# Circle Assignment

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***Abstract*—This document contains the solution to Question 12 of Exercise 5 in Chapter 10 of the class 9 NCERT textbook.**

1) Prove that a cyclic paralellogram is a rectangle.
   **Solution:** Consider the points $\mathbf{P_i}$, $1 \le i \le 4$ in anticlockwise order on the unit circle. Thus, for $1 \le i \le 4$,

$$\mathbf{P_i} = \begin{pmatrix} \cos\theta_i \\ \sin\theta_i \end{pmatrix} \tag{1}$$

where

$$\theta_i \in [0, 2\pi),\ i \neq j \iff \theta_i \neq \theta_j \tag{2}$$

Without loss of generality, suppose that $P_1P_2$ and $P_3P_4$ are parallel to the $x$-axis. Since

$$\mathbf{P_1} - \mathbf{P_2} = \begin{pmatrix} \cos\theta_1 - \cos\theta_2 \\ \sin\theta_1 - \sin\theta_2 \end{pmatrix} \tag{3}$$

$$\mathbf{P_3} - \mathbf{P_4} = \begin{pmatrix} \cos\theta_4 - \cos\theta_4 \\ \sin\theta_3 - \sin\theta_4 \end{pmatrix} \tag{4}$$

we have

$$\sin\theta_1 = \sin\theta_2 \tag{5}$$

$$\implies \theta_1 = n\pi + (-1)^n \theta_2 \tag{6}$$

However, (2) forces $n \in \{1, 3\}$, thus

$$\theta_1 + \theta_2 \in \{\pi, 3\pi\} \tag{7}$$

Similarly,

$$\theta_3 + \theta_4 \in \{\pi, 3\pi\} \tag{8}$$

Since $P_1P_2P_3P_4$ is a parallelogram, its diagonals bisect each other. Thus, using (7) and (8),

$$\frac{\mathbf{P_1} + \mathbf{P_3}}{2} = \frac{\mathbf{P_2} + \mathbf{P_4}}{2} \tag{9}$$

$$\implies \mathbf{P_1} + \mathbf{P_3} = \mathbf{P_2} + \mathbf{P_4} \tag{10}$$

$$\implies \begin{pmatrix} \cos\theta_1 + \cos\theta_3 \\ \sin\theta_1 + \sin\theta_3 \end{pmatrix} = \begin{pmatrix} \cos\theta_2 + \cos\theta_4 \\ \sin\theta_2 + \sin\theta_4 \end{pmatrix} \tag{11}$$

$$\implies \cos\theta_1 + \cos\theta_3 = \cos\theta_2 + \cos\theta_4 \tag{12}$$

$$= -(\cos\theta_1 + \cos\theta_3) \tag{13}$$

$$\implies \cos\theta_1 + \cos\theta_3 = \cos\theta_2 + \cos\theta_4 = 0 \tag{14}$$

Using (14), (7) and (8), we have

$$\cos\theta_1 = -\cos\theta_3 = \cos\theta_4 \tag{15}$$

$$\cos\theta_2 = -\cos\theta_4 = \cos\theta_3 \tag{16}$$

Thus,

$$\mathbf{P_1} - \mathbf{P_4} = \begin{pmatrix} \cos\theta_1 - \cos\theta_4 \\ \sin\theta_1 - \sin\theta_4 \end{pmatrix} \tag{17}$$

$$= \begin{pmatrix} 0 \\ \sin\theta_1 - \sin\theta_4 \end{pmatrix} \tag{18}$$

Thus, from (18),

$$(\mathbf{P_1} - \mathbf{P_2})^\top (\mathbf{P_1} - \mathbf{P_4}) = \begin{pmatrix} \cos\theta_1 - \cos\theta_2 & 0 \end{pmatrix} \begin{pmatrix} 0 \\ \sin\theta_1 - \sin\theta_4 \end{pmatrix} = 0 \tag{19}$$

From (19), we see that $P_1P_2 \perp P_1P_4$. Hence, $P_1P_2P_3P_4$ is a rectangle.
The situation is demonstrated in Fig. 1, plotted by the Python code `codes/circle.py`. The various input parameters are shown in Table 1.

| Parameter | Value |
|---|---|
| $r$ | 1 |
| $\theta_1$ | $\frac{\pi}{6}$ |
| $\theta_2$ | $\frac{5\pi}{6}$ |
| $\theta_3$ | $\frac{7\pi}{6}$ |
| $\theta_4$ | $\frac{11\pi}{6}$ |
| $\mathbf{O}$ | $\begin{pmatrix}0\\0\end{pmatrix}$ |

TABLE 1: Parameters used in the construction of Fig. 1.

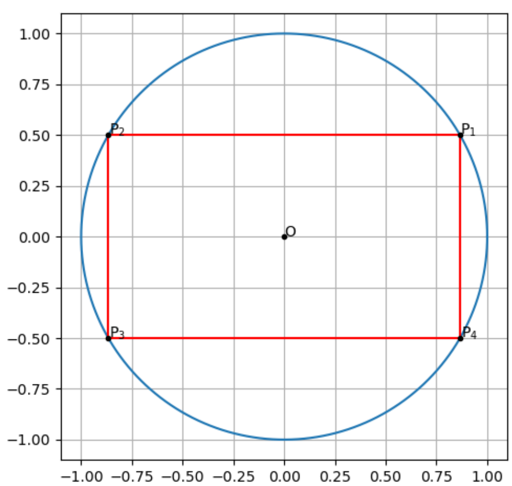


Fig. 1: $P_1P_2P_3P_4$ is a rectangle.