{1.3.2.3}$$
In Fig. 1.1.7, the area of $\triangle ABC$ is defined as
$$\frac{1}{2}ah = \frac{1}{2}ab \sin C \tag{1.3.2.4}$$
$$= \frac{1}{2}ab\sqrt{1-\cos^2 C} \quad \text{(from (1.3.2.1))} \tag{1.3.2.5}$$
$$= \frac{1}{2}ab\sqrt{1-\left(\frac{a^2+b^2-c^2}{2ab}\right)^2} \text{(from (1.1.7.8))} \tag{1.3.2.6}$$
$$= \frac{1}{4}\sqrt{(2ab)^2-(a^2+b^2-c^2)} \tag{1.3.2.7}$$
$$= \frac{1}{4}\sqrt{(2ab+a^2+b^2-c^2)(2ab-a^2-b^2+c^2)} \tag{1.3.2.8}$$
$$= \frac{1}{4}\sqrt{\left\{(a+b)^2-c^2\right\}\left\{c^2-(a-b)^2\right\}} \tag{1.3.2.9}$$
$$= \frac{1}{4}\sqrt{(a+b+c)(a+b-c)(a+c-b)(b+c-a)} \tag{1.3.2.10}$$
Substituting
$$s = \frac{a+b+c}{2} \tag{1.3.2.11}$$
in (1.3.2.10), the area of $\triangle ABC$ is
$$\sqrt{s(s-a)(s-b)(s-c)} \tag{1.3.2.12}$$
This is known as Hero's formula. The following code computes the area of the triangle as 24.

```
codes/triangle/area_tri.py
```

3. Find the area of a triangle formed by the vertices $\mathbf{A} = \begin{pmatrix} 5 \\ 2 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 4 \\ 7 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 7 \\ -4 \end{pmatrix}$.
Solution: The area of $\triangle ABC$ is also obtained in terms of the *magnitude* of the determinant of the matrix $\mathbf{M}$ in (1.3.1.4) as
$$\frac{1}{2}\left|\mathbf{M}\right| \tag{1.3.3.1}$$
The computation is done in **area_tri.py**

4. Find the area of a triangle formed by the points $\mathbf{P} = \begin{pmatrix} -1.5 \\ 3 \end{pmatrix}, \mathbf{Q} = \begin{pmatrix} 6 \\ -2 \end{pmatrix}, \mathbf{R} = \begin{pmatrix} -3 \\ 4 \end{pmatrix}$.
Solution: Another formula for the area of $\triangle ABC$ is
$$\frac{1}{2}\begin{vmatrix} 1 & 1 & 1 \\ \mathbf{A} & \mathbf{B} & \mathbf{C} \end{vmatrix} \tag{1.3.4.1}$$

5. Find the area of a triangle having the points
$$\mathbf{A} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 2 \\ 3 \\ 1 \end{pmatrix} \tag{1.3.5.1}$$
as its vertices.
Solution: The area of a triangle using the *vector product* is obtained as
$$\frac{1}{2}\left\|(\mathbf{B}-\mathbf{A})\times(\mathbf{C}-\mathbf{A})\right\| \tag{1.3.5.2}$$
For any two vectors $\mathbf{a} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix}, \mathbf{b} = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix}$,
$$\mathbf{a}\times\mathbf{b} = \begin{pmatrix} 0 & -a_3 & a_2 \\ a_3 & 0 & -a_1 \\ -a_2 & a_1 & 0 \end{pmatrix}\begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} \tag{1.3.5.3}$$
The following code computes the area using the vector product.

```
codes/triangle/area_tri_vec.py
```

6. The centroid of a $\triangle ABC$ is at the point $\begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$. If the coordinates of $\mathbf{A}$ and $\mathbf{B}$ are $\begin{pmatrix} 3 \\ -5 \\ 7 \end{pmatrix}$ and $\begin{pmatrix} -1 \\ 7 \\ -6 \end{pmatrix}$, respectively, find the coordinates of the point $\mathbf{C}$.
Solution: The centroid of $\triangle ABC$ is given by
$$\mathbf{O} = \frac{\mathbf{A}+\mathbf{B}+\mathbf{C}}{3} \tag{1.3.6.1}$$
Thus,
$$\mathbf{C} = 3\mathbf{C} - \mathbf{A} - \mathbf{B} \tag{1.3.6.2}$$

7. Show that the points
$$\mathbf{A} = \begin{pmatrix} 2 \\ -1 \\ 1 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 1 \\ -3 \\ -5 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 3 \\ -4 \\ -4 \end{pmatrix} \tag{1.3.7.1}$$
are the vertices of a right angled triangle.
Solution: The following code plots Fig. 1.3.7

```
codes/triangle/triangle_3d.py
```

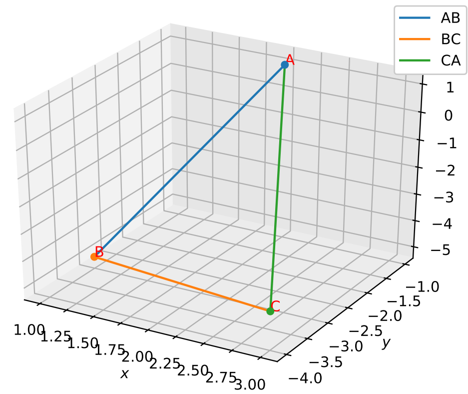

Fig. 1.3.7

From the figure, it appears that $\triangle ABC$ is right angled at $\mathbf{C}$. Since

$$(\mathbf{A}-\mathbf{C})^T(\mathbf{B}-\mathbf{C}) = 0 \tag{1.3.7.2}$$

it is proved that the triangle is indeed right angled.

8. Are the points

$$\mathbf{A} = \begin{pmatrix}3\\6\\9\end{pmatrix}, \mathbf{B} = \begin{pmatrix}10\\20\\30\end{pmatrix}, \mathbf{C} = \begin{pmatrix}25\\-41\\5\end{pmatrix}, \tag{1.3.8.1}$$

the vertices of a right angled triangle?

1.4 Triangle Exercises

1. The vertices of $\triangle PQR$ are $\mathbf{P} = \begin{pmatrix}2\\1\end{pmatrix}, \mathbf{Q} = \begin{pmatrix}-2\\3\end{pmatrix}, \mathbf{R} = \begin{pmatrix}4\\5\end{pmatrix}$. Find the equation of the median through the vertex $\mathbf{R}$.
2. In the $\triangle ABC$ with vertices $\mathbf{A} = \begin{pmatrix}2\\3\end{pmatrix}, \mathbf{B} = \begin{pmatrix}4\\-1\end{pmatrix}, \mathbf{C} = \begin{pmatrix}1\\2\end{pmatrix}$, find the equation and length of the altitude from the vertex $\mathbf{A}$.
3. Find the area of the triangle whose vertices are
   a) $\begin{pmatrix}2\\3\end{pmatrix}, \begin{pmatrix}-1\\0\end{pmatrix}, \begin{pmatrix}2\\-4\end{pmatrix}$
   b) $\begin{pmatrix}-5\\-1\end{pmatrix}, \begin{pmatrix}3\\-5\end{pmatrix}, \begin{pmatrix}5\\2\end{pmatrix}$
4. Find the area of the triangle formed by joining the mid points o the sides of a triangle whose vertices are $\begin{pmatrix}0\\-1\end{pmatrix}, \begin{pmatrix}2\\1\end{pmatrix}, \begin{pmatrix}0\\3\end{pmatrix}$.
5. Verify that the median of $\triangle ABC$ with vertices $\mathbf{A} = \begin{pmatrix}4\\-6\end{pmatrix}, \mathbf{B} = \begin{pmatrix}3\\-2\end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix}5\\2\end{pmatrix}$ divides it into two triangles of equal areas.
6. The vertices of $\triangle ABC$ are $\mathbf{A} = \begin{pmatrix}4\\6\end{pmatrix}, \mathbf{B} = \begin{pmatrix}1\\5\end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix}7\\2\end{pmatrix}$. A line is drawn to intersect sides AB and AC at D and E respectively, such that
$$\frac{AD}{AB} = \frac{AE}{AC} = \frac{1}{4} \tag{1.4.6.1}$$
   Find
$$\frac{\text{area of } \triangle ADE}{\text{area of } \triangle ABC}. \tag{1.4.6.2}$$
7. Let $\mathbf{A} = \begin{pmatrix}4\\2\end{pmatrix}, \mathbf{B} = \begin{pmatrix}6\\5\end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix}1\\4\end{pmatrix}$ be the vertices of $\triangle ABC$.
   a) The median from $\mathbf{A}$ meets BC at $\mathbf{D}$. Find the coordinates of the point $\mathbf{D}$.
   b) Find the coordinates of the point $\mathbf{P}$ on AD such that $AP : PD = 2 : 1$.
   c) Find the coordinates of the points $\mathbf{Q}$ and $\mathbf{R}$ on medians BE and CF respectively such that $BQ : QE = 2 : 1$ and $CR : RF = 2 : 1$.
8. In $\triangle ABC$, Show that the centroid
$$\mathbf{O} = \frac{\mathbf{A}+\mathbf{B}+\mathbf{C}}{3} \tag{1.4.8.1}$$
9. Show that the points
$$\mathbf{A} = \begin{pmatrix}2\\-1\\1\end{pmatrix}, \mathbf{B} = \begin{pmatrix}1\\-3\\-5\end{pmatrix}, \mathbf{C} = \begin{pmatrix}3\\-4\\-4\end{pmatrix} \tag{1.4.9.1}$$
   are the vertices of a right angled triangle.
10. In $\triangle ABC$, $\mathbf{A} = \begin{pmatrix}1\\2\\3\end{pmatrix}, \mathbf{B} = \begin{pmatrix}-1\\0\\0\end{pmatrix}, \mathbf{C} = \begin{pmatrix}0\\1\\2\end{pmatrix}$. Find $\angle B$.
11. Show that the vectors $\begin{pmatrix}2\\-1\\1\end{pmatrix}, \begin{pmatrix}1\\-3\\-5\end{pmatrix}, \begin{pmatrix}3\\-4\\-4\end{pmatrix}$ form the vertices of a right angled triangle.
12. Find the area of a triangle having the points $\mathbf{A} = \begin{pmatrix}1\\1\\1\end{pmatrix}, \mathbf{B} = \begin{pmatrix}1\\2\\3\end{pmatrix}$, and $\mathbf{C} = \begin{pmatrix}2\\3\\1\end{pmatrix}$ as its vertices.

13. Find the area of a triangle with vertices $\mathbf{A} = \begin{pmatrix}1\\1\\2\end{pmatrix}, \mathbf{B} = \begin{pmatrix}2\\3\\5\end{pmatrix}$, and $\mathbf{C} = \begin{pmatrix}1\\5\\5\end{pmatrix}$
14. A girl walks 4km west, then she walks 3km in a direction 30° east of north and stops. Determine the girl's displacement from her initial point of departure.
15. Find the direction vectors of the sides of a triangle with vertices $\mathbf{A} = \begin{pmatrix}3\\5\\-4\end{pmatrix}, \mathbf{B} = \begin{pmatrix}-1\\1\\2\end{pmatrix}$, and $\mathbf{C} = \begin{pmatrix}-5\\-5\\-2\end{pmatrix}$
16. Without using the Pythagoras theorem, show that the points $\begin{pmatrix}4\\4\end{pmatrix}, \begin{pmatrix}3\\5\end{pmatrix}$ and $\begin{pmatrix}-1\\-1\end{pmatrix}$ are the vertices of a right angled triangle.
17. Check whether
$$\begin{pmatrix}5\\-2\end{pmatrix}, \begin{pmatrix}6\\4\end{pmatrix}, \begin{pmatrix}7\\-2\end{pmatrix} \tag{1.4.17.1}$$
are the vertices of an isosceles triangle.

2 Quadrilateral

2.1 Construction Examples

1. Draw $ABCD$ with $AB = a = 4.5, BC = b = 5.5, CD = c = 4, AD = d = 6$ and $AC = e = 7$.
Solution: Fig. 2.1.1 shows a rough sketch of $ABCD$. Letting
$$\mathbf{C} = \begin{pmatrix}p\\q\end{pmatrix}, \mathbf{A} = \begin{pmatrix}0\\0\end{pmatrix}, \mathbf{B} = \begin{pmatrix}a\\0\end{pmatrix} \tag{2.1.1.1}$$
it is trivial to sketch $\triangle ABC$ from Problem 1.1.2. $\triangle ACD$ is can be obtained by rotating an equivalent triangle with AC on the x-axis by an angle θ with
$$\mathbf{D} = \begin{pmatrix}h\\k\end{pmatrix}, \mathbf{A} = \begin{pmatrix}0\\0\end{pmatrix}, \mathbf{C} = \begin{pmatrix}e\\0\end{pmatrix} \tag{2.1.1.2}$$
and
$$\cos\theta = \frac{a^2 + e^2 - b^2}{2ae} \tag{2.1.1.3}$$
$$\sin\theta = \sqrt{1 - \cos^2\theta} \tag{2.1.1.4}$$
The coordinates of the rotated triangle ACD are
$$\mathbf{D} = \mathbf{P}\begin{pmatrix}h\\k\end{pmatrix} \tag{2.1.1.5}$$
$$\mathbf{A} = \mathbf{P}\begin{pmatrix}0\\0\end{pmatrix} \tag{2.1.1.6}$$
$$\mathbf{C} = \mathbf{P}\begin{pmatrix}e\\0\end{pmatrix} \tag{2.1.1.7}$$
where
$$\mathbf{P} = \begin{pmatrix}\cos\theta & -\sin\theta\\ \sin\theta & \cos\theta\end{pmatrix} \tag{2.1.1.8}$$
The following code plots quadrilateral $ABCD$

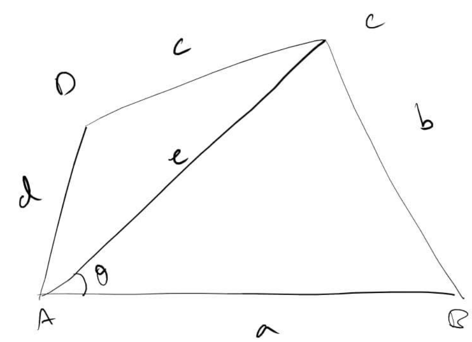

Fig. 2.1.1

in Fig. 2.1.1

```
codes/quad/draw_quad.py
```

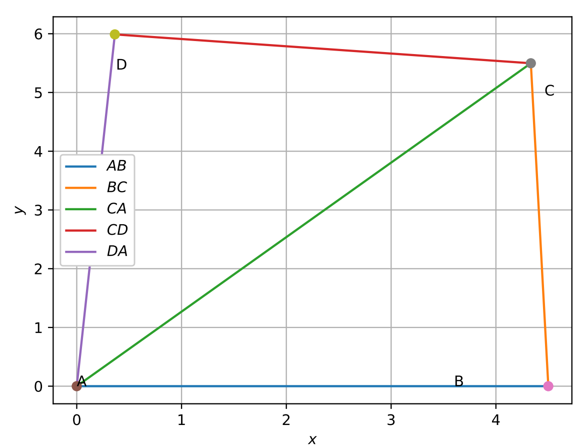

Fig. 2.1.1

2. Draw the parallelogram $MORE$ with $OR = 6, RE = 4.5$ and $EO = 7.5$.

Solution: Diagonals of a parallelogram bisect each other. Opposite sides of a parallelogram are equal and parallel .

3. Construct a kite $EASY$ if $AY = 8, EY = 4$ and $SY = 6$.
Solution: The diagonals of a kite are perpendicular to each other.
4. Draw the rhombus $BEST$ with $BE = 4.5$ and $ET = 6$.
Solution: Diagonals of a rhombus bisect each other at right angles.

2.2 Construction Exercises

1. Construct a quadrilateral $ABCD$ such that $AB = 5, \angle A = 50°, AC = 4, BD = 5$ and $AD = 6$.
2. Construct $PQRS$ where $PQ = 4, QR = 6, RS = 5, PS = 5.5$ and $PR = 7$.
3. Draw $JUMP$ with $JU = 3.5, UM = 4, MP = 5, PJ = 4.5$ and $PU = 6.5$
4. Construct a quadrilateral $ABCD$ such that $BC = 4.5, AC = 5.5, CD = 5, BD = 7$ and $AD = 5.5$.
5. Can you construct a quadrilateral $PQRS$ with $PQ = 3, RS = 3, PS = 7.5, PR = 8$ and $SQ = 4$?
6. Construct $LIFT$ such that $LI = 4, IF = 3, TL = 2.5, LF = 4.5, IT = 4$.
7. Draw $GOLD$ such that $OL = 7.5, GL = 6, GD = 6, LD = 5, OD = 10$.
8. DRAW rhombus $BEND$ such that $BN = 5.6$, $DE = 6.5$.
9. construct a quadrilateral MIST where $MI = 3.5, IS = 6.5, \angle M = 75°, \angle I = 105°$ and $\angle S = 120°$.
10. Can you construct the above quadrilateral MIST if $\angle M = 100°$ instead of 75°.
11. Can you constrcut the quadrilateral PLAN if $PL = 6, LA = 9.5, \angle P = 75°, \angle L = 150°$ and $\angle A = 140°$?
12. Construct $MORE$ where $MO = 6, OR = 4.5, \angle M = 60°, \angle O = 105°, \angle R = 105°$.
13. Construct $PLAN$ where $PL = 4, LA = 6.5, \angle P = 90°, \angle A = 110°$ and $\angle N = 85°$.
14. Constrcut parallelogram $HEAR$ where $HE = 5, EA = 6, \angle R = 85°$.
15. Draw rectangle $OKAY$ with $OK = 7$ and $KA = 5$.
16. Construct $ABCd$, where $AB = 4, BC = 5, Cd = 6.5, \angle B = 105°$ and $\angle C = 80°$.
17. Construct $DEAR$ with $DE = 4, EA = 5, AR = 4.5, \angle E = 60°$ and $\angle A = 90°$.
18. Construct $TRUE$ with $TR = 3.5, RU = 3, UE = 4\angle R = 75°$ and $\angle U = 120°$.
19. Draw a square of side 4.5.
20. Can you construct a rhombus $ABCD$ with $AC = 6$ and $BD = 7$?
21. Draw a square $READ$ with $RE = 5.1$.
22. Draw a rhombus who diagonals are 5.2 and 6.4.
23. Draw a rectangle with adjacent sides 5 and 4.
24. Draw a parallelogram $OKAY$ with $OK = 5.5$ and $KA = 4.2$.

2.3 Quadrilateral Examples

1. Show that the points $\mathbf{A} = \begin{pmatrix}1\\7\end{pmatrix}, \mathbf{B} = \begin{pmatrix}4\\2\end{pmatrix}, \mathbf{C} = \begin{pmatrix}-1\\-1\end{pmatrix}, \mathbf{D} = \begin{pmatrix}-4\\4\end{pmatrix}$ are the vertices of a square.
Solution: By inspection,
$$\frac{\mathbf{A}+\mathbf{C}}{2} = \frac{\mathbf{B}+\mathbf{D}}{2} = \begin{pmatrix}0\\3\end{pmatrix} \tag{2.3.1.1}$$
Hence, the diagonals AC and BD bisect each other. Also,
$$(\mathbf{A}-\mathbf{C})^T(\mathbf{B}-\mathbf{D}) = 0 \tag{2.3.1.2}$$
$\implies AC \perp BD$. Hence $ABCD$ is a square.
2. If the points $\mathbf{A} = \begin{pmatrix}6\\1\end{pmatrix}, \mathbf{B} = \begin{pmatrix}8\\2\end{pmatrix}, \mathbf{C} = \begin{pmatrix}9\\4\end{pmatrix}, \mathbf{D} = \begin{pmatrix}p\\3\end{pmatrix}$ are the vertices of a parallelogram, taken in order, find the value of p.
Solution: In the parallelogram $ABCD$, AC and BD bisect each other. This can be used to find p.
3. If $\mathbf{A} = \begin{pmatrix}-5\\7\end{pmatrix}, \mathbf{B} = \begin{pmatrix}-4\\-5\end{pmatrix}, \mathbf{C} = \begin{pmatrix}-1\\-6\end{pmatrix}, \mathbf{D} = \begin{pmatrix}4\\5\end{pmatrix}$, find the area of the quadrilateral $ABCD$.
Solution: The area of $ABCD$ is the sum of the areas of trianges ABD and CBD and is given by
$$\frac{1}{2}\left\|(\mathbf{A}-\mathbf{B})\times(\mathbf{A}-\mathbf{D})\right\| + \frac{1}{2}\left\|(\mathbf{C}-\mathbf{B})\times(\mathbf{C}-\mathbf{D})\right\| \tag{2.3.3.1}$$
4. Show that the points $\mathbf{A} = \begin{pmatrix}1\\2\\3\end{pmatrix}, \mathbf{B} = \begin{pmatrix}-1\\-2\\-1\end{pmatrix}, \mathbf{C} =$

$\begin{pmatrix}2\\3\\2\end{pmatrix}, \mathbf{D} = \begin{pmatrix}4\\7\\6\end{pmatrix}$. are the vertices of a parallelogram $ABCD$ but it is not a rectangle.

Solution: Since the direction vectors

$$\mathbf{A}-\mathbf{B}=\mathbf{D}-\mathbf{C} \tag{2.3.4.1}$$

$$\mathbf{A}-\mathbf{D}=\mathbf{B}-\mathbf{C} \tag{2.3.4.2}$$

$AB \parallel CD$ and $AD \parallel BC$. Hence $ABCD$ is a parallelogram. However,

$$(\mathbf{A}-\mathbf{B})^T(\mathbf{A}-\mathbf{D}) \neq 0 \tag{2.3.4.3}$$

Hence, it is not a rectangle. The following code plots Fig. 2.3.4

```
codes/triangle/quad_3d.py
```

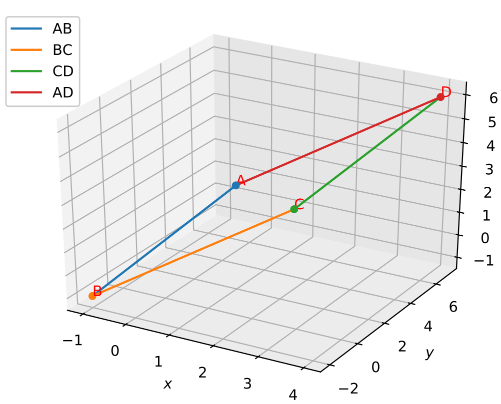

Fig. 2.3.4

5. Find the area of a parallelogram whose adjacent sides are given by the vectors $\begin{pmatrix}3\\1\\4\end{pmatrix}$ and $\begin{pmatrix}1\\-1\\1\end{pmatrix}$.

Solution: The area is given by

$$\frac{1}{2}\left\|\begin{pmatrix}3\\1\\4\end{pmatrix}\times\begin{pmatrix}1\\-1\\1\end{pmatrix}\right\| \tag{2.3.5.1}$$

2.4 Quadrilateral Geometry

1. Draw a quadrilateral in the Cartesian plane, whose vertices are $\begin{pmatrix}-4\\5\end{pmatrix}$, $\begin{pmatrix}0\\7\end{pmatrix}$, $\begin{pmatrix}5\\-5\end{pmatrix}$ and $\begin{pmatrix}-4\\-2\end{pmatrix}$. Also, find its area.
2. Find the area of a rhombus if its vertices are $\begin{pmatrix}3\\0\end{pmatrix}$, $\begin{pmatrix}4\\5\end{pmatrix}$, $\begin{pmatrix}-1\\4\end{pmatrix}$ and $\begin{pmatrix}-2\\-1\end{pmatrix}$ taken in order.
3. Without using distance formula, show that points $\begin{pmatrix}-2\\-1\end{pmatrix}$, $\begin{pmatrix}4\\0\end{pmatrix}$, $\begin{pmatrix}3\\3\end{pmatrix}$ and $\begin{pmatrix}-3\\2\end{pmatrix}$ are the vertices of a parallelogram.
4. Find the area of the quadrilateral whose vertices, taken in order, are $\begin{pmatrix}-4\\2\end{pmatrix}$, $\begin{pmatrix}-3\\-5\end{pmatrix}$, $\begin{pmatrix}3\\-2\end{pmatrix}$, $\begin{pmatrix}2\\3\end{pmatrix}$.
5. The two opposite vertices of a square are $\begin{pmatrix}-1\\2\end{pmatrix}$, $\begin{pmatrix}3\\2\end{pmatrix}$. Find the coordinates of the other two vertices.
6. $ABCD$ is a rectangle formed by the points $\mathbf{A} = \begin{pmatrix}-1\\-1\end{pmatrix}, \mathbf{B} = \begin{pmatrix}-1\\4\end{pmatrix}, \mathbf{C} = \begin{pmatrix}5\\4\end{pmatrix}, \mathbf{D} = \begin{pmatrix}5\\-1\end{pmatrix}$. $\mathbf{P}, \mathbf{Q}, \mathbf{R}, \mathbf{S}$ are the mid points of AB, BC, CD, DA respectively. Is the quadrilateral $PQRS$ a
   a) square?
   b) rectangle?
   c) rhombus?
7. Find the area of a parallelogram whose adjacent sides are given by the vectors $\begin{pmatrix}3\\1\\4\end{pmatrix}$ and $\begin{pmatrix}1\\-1\\1\end{pmatrix}$.
8. Find the area of a parallelogram whose adjacent sides are determined by the vectors $\mathbf{a} = \begin{pmatrix}1\\-1\\3\end{pmatrix}$ and $\mathbf{b} = \begin{pmatrix}2\\-7\\1\end{pmatrix}$.
9. Find the area of a rectangle $ABCD$ with vertices $\mathbf{A} = \begin{pmatrix}-1\\\frac{1}{2}\\4\end{pmatrix}, \mathbf{B} = \begin{pmatrix}1\\\frac{1}{2}\\4\end{pmatrix}, \mathbf{C} = \begin{pmatrix}1\\-\frac{1}{2}\\4\end{pmatrix}, \mathbf{D} = \begin{pmatrix}-1\\-\frac{1}{2}\\4\end{pmatrix}$.
10. The two adjacent sides of a parallelogram are $\begin{pmatrix}2\\-4\\-5\end{pmatrix}$ and $\begin{pmatrix}1\\-2\\-3\end{pmatrix}$. Find the unit vector parallel to its diagonal. Also, find its area.

3 Line

3.1 Examples

1. Verify if $\mathbf{A} = \begin{pmatrix} 3 \\ 1 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 6 \\ 4 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 8 \\ 6 \end{pmatrix}$ are points on a line.
Solution: Refer to Problem 1.3.1.
2. Find the condition for $\mathbf{x} = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$ to be equidistant from the points $\begin{pmatrix} 7 \\ 1 \end{pmatrix}, \begin{pmatrix} 3 \\ 5 \end{pmatrix}$.
Solution: From the given information,
$$\left\|\mathbf{x} - \begin{pmatrix} 7 \\ 1 \end{pmatrix}\right\|^2 = \left\|\mathbf{x} - \begin{pmatrix} 3 \\ 5 \end{pmatrix}\right\|^2 \tag{3.1.2.1}$$
$$\implies \|\mathbf{x}\|^2 + \left\|\begin{pmatrix} 7 \\ 1 \end{pmatrix}\right\|^2 - 2\begin{pmatrix} 7 & 1 \end{pmatrix}\mathbf{x}$$
$$= \|\mathbf{x}\|^2 + \left\|\begin{pmatrix} 3 \\ 5 \end{pmatrix}\right\|^2 - 2\begin{pmatrix} 3 & 5 \end{pmatrix}\mathbf{x} \tag{3.1.2.2}$$
which can be simplified to obtain
$$\begin{pmatrix} 1 & -1 \end{pmatrix}\mathbf{x} = 2 \tag{3.1.2.3}$$
which is the desired condition. The following code plots Fig. 3.1.2

```
codes/line/line_perp_bisect.py
```

cleearly showing that (3.1.2.3) is the perpendicular bisector of AB.

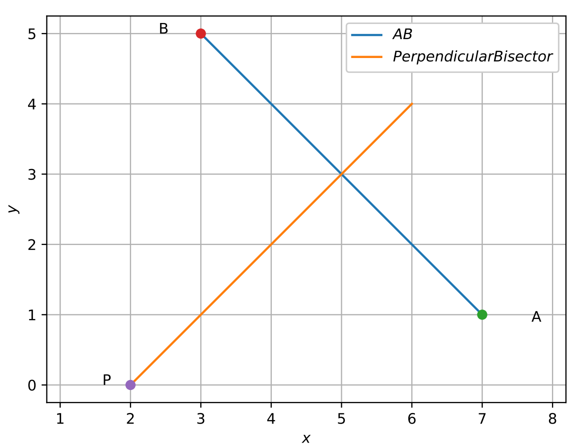

Fig. 3.1.2

3. Find a point on the y-axis which is equidistant from the points $\mathbf{A} = \begin{pmatrix} 6 \\ 5 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} -4 \\ 3 \end{pmatrix}$.
4. Draw a line segement of length 7.6 cm and divide it in the ratio 5 : 8.
Solution: Let the end points of the line be
$$\mathbf{A} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 7.6 \\ 0 \end{pmatrix} \tag{3.1.4.1}$$
Then the point $\mathbf{C}$
$$\mathbf{C} = \frac{k\mathbf{A} + \mathbf{B}}{k+1} \tag{3.1.4.2}$$
divides AB in the ration $k : 1$. For the given problem, $k = \frac{5}{8}$. The following code plots Fig. 3.1.4

```
codes/line/draw_section.py
```

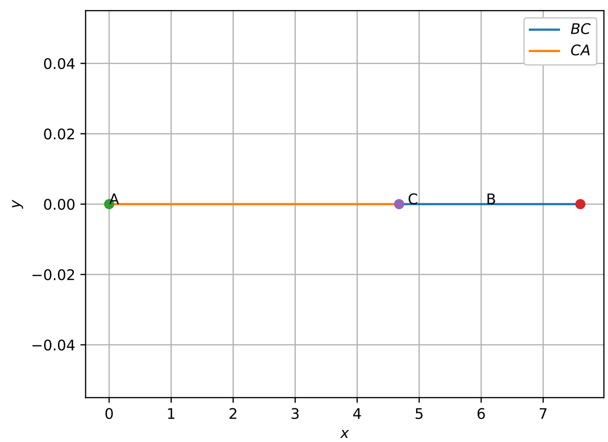

Fig. 3.1.4

5. Find the coordinates of the point which divides the line segment joining the points $\begin{pmatrix} 4 \\ -3 \end{pmatrix}$ and $\begin{pmatrix} 8 \\ 5 \end{pmatrix}$ in the ratio 3 : 1 internally.
6. In what ratio does the point $\begin{pmatrix} -4 \\ 6 \end{pmatrix}$ divide the line segment joining the points
$$\mathbf{A} = \begin{pmatrix} -6 \\ 10 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 3 \\ -8 \end{pmatrix} \tag{3.1.6.1}$$
7. Find the coordinates of the points of trisection of the line segement joining the points
$$\mathbf{A} = \begin{pmatrix} 2 \\ -2 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} -7 \\ 4 \end{pmatrix} \tag{3.1.7.1}$$
8. Find the ratio in which the y-axis divides the

line segment joining the points $\begin{pmatrix}5\\-6\end{pmatrix}$ and $\begin{pmatrix}-1\\-4\end{pmatrix}$.

9. Find the value of k if the points $\mathbf{A} = \begin{pmatrix}2\\3\end{pmatrix}, \mathbf{B} = \begin{pmatrix}4\\k\end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix}6\\-3\end{pmatrix}$ are collinear.
10. Find the direction vectors and slopes of the lines passing through the points
    a) $\begin{pmatrix}3\\-2\end{pmatrix}$ and $\begin{pmatrix}-1\\4\end{pmatrix}$.
    b) $\begin{pmatrix}3\\-2\end{pmatrix}$ and $\begin{pmatrix}7\\-2\end{pmatrix}$.
    c) $\begin{pmatrix}3\\-2\end{pmatrix}$ and $\begin{pmatrix}3\\4\end{pmatrix}$.
    d) Making an inclination of 60° with the positive direction of the x-axis.
11. If the angle between two lines is $\frac{\pi}{4}$ and the slope of one of the lines is $\frac{1}{4}$ find the slope of the other line.
12. The line through the points $\begin{pmatrix}-2\\6\end{pmatrix}$ and $\begin{pmatrix}4\\8\end{pmatrix}$ is perpendicular to the line through the points $\begin{pmatrix}8\\12\end{pmatrix}$ and $\begin{pmatrix}x\\24\end{pmatrix}$. Find the value of x.
13. Two positions of time and distance are recorded as, when $T = 0, D = 2$ and when $T = 3, D = 8$. Using the concept of slope, find law of motion, i.e., how distance depends upon time.
14. Find the equations of the lines parallel to the axes and passing through $\begin{pmatrix}-2\\3\end{pmatrix}$.
15. Find the equation of the line through $\begin{pmatrix}-2\\3\end{pmatrix}$ with slope –4.
16. Find the equations of the lines parallel to axes and passing through $\left(-2, 3\right)$.
17. Write the equation of the line through the points $\begin{pmatrix}1\\-1\end{pmatrix}$ and $\begin{pmatrix}3\\5\end{pmatrix}$.
18. Wrire the equation of the lines for which $\tan\theta = \frac{1}{2}$, where θ is the inclination of the line and
    a) y-intercept is $-\frac{3}{2}$
    b) x-intercept is 4.
19. Find the equation of the line, which makes intercepts -3 and 2 on the x and y axes respectively.
20. Find the equation of the line whose perpendicular distance from the origin is 4 units and the angle which the normal makes with the positive direction of x-axis is 15°.
21. The Farenheit temperature F and absolute temperature K satisfy a linear equation. Given $K = 273$ when $F = 32$ and that $K = 373$ when $F = 212$, express K in terms of F and find the value of F, when $K = 0$.
22. Equation of a line is
$$\begin{pmatrix}3 & -4\end{pmatrix} + 10 = 0. \tag{3.1.22.1}$$
    Find its
    a) slope,
    b) x - and y-intercepts.
23. Find the angle between the lines
$$\begin{pmatrix}1 & -\sqrt{3}\end{pmatrix}\mathbf{x} = 5 \tag{3.1.23.1}$$
$$\begin{pmatrix}\sqrt{3} & -1\end{pmatrix}\mathbf{x} = -6. \tag{3.1.23.2}$$
24. Find the equation of a line perpendicular to the line
$$\begin{pmatrix}1 & -2\end{pmatrix}\mathbf{x} = 3 \tag{3.1.24.1}$$
    and passes through the point $\begin{pmatrix}1\\-2\end{pmatrix}$.
25. Find the distance of the point $\begin{pmatrix}3\\-5\end{pmatrix}$ from the line
$$\begin{pmatrix}3 & -4\end{pmatrix}\mathbf{x} = 26 \tag{3.1.25.1}$$
26. If the lines
$$\begin{pmatrix}2 & 1\end{pmatrix}\mathbf{x} = 3 \tag{3.1.26.1}$$
$$\begin{pmatrix}5 & k\end{pmatrix}\mathbf{x} = 3 \tag{3.1.26.2}$$
$$\begin{pmatrix}3 & 1\end{pmatrix}\mathbf{x} = 2 \tag{3.1.26.3}$$
    are concurrent, find the value of k.
27. Find the distance of the line
$$\begin{pmatrix}4 & 1\end{pmatrix}\mathbf{x} = 0 \tag{3.1.27.1}$$
    from the point $\begin{pmatrix}4\\1\end{pmatrix}$ measured along the line making an angle of 135° with the positive x-axis.
28. Assuming that straight lines work as a plane mirror for a point, find the image of the point

$\begin{pmatrix}1\\2\end{pmatrix}$ in the line

$$\begin{pmatrix}1 & -3\end{pmatrix}\mathbf{x} = -4. \tag{3.1.28.1}$$

29. A line is such that its segment between the lines

$$\begin{pmatrix}5 & -1\end{pmatrix}\mathbf{x} = -4 \tag{3.1.29.1}$$
$$\begin{pmatrix}3 & 4\end{pmatrix}\mathbf{x} = 4 \tag{3.1.29.2}$$

is bisected at the point $\begin{pmatrix}1\\5\end{pmatrix}$. Obtain its equation.

30. Show that the path of a moving point such that its distances from two lines

$$\begin{pmatrix}3 & -2\end{pmatrix}\mathbf{x} = 5 \tag{3.1.30.1}$$
$$\begin{pmatrix}3 & 2\end{pmatrix}\mathbf{x} = 5 \tag{3.1.30.2}$$

are equal is a straight line.

31. Find the distance between the points

$$\mathbf{P} = \begin{pmatrix}1\\-3\\4\end{pmatrix}, \mathbf{Q} = \begin{pmatrix}-4\\1\\2\end{pmatrix} \tag{3.1.31.1}$$

32. Show that the points $\mathbf{A} = \begin{pmatrix}-2\\3\\5\end{pmatrix}, \mathbf{B} = \begin{pmatrix}1\\2\\3\end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix}7\\0\\-1\end{pmatrix}$ are collinear.

33. Find the equation of set of points $\mathbf{P}$ such that

$$PA^2 + PB^2 = 2k^2, \tag{3.1.33.1}$$

$$\mathbf{A} = \begin{pmatrix}3\\4\\5\end{pmatrix}, \mathbf{B} = \begin{pmatrix}-1\\3\\-7\end{pmatrix}, \tag{3.1.33.2}$$

respectively.

34. Find the coordinates of a point which divides the line segment joining the points $\begin{pmatrix}1\\-2\\3\end{pmatrix}$ and $\begin{pmatrix}3\\4\\-5\end{pmatrix}$ in the ratio 2 : 3
   a) internally, and
   b) externally.

35. Using section formular, prove that the three points $\begin{pmatrix}-4\\6\\10\end{pmatrix}, \begin{pmatrix}2\\4\\6\end{pmatrix}$ and $\begin{pmatrix}14\\0\\-2\end{pmatrix}$ are collinear.

36. Find the ratio in which the line segment joining the points $\begin{pmatrix}4\\8\\10\end{pmatrix}$ and $\begin{pmatrix}6\\10\\-8\end{pmatrix}$ is divided by the YZ-plane.

37. Find the equation of the set of points $\mathbf{P}$ such that its distances from the points $\mathbf{A} = \begin{pmatrix}3\\4\\-5\end{pmatrix}, \mathbf{B} = \begin{pmatrix}-2\\1\\4\end{pmatrix}$

38. Find the values of x, y, z such that

$$\begin{pmatrix}x\\2\\z\end{pmatrix} = \begin{pmatrix}2\\y\\1\end{pmatrix} \tag{3.1.38.1}$$

39. If

$$\mathbf{a} = \begin{pmatrix}1\\2\end{pmatrix}, \mathbf{b} = \begin{pmatrix}2\\1\end{pmatrix}, \tag{3.1.39.1}$$

verify if
   a) $\|\mathbf{a}\| = \|\mathbf{b}\|$
   b) $\mathbf{a} = \mathbf{b}$

40. Find a unit vector in the direction of $\begin{pmatrix}2\\3\\1\end{pmatrix}$.

41. Find a vector $\mathbf{x}$ in the direction of $\begin{pmatrix}1\\-2\end{pmatrix}$ such that $\|\mathbf{x}\| = 7$.

42. Find a unit vector in the direction of $\mathbf{a} + \mathbf{b}$, where

$$\mathbf{a} = \begin{pmatrix}2\\2\\-5\end{pmatrix}, \mathbf{b} = \begin{pmatrix}2\\1\\3\end{pmatrix}. \tag{3.1.42.1}$$

43. Find a unit vector in the direction of

$$\begin{pmatrix}1\\1\\-2\end{pmatrix}. \tag{3.1.43.1}$$

44. Find the direction vector of PQ, where

$$\mathbf{P} = \begin{pmatrix}2\\3\\0\end{pmatrix}, \mathbf{Q} = \begin{pmatrix}-1\\-2\\-4\end{pmatrix} \tag{3.1.44.1}$$

45. If

$$\mathbf{P} = 3\mathbf{a} - 2\mathbf{b} \tag{3.1.45.1}$$
$$\mathbf{Q} = \mathbf{a} + \mathbf{b} \tag{3.1.45.2}$$

find $\mathbf{R}$, which divides PQ

a) internally,
b) externally.

46. Find the angle between two vectors $\mathbf{a}$ and $\mathbf{b}$ where
$$\|\mathbf{a}\| = 1, \|\mathbf{b}\| = 2, \mathbf{a}^T\mathbf{b} = 1. \tag{3.1.46.1}$$
47. Find the angle between the vectors $\mathbf{a} = \begin{pmatrix} 1 \\ 1 \\ -1 \end{pmatrix}$ and $\mathbf{b} = \begin{pmatrix} 1 \\ -1 \\ 1 \end{pmatrix}$.
48. If $\mathbf{a} = \begin{pmatrix} 5 \\ -1 \\ -3 \end{pmatrix}$ and $\mathbf{b} = \begin{pmatrix} 1 \\ 3 \\ -5 \end{pmatrix}$, then show that the vectors $\mathbf{a}+\mathbf{b}$ and $\mathbf{a}-\mathbf{b}$ are perpendicular.
49. Find the projection of the vector
$$\mathbf{a} = \begin{pmatrix} 2 \\ 3 \\ 2 \end{pmatrix} \tag{3.1.49.1}$$
on the vector
$$\begin{pmatrix} 1 \\ 2 \\ 1 \end{pmatrix}. \tag{3.1.49.2}$$
50. Find $\|\mathbf{a}-\mathbf{b}\|$, if
$$\|\mathbf{a}\| = 2, \|\mathbf{b}\| = 3, \mathbf{a}^T\mathbf{b} = 4. \tag{3.1.50.1}$$
51. If $\mathbf{a}$ is a unit vector and
$$(\mathbf{x}-\mathbf{a})(\mathbf{x}+\mathbf{a}) = 8, \tag{3.1.51.1}$$
then find $\mathbf{x}$.
52. Given
$$\mathbf{a} = \begin{pmatrix} 2 \\ 1 \\ 3 \end{pmatrix}, \mathbf{b} = \begin{pmatrix} 3 \\ 5 \\ -2 \end{pmatrix}, \tag{3.1.52.1}$$
find $\|\mathbf{a}\times\mathbf{b}\|$.
53. Find a unit vector perpendicular to each of the vectors $\mathbf{a}+\mathbf{b}$ and $\mathbf{a}-\mathbf{b}$, where
$$\mathbf{a} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}, \mathbf{b} = \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}. \tag{3.1.53.1}$$
54. Show that $\mathbf{A} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 2 \\ 5 \\ 0 \end{pmatrix}, \mathbf{C} = \begin{pmatrix} 3 \\ 2 \\ -3 \end{pmatrix}$ and $\mathbf{D} = \begin{pmatrix} 1 \\ -6 \\ -1 \end{pmatrix}$, are collinear.
55. Let $\|\mathbf{a}\| = 3, \|\mathbf{b}\| = 4, \|\mathbf{c}\| = 5$ such that each vector is perpendicular to the other two. Find $\|\mathbf{a}+\mathbf{b}+\mathbf{c}\|$.
56. Given
$$\mathbf{a}+\mathbf{b}+\mathbf{c} = \mathbf{0}, \tag{3.1.56.1}$$
evaluate
$$\mathbf{a}^T\mathbf{b}+\mathbf{b}^T\mathbf{c}+\mathbf{c}^T\mathbf{a}, \tag{3.1.56.2}$$
given that $\|\mathbf{a}\| = 3, \|\mathbf{b}\| = 4$ and $\|\mathbf{c}\| = 2$.
57. Let $\boldsymbol{\alpha} = \begin{pmatrix} 3 \\ -1 \\ 0 \end{pmatrix}, \boldsymbol{\beta} = \begin{pmatrix} 2 \\ 1 \\ -3 \end{pmatrix}$. Find $\boldsymbol{\beta}_1, \boldsymbol{\beta}_2$ such that $\boldsymbol{\beta} = \boldsymbol{\beta}_1 + \boldsymbol{\beta}_2, \boldsymbol{\beta}_1 \parallel \boldsymbol{\alpha}$ and $\boldsymbol{\beta}_2 \perp \boldsymbol{\alpha}$.
58. Find a unit vector that makes an angle of $90°, 60°$ and $30°$ with the positive x, y and z axis respectively.
59. Find a unit vector in the direction of $\begin{pmatrix} 2 \\ -1 \\ -2 \end{pmatrix}$.
60. Find a unit vector in the direction of the line passing through $\begin{pmatrix} -2 \\ 4 \\ -5 \end{pmatrix}$ and $\begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}$.
61. Show that $\mathbf{A} = \begin{pmatrix} 2 \\ 3 \\ -4 \end{pmatrix}, \mathbf{B} = \begin{pmatrix} 1 \\ -2 \\ 3 \end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix} 3 \\ 8 \\ -11 \end{pmatrix}$ are collinear.
62. Find the equation of a line through the point $\begin{pmatrix} 5 \\ 2 \\ -4 \end{pmatrix}$ and parallel to the vector $\begin{pmatrix} 3 \\ 2 \\ -8 \end{pmatrix}$.
63. Find the equation of a line passing through the points $\begin{pmatrix} -1 \\ 0 \\ 2 \end{pmatrix}$ and $\begin{pmatrix} 3 \\ 4 \\ 6 \end{pmatrix}$.
64. If
$$\frac{x+3}{2} = \frac{y-5}{4} = \frac{z+6}{2}, \tag{3.1.64.1}$$
find the equation of the line.
65. Find the angle between the pair of lines given

by

$$\mathbf{x} = \begin{pmatrix} 3 \\ 2 \\ -4 \end{pmatrix} + \lambda_1 \begin{pmatrix} 1 \\ 2 \\ 2 \end{pmatrix} \tag{3.1.65.1}$$

$$\mathbf{x} = \begin{pmatrix} 5 \\ -2 \\ 0 \end{pmatrix} + \lambda_2 \begin{pmatrix} 3 \\ 2 \\ 6 \end{pmatrix} \tag{3.1.65.2}$$

66. Find the angle between the pair of lines

$$\frac{x+3}{3} = \frac{y-1}{5} = \frac{z+3}{4}, \tag{3.1.66.1}$$

$$\frac{x+1}{1} = \frac{y-4}{1} = \frac{z-5}{2} \tag{3.1.66.2}$$

67. Find the shortest distance between the lines

$$L_1 : \quad \mathbf{x} = \begin{pmatrix} 1 \\ 1 \\ 0 \end{pmatrix} + \lambda_1 \begin{pmatrix} 2 \\ -1 \\ 1 \end{pmatrix} \tag{3.1.67.1}$$

$$L_2 : \quad \mathbf{x} = \begin{pmatrix} 2 \\ 1 \\ -1 \end{pmatrix} + \lambda_2 \begin{pmatrix} 3 \\ -5 \\ 2 \end{pmatrix} \tag{3.1.67.2}$$

68. Find the distance between the lines

$$L_1 : \quad \mathbf{x} = \begin{pmatrix} 1 \\ 2 \\ -4 \end{pmatrix} + \lambda_1 \begin{pmatrix} 2 \\ 3 \\ 6 \end{pmatrix} \tag{3.1.68.1}$$

$$L_2 : \quad \mathbf{x} = \begin{pmatrix} 3 \\ 3 \\ -5 \end{pmatrix} + \lambda_2 \begin{pmatrix} 2 \\ 3 \\ 6 \end{pmatrix} \tag{3.1.68.2}$$

69. Find the equation of a plane which is at a distance of $\frac{6}{\sqrt{29}}$ from the origin and has normal vector $\begin{pmatrix} 2 \\ -3 \\ 4 \end{pmatrix}$.
70. Find the unit normal vector of the plane

$$\begin{pmatrix} 6 & -3 & -2 \end{pmatrix} \mathbf{x} = 1. \tag{3.1.70.1}$$

71. Find the distance of the plane

$$\begin{pmatrix} 2 & -3 & 4 \end{pmatrix} \mathbf{x} - 6 = 0 \tag{3.1.71.1}$$

from the origin.
72. Find the coordinates of the foot of the perpendicular drawn from the origin to the plane

$$\begin{pmatrix} 2 & -3 & 4 \end{pmatrix} \mathbf{x} - 6 = 0 \tag{3.1.72.1}$$

73. Find the equation of the plane which passes through the point $\begin{pmatrix} 5 \\ 2 \\ -4 \end{pmatrix}$ and perpendicular to the line with direction vector $\begin{pmatrix} 2 \\ 3 \\ -1 \end{pmatrix}$.
74. Find the equation of the plane passing through $\mathbf{R} = \begin{pmatrix} 2 \\ 5 \\ -3 \end{pmatrix}, \mathbf{S} = \begin{pmatrix} -2 \\ -3 \\ 5 \end{pmatrix}$ and $\mathbf{T} = \begin{pmatrix} 5 \\ 3 \\ -3 \end{pmatrix}$.
75. Find the equation of the plane with intercepts 2, 3 and 4 on the x, y and z axis respectively.
76. Find the equation of the plane passing through the intersection of the planes

$$\begin{pmatrix} 1 & 1 & 1 \end{pmatrix} \mathbf{x} = 6 \tag{3.1.76.1}$$

$$\begin{pmatrix} 2 & 3 & 4 \end{pmatrix} \mathbf{x} = -5 \tag{3.1.76.2}$$

and the point $\begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$.
77. Show that the lines

$$\frac{x+3}{-3} = \frac{y-1}{1} = \frac{z-5}{5}, \tag{3.1.77.1}$$

$$\frac{x+1}{-1} = \frac{y-2}{2} = \frac{z-5}{5} \tag{3.1.77.2}$$

are coplanar.
78. Find the angle between the two planes

$$\begin{pmatrix} 2 & 1 & -2 \end{pmatrix} \mathbf{x} = 5 \tag{3.1.78.1}$$

$$\begin{pmatrix} 3 & -6 & -2 \end{pmatrix} \mathbf{x} = 7. \tag{3.1.78.2}$$

79. Find the angle between the two planes

$$\begin{pmatrix} 2 & 2 & -2 \end{pmatrix} \mathbf{x} = 5 \tag{3.1.79.1}$$

$$\begin{pmatrix} 3 & -6 & 2 \end{pmatrix} \mathbf{x} = 7. \tag{3.1.79.2}$$

Find the distance of a point $\begin{pmatrix} 2 \\ 5 \\ -3 \end{pmatrix}$ from the plane

$$\begin{pmatrix} 6 & -3 & 2 \end{pmatrix} \mathbf{x} = 4 \tag{3.1.79.3}$$

Find the angle between the line

$$\frac{x+1}{2} = \frac{y}{3} = \frac{z-3}{6} \tag{3.1.79.4}$$

and the plane

$$\begin{pmatrix} 10 & 2 & -11 \end{pmatrix} \mathbf{x} = 3 \tag{3.1.79.5}$$

80. Find the equation of the plane that contains the point $\begin{pmatrix}1\\-1\\2\end{pmatrix}$ and is perpedicular to each of the planes

$$\begin{pmatrix}2 & 3 & -2\end{pmatrix}\boldsymbol{x} = 5 \tag{3.1.80.1}$$

$$\begin{pmatrix}1 & 2 & -3\end{pmatrix}\boldsymbol{x} = 8 \tag{3.1.80.2}$$

81. Find the distance between the point $\boldsymbol{P} = \begin{pmatrix}6\\5\\9\end{pmatrix}$ and the plane determined by the points $\boldsymbol{A} = \begin{pmatrix}3\\-1\\2\end{pmatrix}, \boldsymbol{B} = \begin{pmatrix}5\\2\\4\end{pmatrix}$ and $\boldsymbol{C} = \begin{pmatrix}-1\\-1\\6\end{pmatrix}$.
82. Find the coordinates of the point where the lines through the points $\boldsymbol{A} = \begin{pmatrix}3\\4\\1\end{pmatrix}, \boldsymbol{B} = \begin{pmatrix}5\\1\\6\end{pmatrix}$ crosses the XY plane.

3.2 *Points and Vectors*

1. Find the distance between the following pairs of points

a)

$$\begin{pmatrix}2\\3\end{pmatrix}, \begin{pmatrix}4\\1\end{pmatrix} \tag{3.2.1.1}$$

b)

$$\begin{pmatrix}-5\\7\end{pmatrix}, \begin{pmatrix}-1\\3\end{pmatrix} \tag{3.2.1.2}$$

c)

$$\begin{pmatrix}a\\b\end{pmatrix}, \begin{pmatrix}-1\\b\end{pmatrix} \tag{3.2.1.3}$$

2. Find the distance between the points

$$\begin{pmatrix}0\\0\end{pmatrix}, \begin{pmatrix}36\\15\end{pmatrix} \tag{3.2.2.1}$$

3. A town B is located 36km east and 15 km north of the town A. How would you find the distance from town A to town B without actually measuring it?
4. Name the type of quadrilateral formed, if any, by the following points, and give reasons for your answer.

a)

$$\begin{pmatrix}-1\\-2\end{pmatrix}, \begin{pmatrix}1\\0\end{pmatrix}, \begin{pmatrix}-1\\2\end{pmatrix}, \begin{pmatrix}-3\\0\end{pmatrix} \tag{3.2.4.1}$$

b)

$$\begin{pmatrix}-3\\5\end{pmatrix}, \begin{pmatrix}3\\1\end{pmatrix}, \begin{pmatrix}0\\3\end{pmatrix}, \begin{pmatrix}-1\\-4\end{pmatrix} \tag{3.2.4.2}$$

c)

$$\begin{pmatrix}4\\5\end{pmatrix}, \begin{pmatrix}7\\6\end{pmatrix}, \tag{3.2.4.3}$$

$$\begin{pmatrix}4\\3\end{pmatrix}, \begin{pmatrix}1\\2\end{pmatrix} \tag{3.2.4.4}$$

5. Find the angle between the x-axis and the line joining the points $\begin{pmatrix}3\\-1\end{pmatrix}$ and $\begin{pmatrix}4\\-2\end{pmatrix}$.
6. Find the point on the x-axis which is equidistant from

$$\begin{pmatrix}2\\-5\end{pmatrix}, \begin{pmatrix}-2\\9\end{pmatrix}, \tag{3.2.6.1}$$

7. Find the values of y for which the distance between the points

$$\mathbf{P} = \begin{pmatrix}2\\-3\end{pmatrix}, \mathbf{Q} = \begin{pmatrix}10\\y\end{pmatrix} \tag{3.2.7.1}$$

is 10 units.
8. Show that each of the given three vectors is a unit vector

$$\frac{1}{7}\begin{pmatrix}2\\3\\6\end{pmatrix}, \frac{1}{7}\begin{pmatrix}3\\-6\\2\end{pmatrix}, \frac{1}{7}\begin{pmatrix}6\\2\\-3\end{pmatrix}. \tag{3.2.8.1}$$

Also, show that they are mutually perpendicular to each other.
9. For

$$\mathbf{a} = \begin{pmatrix}2\\2\\3\end{pmatrix}, \mathbf{b} = \begin{pmatrix}-1\\2\\1\end{pmatrix}, \mathbf{c} = \begin{pmatrix}3\\1\\0\end{pmatrix}, \tag{3.2.9.1}$$

$(\mathbf{a} + \lambda\mathbf{b}) \perp \mathbf{c}$. Find λ.
10. Find $\mathbf{a} \times \mathbf{b}$ if

$$\mathbf{a} = \begin{pmatrix}1\\-7\\7\end{pmatrix}, \mathbf{b} = \begin{pmatrix}3\\-2\\2\end{pmatrix}. \tag{3.2.10.1}$$

11. Find a unit vector perpendicular to each of the

vectors $\mathbf{a}+\mathbf{b}$ and $\mathbf{a}-\mathbf{b}$, where

$$\mathbf{a}=\begin{pmatrix}3\\2\\2\end{pmatrix}, \mathbf{b}=\begin{pmatrix}1\\2\\-2\end{pmatrix}. \quad (3.2.11.1)$$

12. If $\mathbf{a}=\begin{pmatrix}1\\1\\1\end{pmatrix}, \mathbf{b}=\begin{pmatrix}2\\-1\\3\end{pmatrix}, \mathbf{c}=\begin{pmatrix}1\\-2\\1\end{pmatrix}$, find a unit vector parallel to the vector $2\mathbf{a}-\mathbf{b}+3\mathbf{c}$.
13. Find a vector of magnitude 5 units, and parallel to the resultant of the vectors $\mathbf{a}=\begin{pmatrix}2\\3\\-1\end{pmatrix}, \mathbf{b}=\begin{pmatrix}1\\-2\\1\end{pmatrix}$,
14. Show that the unit direction vector inclined equally to the coordinate axes is $\begin{pmatrix}\frac{1}{\sqrt{3}}\\\frac{1}{\sqrt{3}}\\\frac{1}{\sqrt{3}}\end{pmatrix}$.
15. Let $\mathbf{a}=\begin{pmatrix}1\\4\\2\end{pmatrix}, \mathbf{b}=\begin{pmatrix}3\\-2\\7\end{pmatrix}$ and $\mathbf{c}=\begin{pmatrix}2\\-1\\4\end{pmatrix}$. Find a vector $\mathbf{d}$ such that $\mathbf{d}\perp\mathbf{a}, \mathbf{d}\perp\mathbf{b}$ and $\mathbf{d}^T\mathbf{c}=15$.
16. The scalar product of $\begin{pmatrix}1\\1\\1\end{pmatrix}$ with a unit vector along the sum of the vectors $\begin{pmatrix}2\\4\\-5\end{pmatrix}$ and $\begin{pmatrix}\lambda\\2\\3\end{pmatrix}$ is unity. Find the value of λ.
17. The value of

$$\begin{pmatrix}1\\0\\0\end{pmatrix}^T\left(\begin{pmatrix}0\\1\\0\end{pmatrix}\times\begin{pmatrix}0\\0\\1\end{pmatrix}\right)+\begin{pmatrix}0\\1\\0\end{pmatrix}^T\left(\begin{pmatrix}1\\0\\0\end{pmatrix}\times\begin{pmatrix}0\\0\\1\end{pmatrix}\right)+\begin{pmatrix}0\\0\\1\end{pmatrix}^T\left(\begin{pmatrix}1\\0\\0\end{pmatrix}\times\begin{pmatrix}0\\1\\0\end{pmatrix}\right) \quad (3.2.17.1)$$

is

a) 0
b) -1
c) 1
d) 3

18. Find a unit vector that makes an angle of $90°, 135°$ and $45°$ with the positive x, y and z axis respectively.
19. Show that the lines with direction vectors $\begin{pmatrix}12\\-3\\-4\end{pmatrix}$, $\begin{pmatrix}4\\12\\3\end{pmatrix}$ and $\begin{pmatrix}3\\-4\\12\end{pmatrix}$ are mutually perpendicular.
20. Show that the line through the points $\begin{pmatrix}1\\-1\\2\end{pmatrix}$, $\begin{pmatrix}3\\4\\-2\end{pmatrix}$ is parallel to the line through the points $\begin{pmatrix}0\\3\\2\end{pmatrix}, \begin{pmatrix}3\\5\\6\end{pmatrix}$.
21. Show that the line through the points $\begin{pmatrix}4\\7\\8\end{pmatrix}, \begin{pmatrix}2\\3\\4\end{pmatrix}$ is parallel to the line through the points $\begin{pmatrix}-1\\-2\\1\end{pmatrix}$, $\begin{pmatrix}1\\2\\5\end{pmatrix}$.
22. Find a point on the x-axis, which is equidistant from the points $\begin{pmatrix}7\\6\end{pmatrix}$ and $\begin{pmatrix}3\\4\end{pmatrix}$.
23. Find the angle between the vectors

$$\begin{pmatrix}1\\-2\\3\end{pmatrix}, \begin{pmatrix}3\\-2\\1\end{pmatrix} \quad (3.2.23.1)$$

24. Find the projection of the vector

$$\begin{pmatrix}1\\3\\7\end{pmatrix} \quad (3.2.24.1)$$

on the vector

$$\begin{pmatrix}7\\-1\\8\end{pmatrix} \quad (3.2.24.2)$$

25. Write down a unit vector in the xy-plane, makeing an angle of $30°$ with the positive direction of the x-axis.
26. Find the value of x for which $x\begin{pmatrix}1\\1\\1\end{pmatrix}$ is a unit vector.

3.3 Points on a Line

1. Find the coordinates of the point which divides the join of

$$\begin{pmatrix}-1\\7\end{pmatrix}, = \begin{pmatrix}4\\-3\end{pmatrix} \tag{3.3.1.1}$$

in the ratio 2 : 3.

2. Find the coordinates of the points of trisection of the line segment joining $\begin{pmatrix}4\\-1\end{pmatrix}$ and $\begin{pmatrix}-2\\-3\end{pmatrix}$.
3. Find the ratio in which the line segment joining the points $\begin{pmatrix}-3\\10\end{pmatrix}$ and $\begin{pmatrix}6\\-8\end{pmatrix}$ is divided by $\begin{pmatrix}-1\\6\end{pmatrix}$.
4. Find the ratio in whcih the line segment joining $\mathbf{A} = \begin{pmatrix}1\\-5\end{pmatrix}, \mathbf{B} = \begin{pmatrix}-4\\5\end{pmatrix}$ is divided by the x-axis. Also find the coordinates of the point of division.
5. If $\begin{pmatrix}1\\2\end{pmatrix}$, $\begin{pmatrix}4\\y\end{pmatrix}$, $\begin{pmatrix}x\\6\end{pmatrix}$ and $\begin{pmatrix}3\\5\end{pmatrix}$ are the vertices of a parallelogram taken in order, find x and y.
6. If $\mathbf{A} = \begin{pmatrix}-2\\-2\end{pmatrix}, \mathbf{B} = \begin{pmatrix}2\\-4\end{pmatrix}$ respectively, find the coordinates of $\mathbf{P}$ such that $AP = \frac{3}{7}AB$ and $\mathbf{P}$ lies on the line segment AB.
7. Find the coordinates of the points which divide the line segment joining $\mathbf{A} = \begin{pmatrix}-2\\2\end{pmatrix}, \mathbf{B} = \begin{pmatrix}2\\8\end{pmatrix}$ into four equal parts.
8. Determine if the points

$$\begin{pmatrix}1\\5\end{pmatrix}, \begin{pmatrix}2\\3\end{pmatrix}, \begin{pmatrix}-2\\-11\end{pmatrix} \tag{3.3.8.1}$$

are collinear.

9. By using the concept of equation of a line, prove that the three points $\begin{pmatrix}3\\0\end{pmatrix}$, $\begin{pmatrix}-2\\-2\end{pmatrix}$ and $\begin{pmatrix}8\\2\end{pmatrix}$ are collinear.
10. Find the value of x for which the points $\begin{pmatrix}x\\-1\end{pmatrix}$, $\begin{pmatrix}2\\1\end{pmatrix}$ and $\begin{pmatrix}4\\5\end{pmatrix}$ are collinear.
11. In each of the following, find the value of k for which the points are collinear
    a) $\begin{pmatrix}7\\-2\end{pmatrix}$, $\begin{pmatrix}5\\1\end{pmatrix}$, $\begin{pmatrix}3\\k\end{pmatrix}$
    b) $\begin{pmatrix}8\\1\end{pmatrix}$, $\begin{pmatrix}k\\-4\end{pmatrix}$, $\begin{pmatrix}2\\-5\end{pmatrix}$
12. Find a condition on $\mathbf{x}$ such that the points $\mathbf{x}, \begin{pmatrix}1\\2\end{pmatrix}\begin{pmatrix}7\\0\end{pmatrix}$ are collinear.
13. Show that the points $\mathbf{A} = \begin{pmatrix}1\\2\\7\end{pmatrix}, \mathbf{B} = \begin{pmatrix}2\\6\\3\end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix}3\\10\\-1\end{pmatrix}$ are collinear.
14. Show that the points $\mathbf{A} = \begin{pmatrix}1\\-2\\8\end{pmatrix}, \mathbf{B} = \begin{pmatrix}5\\0\\-2\end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix}11\\3\\7\end{pmatrix}$ are collinear, and find the ratio in which $\mathbf{B}$ divides AC.
15. Show that $\mathbf{A} = \begin{pmatrix}2\\3\\4\end{pmatrix}, \mathbf{B} = \begin{pmatrix}-1\\-2\\1\end{pmatrix}$ and $\mathbf{C} = \begin{pmatrix}5\\8\\7\end{pmatrix}$ are collinear.

3.4 Lines and Planes

1. Find the slope of a line, which passes through the origin, and the mid-point of the line segment joining the points $\mathbf{P} = \begin{pmatrix}0\\-4\end{pmatrix}$ and $\mathbf{B} = \begin{pmatrix}8\\0\end{pmatrix}$.
2. The slope of a line is double of the slope of another line. If the tangent of the angle between them is $\frac{1}{3}$, find the slopes of the lines.
3. Find the slope of the line, which makes an angle of 30° of y-axis measured anticlockwise.
4. Write the equations for the x and y axes.
5. Find the equation of the line satisfying the following conditions
    a) passing through the point $\begin{pmatrix}-4\\3\end{pmatrix}$ with slope $\frac{1}{2}$.
    b) passing through the point $\begin{pmatrix}0\\0\end{pmatrix}$ with slope m.
    c) passing through the point $\begin{pmatrix}2\\2\sqrt{3}\end{pmatrix}$ and inclined with the x-axis at an angle of 75°.
    d) Intersecting the x-axis at a distance of 3 units to the let of the origin with slope -2.
    e) intersecting the y-axis at a distance of 2 units above the origin and making an angle of 30° with the positive direction of the x-axis.
    f) passing through the points $\begin{pmatrix}-1\\1\end{pmatrix}$ and $\begin{pmatrix}2\\-4\end{pmatrix}$.
    g) perpendicular distance from the origin is 5 and the angle made by the perpendicular with the positive x-axis is 30°.

6. Find the equation of the line passing through $\begin{pmatrix}-3\\5\end{pmatrix}$ and perpendicular to the line through the points $\begin{pmatrix}2\\5\end{pmatrix}$ and $\begin{pmatrix}-3\\6\end{pmatrix}$.
7. Find the direction vectors and and y-intercepts of the following lines
   a) $\begin{pmatrix}1 & 7\end{pmatrix}\mathbf{x} = 0.$
   b) $\begin{pmatrix}6 & 3\end{pmatrix}\mathbf{x} = 5.$
   c) $\begin{pmatrix}0 & 1\end{pmatrix}\mathbf{x} = 0.$
8. Find the intercepts of the following lines on the axes.
   a) $\begin{pmatrix}3 & 2\end{pmatrix}\mathbf{x} = 12.$
   b) $\begin{pmatrix}4 & -3\end{pmatrix}\mathbf{x} = 6.$
   c) $\begin{pmatrix}3 & 2\end{pmatrix}\mathbf{x} = 0.$
9. Find the perpendicular distances of the following lines from the origin and angle between the perpendicular and the positive x-axis.
   a) $\begin{pmatrix}1 & -\sqrt{3}\end{pmatrix}\mathbf{x} = -8.$
   b) $\begin{pmatrix}0 & 1\end{pmatrix}\mathbf{x} = 2.$
   c) $\begin{pmatrix}1 & -1\end{pmatrix}\mathbf{x} = 4.$
10. Find the distance of the point $\begin{pmatrix}1\\-1\end{pmatrix}$ from the line $\begin{pmatrix}12 & -5\end{pmatrix}\mathbf{x} = -82.$
11. Find the points on the x-axis, whose distances from the line
$$\begin{pmatrix}4 & 3\end{pmatrix}\mathbf{x} = 12 \tag{3.4.11.1}$$
are 4 units.
12. Find the distance between the parallel lines
$$\begin{pmatrix}15 & 8\end{pmatrix}\mathbf{x} = 34 \tag{3.4.12.1}$$
$$\begin{pmatrix}15 & 8\end{pmatrix}\mathbf{x} = -31 \tag{3.4.12.2}$$
13. Find the equation of the line parallel to the line
$$\begin{pmatrix}3 & -4\end{pmatrix}\mathbf{x} = -2 \tag{3.4.13.1}$$
and passing through the point $\begin{pmatrix}-2\\3\end{pmatrix}$.
14. Find the equation of a line perpendicular to the line
$$\begin{pmatrix}1 & -7\end{pmatrix}\mathbf{x} = -5 \tag{3.4.14.1}$$
and having x intercept 3.
15. Find angles between the lines
$$\begin{pmatrix}\sqrt{3} & 1\end{pmatrix}\mathbf{x} = 1 \tag{3.4.15.1}$$
$$\begin{pmatrix}1 & \sqrt{3}\end{pmatrix}\mathbf{x} = 1 \tag{3.4.15.2}$$
16. The line through the points $\begin{pmatrix}h\\3\end{pmatrix}$ and $\begin{pmatrix}4\\1\end{pmatrix}$ intersects the line
$$\begin{pmatrix}7 & -9\end{pmatrix}\mathbf{x} = 19 \tag{3.4.16.1}$$
at right angle. Find the value of h.
17. Two lines passing through the point $\begin{pmatrix}2\\3\end{pmatrix}$ intersect each other at angle of 60°. If the slope of one line is 2, find the equation of the other line.
18. Find the equation of the right bisector of the line segment joining the points $\begin{pmatrix}3\\4\end{pmatrix}$ and $\begin{pmatrix}-1\\2\end{pmatrix}$.
19. Find the coordinates of the foot of the perpendicular from the point $\begin{pmatrix}-1\\3\end{pmatrix}$ to the line
$$\begin{pmatrix}3 & -4\end{pmatrix}\mathbf{x} = 16. \tag{3.4.19.1}$$
20. The perpendicular from the origin to the line
$$\begin{pmatrix}-m & 1\end{pmatrix}\mathbf{x} = c \tag{3.4.20.1}$$
meets it at the point $\begin{pmatrix}-1\\2\end{pmatrix}$. Find the values of m and c.
21. Find θ and p if
$$\begin{pmatrix}\sqrt{3} & 1\end{pmatrix}\mathbf{x} = -2 \tag{3.4.21.1}$$
is equivalent to
$$\begin{pmatrix}\cos\theta & \sin\theta\end{pmatrix}\mathbf{x} = p \tag{3.4.21.2}$$
22. Find the equations of the lines, which cut-off intercepts on the axes whose sum and product are 1 and -6 respectively.
23. Find the equation of the line parallel to the y-axis whose distance from the line
$$\begin{pmatrix}4 & 3\end{pmatrix}\mathbf{x} = 12 \tag{3.4.23.1}$$
4 units.
24. Find the equation of the line parallel to the y-axis drawn through the point of intersection of

the lines

$$\begin{pmatrix}1 & -7\end{pmatrix}\mathbf{x} = -5 \quad (3.4.24.1)$$
$$\begin{pmatrix}3 & 1\end{pmatrix}\mathbf{x} = 0 \quad (3.4.24.2)$$

25. Find the alue of p so that the three lines

$$\begin{pmatrix}3 & 1\end{pmatrix}\mathbf{x} = 2 \quad (3.4.25.1)$$
$$\begin{pmatrix}p & 2\end{pmatrix}\mathbf{x} = 3 \quad (3.4.25.2)$$
$$\begin{pmatrix}2 & -1\end{pmatrix}\mathbf{x} = 3 \quad (3.4.25.3)$$

may intersect at one point.

26. Find the equation of the lines through the point $\begin{pmatrix}3\\2\end{pmatrix}$ which make an angle of 45° with the line

$$\begin{pmatrix}1 & -2\end{pmatrix}\mathbf{x} = 3. \quad (3.4.26.1)$$

27. Find the equation of the line passing through the point of intersection of the lines

$$\begin{pmatrix}4 & 7\end{pmatrix}\mathbf{x} = 3 \quad (3.4.27.1)$$
$$\begin{pmatrix}2 & -3\end{pmatrix}\mathbf{x} = -1 \quad (3.4.27.2)$$

that has equal intercepts on the axes.

28. In what ratio is the line joining $\begin{pmatrix}-1\\1\end{pmatrix}$ and $\begin{pmatrix}5\\7\end{pmatrix}$ divided by the line

$$\begin{pmatrix}1 & 1\end{pmatrix}\mathbf{x} = 4 \quad (3.4.28.1)$$

29. Find the distance of the line

$$\begin{pmatrix}4 & 7\end{pmatrix}\mathbf{x} = -5 \quad (3.4.29.1)$$

from the point $\begin{pmatrix}1\\2\end{pmatrix}$ along the line

$$\begin{pmatrix}2 & -1\end{pmatrix}\mathbf{x} = 0. \quad (3.4.29.2)$$

30. Find the direction in which a straight line must be drawn through the point $\begin{pmatrix}-1\\2\end{pmatrix}$ so that its point of intersection with the line

$$\begin{pmatrix}1 & 1\end{pmatrix}\mathbf{x} = 4 \quad (3.4.30.1)$$

may be at a distance of 3 units from this point.

31. The hypotenuse of a right angled triangle has its ends at the points $\begin{pmatrix}1\\3\end{pmatrix}$ and $\begin{pmatrix}-4\\1\end{pmatrix}$. Find an equation of the legs of the triangle.

32. Find the image of the point $\begin{pmatrix}3\\8\end{pmatrix}$ with respect to the line

$$\begin{pmatrix}1 & 3\end{pmatrix}\mathbf{x} = 7 \quad (3.4.32.1)$$

assuming the line to be a plane mirror.

33. If the lines

$$\begin{pmatrix}-3 & 1\end{pmatrix}\mathbf{x} = 1 \quad (3.4.33.1)$$
$$\begin{pmatrix}-1 & 2\end{pmatrix}\mathbf{x} = 3 \quad (3.4.33.2)$$

are equally inclined to the line

$$\begin{pmatrix}-m & 1\end{pmatrix}\mathbf{x} = 4, \quad (3.4.33.3)$$

find the value of m.

34. The sum of the perpendicular distances of a variable point $\mathbf{P}$ from the lines

$$\begin{pmatrix}1 & 1\end{pmatrix}\mathbf{x} = 0 \quad (3.4.34.1)$$
$$\begin{pmatrix}3 & -2\end{pmatrix}\mathbf{x} = -7 \quad (3.4.34.2)$$

is always 10. Show that $\mathbf{P}$ must move on a line.

35. Find the equation of the line which is equidistant from parallel lines

$$\begin{pmatrix}9 & 7\end{pmatrix}\mathbf{x} = 7 \quad (3.4.35.1)$$
$$\begin{pmatrix}3 & 2\end{pmatrix}\mathbf{x} = -6. \quad (3.4.35.2)$$

36. A ray of light passing through the point $\begin{pmatrix}1\\2\end{pmatrix}$ reflects on the x-axis at point $\mathbf{A}$ and the reflected ray passes through the point $\begin{pmatrix}5\\3\end{pmatrix}$. Find the coordinates of $\mathbf{A}$.

37. A person standing at the junction of two straight paths represented by the equations

$$\begin{pmatrix}2 & -3\end{pmatrix}\mathbf{x} = 4 \quad (3.4.37.1)$$
$$\begin{pmatrix}3 & 4\end{pmatrix}\mathbf{x} = 5 \quad (3.4.37.2)$$

wants to reach the path whose equation is

$$\begin{pmatrix}6 & -7\end{pmatrix}\mathbf{x} = -8 \quad (3.4.37.3)$$

in the least time. Find the equation of the path that he should follow.

38. Determine the ratio in which the line

$$\begin{pmatrix}2 & 1\end{pmatrix}\mathbf{x} - 4 = 0 \quad (3.4.38.1)$$

divides the line segment joining the points $\mathbf{A} = \begin{pmatrix}2\\-2\end{pmatrix}, \mathbf{B} = \begin{pmatrix}3\\7\end{pmatrix}$.

39. A line perpendicular to the line segment joining

the points $\begin{pmatrix}1\\0\end{pmatrix}$ and $\begin{pmatrix}2\\3\end{pmatrix}$ divides it in the ratio $1 : n$. Find the equation of the line.

40. Find the equation of a line that cuts off equal intercepts on the coordinate axes and passes through the point $\begin{pmatrix}2\\3\end{pmatrix}$.
41. Find the equation of the line passing through the point $\begin{pmatrix}2\\2\end{pmatrix}$ and cutting off intercepts on the axes whose sum is 9.
42. Find the equation of the line through the point $\begin{pmatrix}0\\2\end{pmatrix}$ making an angle $\frac{2\pi}{3}$ with the positive x-axis. Also, find the equation of the line parallel to it and crossing the y-axis at a distance of 2 units below the origin.
43. The perpendicular from the origin to a line meets it at a point $\begin{pmatrix}-2\\9\end{pmatrix}$, find the equation of the line.
44. The length L (in cm) of a copper rod is a linear function of its Celsius temperature C. In an experiment, if $L = 124.942$ when $C = 20$ and $L = 125.134$ when $C = 110$, express L in terms of C.
45. The owner of a milk store finds that, he can sell 980 litres of milk each week at Rs 14/litre and 1220 litres of milk each week at Rs 16/litre. Assuming a linear relationship between selling price and demand, how many litres could he sell weekly at Rs 17/litre?
46. Find the equation of a line which passes through the point $\begin{pmatrix}1\\2\\3\end{pmatrix}$ and is parallel to the vector $\begin{pmatrix}3\\2\\-2\end{pmatrix}$.
47. Find the equaion off the line that passes through $\begin{pmatrix}2\\-1\\4\end{pmatrix}$ and is in the direction $\begin{pmatrix}1\\2\\-1\end{pmatrix}$.
48. Find the equation of the line which passes through the point $\begin{pmatrix}-2\\4\\-5\end{pmatrix}$ and parallel to the line given by
$$\frac{x+3}{3} = \frac{y-4}{5} = \frac{z+8}{6}. \tag{3.4.48.1}$$
49. Find the equation of the line given by
$$\frac{x-5}{3} = \frac{y+4}{7} = \frac{z-6}{2}. \tag{3.4.49.1}$$
50. Find the equation of the line passing through the origin and the point $\begin{pmatrix}5\\-2\\3\end{pmatrix}$.
51. Find the equation of the line passing through the points $\begin{pmatrix}3\\-2\\-5\end{pmatrix}, \begin{pmatrix}3\\-2\\6\end{pmatrix}$.
52. Find the angle between the following pair of lines:

a)
$$L_1 : \quad \boldsymbol{x} = \begin{pmatrix}2\\-5\\1\end{pmatrix} + \lambda_1 \begin{pmatrix}3\\2\\6\end{pmatrix} \tag{3.4.52.1}$$
$$L_2 : \quad \boldsymbol{x} = \begin{pmatrix}7\\-6\\0\end{pmatrix} + \lambda_2 \begin{pmatrix}1\\2\\2\end{pmatrix} \tag{3.4.52.2}$$

b)
$$L_1 : \quad \boldsymbol{x} = \begin{pmatrix}3\\1\\-2\end{pmatrix} + \lambda_1 \begin{pmatrix}1\\-1\\-2\end{pmatrix} \tag{3.4.52.3}$$
$$L_2 : \quad \boldsymbol{x} = \begin{pmatrix}2\\-1\\-56\end{pmatrix} + \lambda_2 \begin{pmatrix}3\\-5\\-4\end{pmatrix} \tag{3.4.52.4}$$

53. Find the angle between the following pair of lines

a)
$$\frac{x-2}{2} = \frac{y-1}{5} = \frac{z+3}{-3}, \tag{3.4.53.1}$$
$$\frac{x+2}{-1} = \frac{y-4}{8} = \frac{z-5}{4} \tag{3.4.53.2}$$

b)
$$\frac{x}{2} = \frac{y}{2} = \frac{z}{1}, \tag{3.4.53.3}$$
$$\frac{x-5}{4} = \frac{y-2}{1} = \frac{z-3}{8} \tag{3.4.53.4}$$

54. Find the values of p so that the lines
$$\frac{1-x}{3} = \frac{7y-14}{2p} = \frac{z-3}{2}, \tag{3.4.54.1}$$
$$\frac{7-7x}{3p} = \frac{y-5}{1} = \frac{6-z}{5} \tag{3.4.54.2}$$

are at right angles.

55. Show that the lines

$$\frac{x-5}{7} = \frac{y+2}{-5} = \frac{z}{1}, \tag{3.4.55.1}$$
$$\frac{x}{1} = \frac{y}{2} = \frac{z}{3} \tag{3.4.55.2}$$

are perpendicular to each other.

56. Find the shortest distance between the lines

$$L_1: \quad \boldsymbol{x} = \begin{pmatrix}1\\2\\1\end{pmatrix} + \lambda_1 \begin{pmatrix}1\\-1\\1\end{pmatrix} \tag{3.4.56.1}$$
$$L_2: \quad \boldsymbol{x} = \begin{pmatrix}2\\-1\\-1\end{pmatrix} + \lambda_2 \begin{pmatrix}2\\1\\2\end{pmatrix} \tag{3.4.56.2}$$

57. Find the shortest distance between the lines

$$\frac{x+1}{7} = \frac{y+1}{-6} = \frac{z+1}{1}, \tag{3.4.57.1}$$
$$\frac{x-3}{1} = \frac{y-5}{-2} = \frac{z-7}{1} \tag{3.4.57.2}$$

58. Find the shortest distance between the lines

$$L_1: \quad \boldsymbol{x} = \begin{pmatrix}1\\2\\3\end{pmatrix} + \lambda_1 \begin{pmatrix}1\\-3\\2\end{pmatrix} \tag{3.4.58.1}$$
$$L_2: \quad \boldsymbol{x} = \begin{pmatrix}4\\5\\6\end{pmatrix} + \lambda_2 \begin{pmatrix}2\\3\\1\end{pmatrix} \tag{3.4.58.2}$$

59. Find the shortest distance between the lines

$$L_1: \quad \boldsymbol{x} = \begin{pmatrix}1-t\\t-2\\3-2t\end{pmatrix} \tag{3.4.59.1}$$
$$L_2: \quad \boldsymbol{x} = \begin{pmatrix}s+1\\2s-1\\-2s-1\end{pmatrix} \tag{3.4.59.2}$$

60. In each of the following cases, determine the normal to the plane and the distance from the origin.

a) $\begin{pmatrix}0 & 0 & 1\end{pmatrix}\boldsymbol{x} = 2$ c) $\begin{pmatrix}0 & 5 & 0\end{pmatrix}\boldsymbol{x} = -8$
b) $\begin{pmatrix}1 & 1 & 1\end{pmatrix}\boldsymbol{x} = 1$ d) $\begin{pmatrix}2 & 3 & -1\end{pmatrix}\boldsymbol{x} = 5$

61. Find the equation of a plane which is at a distance of 7 units from the origin and normal to $\begin{pmatrix}3\\5\\-6\end{pmatrix}$.

62. For the following planes, find the coordinates of the foot of the perpendicular drawn from the origin

a) $\begin{pmatrix}2 & 3 & 4\end{pmatrix}\boldsymbol{x} = 12$ c) $\begin{pmatrix}1 & 1 & 1\end{pmatrix}\boldsymbol{x} = 1$
b) $\begin{pmatrix}3 & 4 & -6\end{pmatrix}\boldsymbol{x} = 0$ d) $\begin{pmatrix}0 & 5 & 0\end{pmatrix}\boldsymbol{x} = -8$

63. Find the equation of the planes

a) that passes through the point $\begin{pmatrix}1\\0\\-2\end{pmatrix}$ and the normal to the plane is $\begin{pmatrix}1\\1\\-1\end{pmatrix}$.

b) that passes through the point $\begin{pmatrix}1\\4\\6\end{pmatrix}$ and the normal vetor the plane is $\begin{pmatrix}1\\-2\\1\end{pmatrix}$.

64. Find the equation of the planes that passes through three points

a) $\begin{pmatrix}1\\1\\-1\end{pmatrix}, \begin{pmatrix}6\\4\\-5\end{pmatrix}, \begin{pmatrix}-4\\-2\\3\end{pmatrix}$

b) $\begin{pmatrix}1\\1\\0\end{pmatrix}, \begin{pmatrix}1\\2\\1\end{pmatrix}, \begin{pmatrix}-2\\2\\-1\end{pmatrix}$.

65. Find the intercepts cut off by the plane $\begin{pmatrix}2 & 1 & 1\end{pmatrix}\boldsymbol{x} = 5$.

66. Find the equaion of the plane with intercept 3 on the y-axis and parallel to ZOX plane.

67. Find the equation of the plane through the intersection of the planes $\begin{pmatrix}3 & -1 & 2\end{pmatrix}\boldsymbol{x} = 4$ and $\begin{pmatrix}1 & 1 & 1\end{pmatrix}\boldsymbol{x} = -2$ and the pont $\begin{pmatrix}2\\2\\1\end{pmatrix}$.

68. Find the equation of the plane passing through the intersection of the planes $\begin{pmatrix}2 & 2 & -3\end{pmatrix}\boldsymbol{x} = 7$ and $\begin{pmatrix}2 & 5 & 3\end{pmatrix}\boldsymbol{x} = 9$ and the pont $\begin{pmatrix}2\\1\\3\end{pmatrix}$.

69. Find the equation of the plane through the intersection of the planes $\begin{pmatrix}1 & 1 & 1\end{pmatrix}\boldsymbol{x} = 1$ and $\begin{pmatrix}2 & 3 & 4\end{pmatrix}\boldsymbol{x} = 5$ which is perpendicular to the plane $\begin{pmatrix}1 & -1 & 1\end{pmatrix}\boldsymbol{x} = 0$.

70. Find the angle between the planes whose equations are $\begin{pmatrix}2 & 2 & -3\end{pmatrix}\boldsymbol{x} = 5$ and $\begin{pmatrix}3 & -3 & 5\end{pmatrix}\boldsymbol{x} = 3$

71. In the following cases, determine whether the given planes are parallel or perpendicular, and in case they are neither, find the angles between them.
    a) $\begin{pmatrix}7 & 5 & 6\end{pmatrix}\boldsymbol{x} = -30$ and $\begin{pmatrix}3 & -1 & -10\end{pmatrix}\boldsymbol{x} = -4$
    b) $\begin{pmatrix}2 & 1 & 3\end{pmatrix}\boldsymbol{x} = 2$ and $\begin{pmatrix}1 & -2 & 5\end{pmatrix}\boldsymbol{x} = 0$
    c) $\begin{pmatrix}2 & -2 & 4\end{pmatrix}\boldsymbol{x} = -5$ and $\begin{pmatrix}3 & -3 & 6\end{pmatrix}\boldsymbol{x} = 1$
    d) $\begin{pmatrix}2 & -1 & 3\end{pmatrix}\boldsymbol{x} = 1$ and $\begin{pmatrix}2 & -1 & 3\end{pmatrix}\boldsymbol{x} = -3$
    e) $\begin{pmatrix}4 & 8 & 1\end{pmatrix}\boldsymbol{x} = 8$ and $\begin{pmatrix}0 & 1 & 1\end{pmatrix}\boldsymbol{x} = 4$
72. In the following cases, find the distance of each of the given points from the corresponding plane.

Item	Point	Plane
a)	$\begin{pmatrix}0\\0\\0\end{pmatrix}$	$\begin{pmatrix}3 & -4 & 12\end{pmatrix}\boldsymbol{x} = 3$
b)	$\begin{pmatrix}3\\-2\\1\end{pmatrix}$	$\begin{pmatrix}2 & -1 & 2\end{pmatrix}\boldsymbol{x} = -3$
c)	$\begin{pmatrix}2\\3\\-5\end{pmatrix}$	$\begin{pmatrix}1 & 2 & -2\end{pmatrix}\boldsymbol{x} = 9$
d)	$\begin{pmatrix}-6\\0\\0\end{pmatrix}$	$\begin{pmatrix}2 & -3 & 6\end{pmatrix}\boldsymbol{x} = 2$

TABLE 3.4.72

73. Show that the line joining the origin to the point $\begin{pmatrix}2\\1\\1\end{pmatrix}$ is perpendicular to the line determined by the points $\begin{pmatrix}3\\5\\-1\end{pmatrix}, \begin{pmatrix}4\\3\\-1\end{pmatrix}$.
74. If the coordinates of the points $\boldsymbol{A}, \boldsymbol{B}, \boldsymbol{C}, \boldsymbol{D}$ be $\begin{pmatrix}1\\2\\3\end{pmatrix}, \begin{pmatrix}4\\5\\7\end{pmatrix}, \begin{pmatrix}-4\\3\\-6\end{pmatrix}, \begin{pmatrix}2\\9\\2\end{pmatrix}$, then find the angle between the lines AB and CD.
75. If the lines

$$\frac{x-1}{-3} = \frac{y-2}{2k} = \frac{z-3}{2}, \tag{3.4.75.1}$$

$$\frac{x-3}{3k} = \frac{y-1}{1} = \frac{z-6}{-5}, \tag{3.4.75.2}$$

find the value of k.

76. Find the equation of the line passing through $\begin{pmatrix}1\\2\\3\end{pmatrix}$ and perpendicular to the plane

$$\begin{pmatrix}1 & 2 & -5\end{pmatrix}\boldsymbol{x} = -9 \tag{3.4.76.1}$$

77. Find the shortest distance between the lines

$$\mathbf{x} = \begin{pmatrix}6\\2\\2\end{pmatrix} + \lambda_1\begin{pmatrix}1\\-2\\2\end{pmatrix} \text{ and} \tag{3.4.77.1}$$

$$\mathbf{x} = \begin{pmatrix}-4\\0\\-1\end{pmatrix} + \lambda_2\begin{pmatrix}3\\-2\\-2\end{pmatrix} \tag{3.4.77.2}$$

78. Find the coordinates of the point where the line through $\begin{pmatrix}5\\1\\6\end{pmatrix}$ and $\begin{pmatrix}3\\4\\1\end{pmatrix}$ crosses the YZ-plane.
79. Find the coordinates of the point where the line through $\begin{pmatrix}5\\1\\6\end{pmatrix}$ and $\begin{pmatrix}3\\4\\1\end{pmatrix}$ crosses the ZX-plane.
80. Find the coordinates of the point where the line through $\begin{pmatrix}3\\-4\\-5\end{pmatrix}$ and $\begin{pmatrix}\\-3\\1\end{pmatrix}$ crosses the plane

$$\begin{pmatrix}2 & 1 & 1\end{pmatrix}\boldsymbol{x} = 7 \tag{3.4.80.1}$$

81. Find the equation of the plane passing through the point $\begin{pmatrix}-1\\3\\2\end{pmatrix}$ and perpendicular to each of the planes

$$\begin{pmatrix}1 & 2 & 3\end{pmatrix}\boldsymbol{x} = 5 \tag{3.4.81.1}$$

$$\begin{pmatrix}3 & 3 & 1\end{pmatrix}\boldsymbol{x} = 0 \tag{3.4.81.2}$$

82. If the points $\begin{pmatrix}1\\1\\p\end{pmatrix}$ and $\begin{pmatrix}-3\\0\\1\end{pmatrix}$ be equidistant from the plane

$$\begin{pmatrix}3 & 4 & -12\end{pmatrix}\boldsymbol{x} = -13, \tag{3.4.82.1}$$

then find the value of p.

83. Find the equation of the plane passing through the line of intersection of the planes

$$\begin{pmatrix}1 & 1 & 1\end{pmatrix}\boldsymbol{x} = 1 \text{ and} \tag{3.4.83.1}$$

$$\begin{pmatrix}2 & 3 & -1\end{pmatrix}\boldsymbol{x} = -4 \tag{3.4.83.2}$$

and parallel to the x-axis.

84. If **O** be the origin and the coordinates of **P** be $\begin{pmatrix}1\\2\\3\end{pmatrix}$, then find the equation of the plane passing through **P** and perpendicular to OP.

85. Find the equation of the plane which contains the line of intersection of the planes

$$\begin{pmatrix}1 & 2 & 3\end{pmatrix}\boldsymbol{x} = 4 \tag{3.4.85.1}$$

$$\begin{pmatrix}2 & 1 & -1\end{pmatrix}\boldsymbol{x} = -5 \tag{3.4.85.2}$$

and which is perpendicular to the plane

$$\begin{pmatrix}5 & 3 & -6\end{pmatrix}\boldsymbol{x} = -8 \tag{3.4.85.3}$$

86. Find the distance of the point $\begin{pmatrix}-1\\-5\\-10\end{pmatrix}$ from the point of intersection of the line

$$\mathbf{x} = \begin{pmatrix}2\\-1\\2\end{pmatrix} + \lambda\begin{pmatrix}3\\4\\2\end{pmatrix} \tag{3.4.86.1}$$

and the plane

$$\begin{pmatrix}1 & -1 & 1\end{pmatrix}\boldsymbol{x} = 5 \tag{3.4.86.2}$$

87. Find the vector equation of the line passing through $\begin{pmatrix}1\\2\\3\end{pmatrix}$ and parallel to the planes

$$\begin{pmatrix}1 & -1 & 2\end{pmatrix}\boldsymbol{x} = 5 \tag{3.4.87.1}$$

$$\begin{pmatrix}3 & 1 & 1\end{pmatrix}\boldsymbol{x} = 6 \tag{3.4.87.2}$$

88. Find the vector equation of the line passing through the point $\begin{pmatrix}1\\2\\-4\end{pmatrix}$ and perpendicular to the two lines

$$\frac{x-8}{3} = \frac{y+19}{-16} = \frac{z-10}{7}, \tag{3.4.88.1}$$

$$\frac{x-15}{3} = \frac{y-29}{8} = \frac{z-5}{-5} \tag{3.4.88.2}$$

89. Distance between the two planes

$$\begin{pmatrix}2 & 3 & 4\end{pmatrix}\boldsymbol{x} = 4 \tag{3.4.89.1}$$

$$\begin{pmatrix}4 & 6 & 8\end{pmatrix}\boldsymbol{x} = 12 \tag{3.4.89.2}$$

a) 2
b) 4
c) 8
d) $\frac{2}{\sqrt{29}}$

90. The planes

$$\begin{pmatrix}2 & -1 & 4\end{pmatrix}\boldsymbol{x} = 5 \tag{3.4.90.1}$$

$$\begin{pmatrix}5 & -\frac{5}{2} & 10\end{pmatrix}\boldsymbol{x} = 6 \tag{3.4.90.2}$$

are

a) Perpendicular
b) Parallel
c) intersect y-axis
d) passes through $\begin{pmatrix}0\\0\\\frac{5}{4}\end{pmatrix}$

3.5 *Miscellaneous*

1. In $\triangle ABC$, Show that the centroid

$$\mathbf{O} = \frac{\mathbf{A}+\mathbf{B}+\mathbf{C}}{3} \tag{3.5.1.1}$$

2. (Cauchy-Schwarz Inequality:) Show that

$$\left|\mathbf{a}^T\mathbf{b}\right| \le \|\mathbf{a}\|\,\|\mathbf{b}\| \tag{3.5.2.1}$$

3. (Triangle Inequality:) Show that

$$\|\mathbf{a}+\mathbf{b}\| \le \|\mathbf{a}\| + \|\mathbf{b}\| \tag{3.5.3.1}$$

4. The base of an equilateral triangle with side $2a$ lies along the y-axis such that the mid-point of the base is at the origin. Find vertices of the triangle.

5. Find the distance between $\mathbf{P} = \begin{pmatrix}x_1\\y_1\end{pmatrix}$ and $\mathbf{Q} = \begin{pmatrix}x_2\\y_2\end{pmatrix}$ when
   a) PQ is parallel to the y-axis.
   b) PQ is parallel to the x-axis.

6. If three points $\begin{pmatrix}h\\0\end{pmatrix}$, $\begin{pmatrix}a\\b\end{pmatrix}$ and $\begin{pmatrix}0\\k\end{pmatrix}$ lie on a line, show that $\frac{a}{h}+\frac{b}{k} = 1$.

7. $\mathbf{P} = \begin{pmatrix}a\\b\end{pmatrix}$ is the mid-point of a line segment between axes. Show that equation of the line is

$$\begin{pmatrix}\frac{1}{a} & \frac{1}{b}\end{pmatrix}\mathbf{x} = 2 \tag{3.5.7.1}$$

8. Point $\mathbf{R} = \begin{pmatrix}h\\k\end{pmatrix}$ divides a line segment between the axes in the ratio 1: 2. Find equation of the line.

9. Show that two lines

$$\begin{pmatrix} a_1 & b_1 \end{pmatrix} \mathbf{x} + c_1 = 0 \tag{3.5.9.1}$$

$$\begin{pmatrix} a_2 & b_2 \end{pmatrix} \mathbf{x} + c_2 = 0 \tag{3.5.9.2}$$

are

a) parallel if $\frac{a_1}{b_1} = \frac{a_2}{b_2}$ and
b) perpendicular if $a_1 a_2 - b_1 b_2 = 0$.

10. Find the distance between the parallel lines

$$l \begin{pmatrix} 1 & 1 \end{pmatrix} \mathbf{x} = -p \tag{3.5.10.1}$$

$$l \begin{pmatrix} 1 & 1 \end{pmatrix} \mathbf{x} = r \tag{3.5.10.2}$$

11. Find th equation of the line through the point $\mathbf{x}_1$ and parallel to the line

$$\begin{pmatrix} A & B \end{pmatrix} \mathbf{x} = -C \tag{3.5.11.1}$$

12. If p and q are the lengths of perpendiculars from the origin to the lines

$$\begin{pmatrix} \cos\theta & \sin\theta \end{pmatrix} \mathbf{x} = k\cos 2\theta \tag{3.5.12.1}$$

$$\begin{pmatrix} \sec\theta & \operatorname{cosec}\theta \end{pmatrix} \mathbf{x} = k \tag{3.5.12.2}$$

respectively, prove that $p^2 + 4q^2 = k^2$.

13. If p is the length of the perpendicular from the origin to the line whose intercepts on the axes are a and b, then show that

$$\frac{1}{p^2} = \frac{1}{a^2} + \frac{1}{b^2}. \tag{3.5.13.1}$$

14. Show that the area of the triangle formed by the lines

$$\begin{pmatrix} -m_1 & 1 \end{pmatrix} \mathbf{x} = c_1 \tag{3.5.14.1}$$

$$\begin{pmatrix} -m_2 & 1 \end{pmatrix} \mathbf{x} = c_2 \tag{3.5.14.2}$$

$$\begin{pmatrix} 1 & 0 \end{pmatrix} \mathbf{x} = 0 \tag{3.5.14.3}$$

is $\frac{(c_1-c_2)^2}{2|m_1-m_2|}$.

15. Find the values of k for which the line

$$\begin{pmatrix} k-3 & -\left(4-k^2\right) \end{pmatrix} \mathbf{x} + k^2 - 7k + 6 = 0 \tag{3.5.15.1}$$

is

a) parallel to the x-axis
b) parallel to the y-axis
c) passing through the origin.

16. Find the perpendicular distance from the origin to the line joining the points $\begin{pmatrix} \cos\theta \\ \sin\theta \end{pmatrix}$ and $\begin{pmatrix} \cos\phi \\ \sin\phi \end{pmatrix}$.

17. Find the area of the triangle formed by the lines

$$\begin{pmatrix} 1 & -1 \end{pmatrix} \mathbf{x} = 0 \tag{3.5.17.1}$$

$$\begin{pmatrix} 1 & 1 \end{pmatrix} \mathbf{x} = 0 \tag{3.5.17.2}$$

$$\begin{pmatrix} 1 & 0 \end{pmatrix} \mathbf{x} = k \tag{3.5.17.3}$$

18. If three lines whose equations are

$$\begin{pmatrix} -m_1 & 1 \end{pmatrix} \mathbf{x} = c_1 \tag{3.5.18.1}$$

$$\begin{pmatrix} -m_2 & 1 \end{pmatrix} \mathbf{x} = c_2 \tag{3.5.18.2}$$

$$\begin{pmatrix} -m_3 & 1 \end{pmatrix} \mathbf{x} = c_3 \tag{3.5.18.3}$$

are concurrent, show that

$$m_1(c_2 - c_3) + m_2(c_3 - c_1) + m_3(c_1 - c_2) = 0 \tag{3.5.18.4}$$

19. Find the equation of the line passing through the origin and making an angle θ with the line

$$\begin{pmatrix} -m & 1 \end{pmatrix} \mathbf{x} = c \tag{3.5.19.1}$$

20. Prove that the product of the lengths of the perpendiculars drawn from the points $\begin{pmatrix} \sqrt{a^2-b^2} \\ 0 \end{pmatrix}$ and $\begin{pmatrix} \sqrt{a^2-b^2} \\ 0 \end{pmatrix}$ to the line

$$\begin{pmatrix} \frac{\cos\theta}{a} & \frac{\sin\theta}{b} \end{pmatrix} \mathbf{x} = 1 \tag{3.5.20.1}$$

is b^2.

21. If $\begin{pmatrix} l_1 \\ m_1 \\ n_1 \end{pmatrix}$ and $\begin{pmatrix} l_2 \\ m_2 \\ n_2 \end{pmatrix}$ are the unit direction vectors of two mutually perpendicular lines, the shown that the unit direction vector of the line perpendicular to both of these is $\begin{pmatrix} m_1 n_2 - m_2 n_1 \\ n_1 l_2 - n_2 l_1 \\ l_1 m_2 - l_2 m_1 \end{pmatrix}$.

22. A line makes angles $\alpha, \beta, \gamma, \delta$ with the diagonals of a cube, prove that

$$\cos^2\alpha + \cos^2\beta + \cos^2\gamma + \cos^2\delta = \frac{4}{3}. \tag{3.5.22.1}$$

23. Show that the lines

$$\frac{x-a+d}{\alpha-\delta} = \frac{y-a}{\alpha} = \frac{z-a-d}{\alpha+\delta}, \tag{3.5.23.1}$$

$$\frac{x-b+c}{\beta-\gamma} = \frac{y-b}{\beta} = \frac{z-b-c}{\beta+\gamma} \tag{3.5.23.2}$$

are coplanar.

24. Find $\mathbf{R}$ which divides the line joining the points
$$\mathbf{P} = 2\mathbf{a} + \mathbf{b} \tag{3.5.24.1}$$
$$\mathbf{Q} = \mathbf{a} - \mathbf{b} \tag{3.5.24.2}$$
externally in the ratio 1 : 2.

25. Find $\|\mathbf{a}\|$ and $\|\mathbf{b}\|$ if
$$(\mathbf{a} + \mathbf{b})^T (\mathbf{a} - \mathbf{b}) = 8 \tag{3.5.25.1}$$
$$\|\mathbf{a}\| = 8\,\|\mathbf{b}\| \tag{3.5.25.2}$$

26. Evaluate the product
$$(3\mathbf{a} - 5\mathbf{b})^T (2\mathbf{a} + 7\mathbf{b}) \tag{3.5.26.1}$$

27. Find $\|\mathbf{a}\|$ and $\|\mathbf{b}\|$, if
$$\|\mathbf{a}\| = \|\mathbf{b}\|, \tag{3.5.27.1}$$
$$\mathbf{a}^T\mathbf{b} = \frac{1}{2} \tag{3.5.27.2}$$
and the angle between $\mathbf{a}$ and $\mathbf{b}$ is 60°.

28. Show that
$$(\|\mathbf{a}\|\,\mathbf{b} + \|\mathbf{b}\|\,\mathbf{a}) \perp (\|\mathbf{a}\|\,\mathbf{b} - \|\mathbf{b}\|\,\mathbf{a}) \tag{3.5.28.1}$$

29. If $\mathbf{a}^T\mathbf{a} = 0$ and $\mathbf{ab} = 0$, what can be concluded about the vector $\mathbf{b}$?

30. If $\mathbf{a}, \mathbf{b}, \mathbf{c}$ are unit vectors such that
$$\mathbf{a} + \mathbf{b} + \mathbf{c} = 0, \tag{3.5.30.1}$$
find the value of
$$\mathbf{a}^T\mathbf{b} + \mathbf{b}^T\mathbf{c} + \mathbf{c}^T\mathbf{a}. \tag{3.5.30.2}$$

31. If $\mathbf{a} \neq \mathbf{0}, \lambda \neq 0$, then $\|\lambda\mathbf{a}\| = 1$ if
    a) $\lambda = 1$
    b) $\lambda = -1$
    c) $\|\mathbf{a}\| = |\lambda|$
    d) $\|\mathbf{a}\| = \frac{1}{|\lambda|}$

32. If a unit vector $\mathbf{a}$ makes angles $\frac{\pi}{3}$ with the x-axis and $\frac{\pi}{4}$ with the y-axis and an acute angle θ with the z-axis, find θ and $\mathbf{a}$.

33. Show that
$$(\mathbf{a} - \mathbf{b}) \times (\mathbf{a} + \mathbf{b}) = 2\,(\mathbf{a} \times \mathbf{b}) \tag{3.5.33.1}$$

34. If $\mathbf{a}^T\mathbf{b} = 0$ and $\mathbf{a}\times\mathbf{b} = 0$, what can you conclude about $\mathbf{a}$ and $\mathbf{b}$?

35. Find $\mathbf{x}$ if $\mathbf{a}$ is a unit vector such that
$$(\mathbf{x} - \mathbf{a})^T (\mathbf{x} + \mathbf{a}) = 12. \tag{3.5.35.1}$$

36. If $\|\mathbf{a}\| = 3, \|\mathbf{b}\| = \frac{\sqrt{2}}{3}$, then $\mathbf{a}\times\mathbf{b}$ is a unit vector if the angle between $\mathbf{a}$ and $\mathbf{b}$ is
    a) $\frac{\pi}{6}$ c) $\frac{\pi}{3}$
    b) $\frac{\pi}{4}$ d) $\frac{\pi}{2}$

37. Prove that
$$(\mathbf{a} + \mathbf{b})^T (\mathbf{a} + \mathbf{b}) = \|\mathbf{a}\|^2 + \|\mathbf{b}\|^2 \tag{3.5.37.1}$$
$$\iff \mathbf{a} \perp \mathbf{b}. \tag{3.5.37.2}$$

38. If θ is the angle between two vectors $\mathbf{a}$ and $\mathbf{b}$, then $\mathbf{a}^T\mathbf{b} \geq$ only when
    a) $0 < \theta < \frac{\pi}{2}$ c) $0 < \theta < \pi$
    b) $0 \leq \theta \leq \frac{\pi}{2}$ d) $0 \leq \theta \leq \pi$

39. Let $\mathbf{a}$ and $\mathbf{b}$ be two unit vectors and θ be the angle between them. Then $\mathbf{a}+\mathbf{b}$ is a unit vector if
    a) $\theta = \frac{\pi}{4}$ c) $\theta = \frac{\pi}{2}$
    b) $\theta = \frac{\pi}{3}$ d) $\theta = \frac{2\pi}{3}$

40. If θ is the angle between any two vectors $\mathbf{a}$ and $\mathbf{b}$, then $\left\|\mathbf{a}^T\mathbf{b}\right\| = \|\mathbf{a} \times \mathbf{b}\|$ when θ is equal to
    a) 0   c) $\frac{\pi}{2}$
    b) $\frac{\pi}{4}$ d) π.

41. Find the angle between the lines whose direction vectors are $\begin{pmatrix} a \\ b \\ c \end{pmatrix}$ and $\begin{pmatrix} b-c \\ c-a \\ a-b \end{pmatrix}$.

42. Find the equation of a line parallel to the x-axis and passing through the origin.

43. Find the equation of a plane passing through $\begin{pmatrix} a \\ b \\ c \end{pmatrix}$ and parallel to the plane
$$\begin{pmatrix} 1 & 1 & 1 \end{pmatrix} \boldsymbol{x} = 2 \tag{3.5.43.1}$$

44. Prove that if a plane has the intercepts a, b, c and is at a distance of p units from the origin, then,
$$\frac{1}{a^2} + \frac{1}{b^2} + \frac{1}{c^2} = \frac{1}{p^2} \tag{3.5.44.1}$$

4 Circle

4.1 Construction Examples

1. Draw a circle with centre $\mathbf{B}$ and radius 6. If $\mathbf{C}$ be a point 10 units away from its centre,

construct the pair of tangents AC and CD to the circle.

Solution: The tangent is perpendicular to the radius. From the given information, in $\triangle ABC, AC \perp AB, a = 10$ and $c = 6$.

$$b = \sqrt{a^2 - c^2} \tag{4.1.1.1}$$

The following code plots Fig. 4.1.1

```
codes/circle/draw_circle_eg.py
```

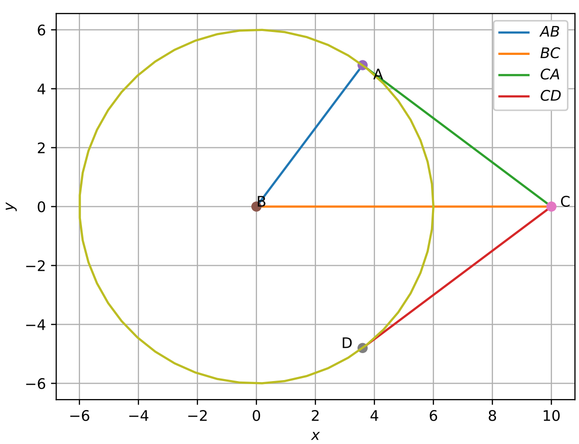

Fig. 4.1.1

2. Draw a circle of radius 3. Mark any point **A** on the circle, point **B** inside the circle and point **C** outside the circle.
   Solution: For any angle θ, a point on the circle with radius 3 has coordinates

$$3\begin{pmatrix}\cos\theta \\ \sin\theta\end{pmatrix} \tag{4.1.2.1}$$

4.2 Construction Exercises

1. Draw a circle of diameter 6.1
2. With the same centre **O**, draw two circles of radii 4 and 2.5
3. Draw a circle of radius 3 and any two of its diameters. draw the ends of these diameters. What figure do you get?
4. Let **A** and **B** be two circles of equal radii 3 such that each one of them passes through the centre of the other. Let them intersect at **C** and **D**. Is $AB \perp CD$?
5. Construct a tangent to a circle of radius 4 units from a point on the concentric circle of radius 6 units.
   Solution: Take the centre of both circles to be at the origin.
6. Draw a circle of radius 3 units. Take two points **P** and **Q** on one of its extended diameter each at a distance of 7 units from its centre. Draw tangents to the circle from these two points **P** and **Q**.
   Solution: Take the diameter to be on the x-axis.
7. Draw a pair of tangents to a circle of radius 5 units which are inclined to each other at an angle of 60°.
   Solution: The tangent is perpendicular to the radius.
8. Draw a line segment AB of length 8 units. Taking **A** as centre, draw a circle of radius 4 units and taking **B** as centre, draw another circle of radius 3 units. Construct tangents to each circle from the centre of the other circle.
   Solution: Let

$$\mathbf{A} = \begin{pmatrix}0 \\ 0\end{pmatrix}, \mathbf{B} = \begin{pmatrix}8 \\ 0\end{pmatrix}. \tag{4.2.2.1}$$

9. Let ABC be a right triangle in which $a = 8, c = 6$ and $\angle B = 90^{\circ}$. BD is the perpendicular from **B** on AC (altitude). The circle through **B, C, D** (circumcircle of $\triangle BCD$) is drawn. Construct the tangents from **A** to this circle.
10. Draw a circle with centre **C** and radius 3.4. Draw any chord. Construct the perpendicular bisector of the chord and examine if it passes through **C**

4.3 Circle Geometry

1. Find the coordinates of a point **A**, where AB is the diameter of a circle whose centre is $\begin{pmatrix}2, -3\end{pmatrix}$ and $\mathbf{B} = \begin{pmatrix}1 \\ 4\end{pmatrix}$.
2. Find the centre of a circle passing through the points $\begin{pmatrix}6 \\ -6\end{pmatrix}, \begin{pmatrix}3 \\ -7\end{pmatrix}$ and $\begin{pmatrix}3 \\ 3\end{pmatrix}$.
3. Find the locus of all the unit vectors in the xy-plane.