

# Problem: 11.11.3.9

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## 1 PROBLEM

Find the co-ordinates of the foci, the vertices, the length of major axis, the minor axis, the eccentricity and the length of latus rectum of the ellipse  $4x^2 + 9y^2 = 36$ .

## 2 SOLUTION

1) Given ellipse equation:

$$\mathbf{x}^T \mathbf{V} \mathbf{x} + 2\mathbf{u}^T \mathbf{x} + f = 0 \quad (2.0.1)$$

$$\text{here, } \mathbf{V} = \begin{pmatrix} \frac{4}{9} & 0 \\ 0 & 1 \end{pmatrix} \quad (2.0.2)$$

$$f = -4 \quad (2.0.3)$$

$$\mathbf{u} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (2.0.4)$$

2) points of intersection of a line  $\mathbf{x} = \mathbf{h} + \mu \mathbf{m}$  with ellipse are given by:

$$\mu_i = \frac{1}{\mathbf{m}^T \mathbf{V} \mathbf{m}} \left( -\mathbf{m}^T (\mathbf{V} \mathbf{h} + \mathbf{u}) \pm \sqrt{(\mathbf{m}^T (\mathbf{V} \mathbf{h} + \mathbf{u}))^2 - g(\mathbf{h}) (\mathbf{m}^T \mathbf{V} \mathbf{m})} \right) \quad (2.0.5)$$

where,

$$g(\mathbf{h}) = \mathbf{h}^T \mathbf{V} \mathbf{h} + 2\mathbf{u}^T \mathbf{h} + f \quad (2.0.6)$$

3) Center of the Ellipse

$$\mathbf{c} = -\mathbf{V}^{-1} \mathbf{u} \quad (2.0.7)$$

$$= \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (2.0.8)$$

4) Major axis

$$\mathbf{p}_2^T (\mathbf{x} - \mathbf{c}) = 0 \quad (2.0.9)$$

$$\begin{pmatrix} 0 & 1 \end{pmatrix} \mathbf{x} = 0 \quad (2.0.10)$$

$$\text{i.e., } \mathbf{x} = \mu \begin{pmatrix} 1 \\ 0 \end{pmatrix} \quad (2.0.11)$$

5) Vertices

Vertices lie on major axis, therefore let

$$\mathbf{v} = \mu_i \begin{pmatrix} 1 \\ 0 \end{pmatrix} \quad (2.0.12)$$

$$\mathbf{m}^T \mathbf{V} \mathbf{m} = \frac{4}{9} \quad (2.0.13)$$

$$\mathbf{m}^T (\mathbf{V} \mathbf{h} + \mathbf{u}) = 0 \quad (2.0.14)$$

$$g(\mathbf{h}) = -4 \quad (2.0.15)$$

$$\mu_i = \frac{0 \pm \sqrt{0 - (-4) \frac{4}{9}}}{\frac{4}{9}} \quad (2.0.16)$$

$$= \pm 3 \quad (2.0.17)$$

Vertices are  $\begin{pmatrix} 3 \\ 0 \end{pmatrix}$  and  $\begin{pmatrix} -3 \\ 0 \end{pmatrix}$

6) Length of major axis

length of major axis = distance between vertices (2.0.18)

$$= 6 \quad (2.0.19)$$

7) minor axis

$$\begin{pmatrix} 1 & 0 \end{pmatrix} \mathbf{x} = 0 \quad (2.0.20)$$

$$\mu_i = \frac{1}{\mathbf{m}^T \mathbf{V} \mathbf{m}} \left( -\mathbf{m}^T (\mathbf{V} \mathbf{h} + \mathbf{u}) \pm \sqrt{(\mathbf{m}^T (\mathbf{V} \mathbf{h} + \mathbf{u}))^2 - g(\mathbf{h}) (\mathbf{m}^T \mathbf{V} \mathbf{m})} \right) \quad (2.0.21)$$

$$\mathbf{m}^T \mathbf{V} \mathbf{m} = 1 \quad (2.0.22)$$

$$\mathbf{m}^T (\mathbf{V} \mathbf{h} + \mathbf{u}) = 0 \quad (2.0.23)$$

$$g(\mathbf{h}) = -4 \quad (2.0.24)$$

$$\mu_i = 0 \pm \sqrt{0 - (-4)} \quad (2.0.25)$$

$$= \pm 2 \quad (2.0.26)$$

Points of intersection of minor axis with ellipse be  $\mu_i \begin{pmatrix} 0 \\ 1 \end{pmatrix}$

Points of intersection of minor axis with ellipse =  $\pm \begin{pmatrix} 0 \\ 2 \end{pmatrix}$  (2.0.27)

## 8) Length of minor axis

here,

$$\text{length of minor axis} = \text{distance between Points of intersection} \mathbf{m}^\top \mathbf{V} \mathbf{m} = 1 \quad (2.0.44)$$

$$\mathbf{m}^\top (\mathbf{V} \mathbf{h} + \mathbf{u}) = 0 \quad (2.0.45)$$

$$= 4 \quad (2.0.29)$$

$$g(h) = -\frac{16}{9} \quad (2.0.46)$$

Normal to directrix,

$$\mathbf{n} = \text{direction vector of major axis} \quad (2.0.30)$$

$$= \begin{pmatrix} 1 \\ 0 \end{pmatrix} \quad (2.0.31)$$

$$\mu_i = 0 \pm \sqrt{0 - (-1) \frac{16}{9}} \quad (2.0.47)$$

$$= \pm \frac{4}{3} \quad (2.0.48)$$

## 12) Length of latus recta

$$\text{length of latus recta} = \text{distance between points of intersection} \quad (2.0.49)$$

$$= \frac{8}{3} \quad (2.0.50)$$

$$\mathbf{V} = \|\mathbf{n}\|^2 \mathbf{I} - e^2 \mathbf{n} \mathbf{n}^\top = \begin{pmatrix} \frac{4}{9} & 0 \\ 0 & 1 \end{pmatrix} \quad (2.0.32)$$

$$\mathbf{u} = ce^2 \mathbf{n} - \|\mathbf{n}\|^2 \mathbf{F} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (2.0.33)$$

$$f = \|\mathbf{n}\|^2 \|\mathbf{F}\|^2 - c^2 e^2 = -4 \quad (2.0.34)$$

## 9) Eccentricity

Substituting value of  $\mathbf{n}$  in (??),

$$e = \frac{\sqrt{5}}{3} \quad (2.0.35)$$

substituting (??) in (??) and (??),

$$\mathbf{F} = \frac{5c}{9} \begin{pmatrix} 1 \\ 0 \end{pmatrix} \quad (2.0.36)$$

$$\|\mathbf{F}\|^2 = c^2 e^2 - 4 = \frac{25c^2}{81} \quad (2.0.37)$$

upon substituting (??) in (??),

$$c = \pm \frac{9}{\sqrt{5}} \quad (2.0.38)$$

## 10) Foci

substitung (??) in (??),

$$\mathbf{F} = \begin{pmatrix} \pm \sqrt{5} \\ 0 \end{pmatrix} \quad (2.0.39)$$

## 11) equation of Latus Recta

$$\mathbf{n}^\top (\mathbf{x} - \mathbf{F}) = 0 \quad (2.0.40)$$

$$\begin{pmatrix} 1 & 0 \end{pmatrix} \mathbf{x} = 3 \quad (2.0.41)$$

$$i.e., \mathbf{x} = \begin{pmatrix} 3 \\ 0 \end{pmatrix} + \mu \begin{pmatrix} 0 \\ 1 \end{pmatrix} \quad (2.0.42)$$

Let points of intersection of latus rectum and curve be,

$$\mathbf{x} = \mathbf{F} + \mu_i \mathbf{m} \quad (2.0.43)$$

Parameter	Value	Description
$\mathbf{V}$	$\begin{pmatrix} \frac{4}{9} & 0 \\ 0 & 1 \end{pmatrix}$	matrix $\mathbf{V}$ from ellipse equation
$\mathbf{u}$	$\begin{pmatrix} 0 \\ 0 \end{pmatrix}$	vector $\mathbf{u}$ from ellipse equation
$f$	-4	constant $f$ from ellipse equation

TABLE 12: Table 1

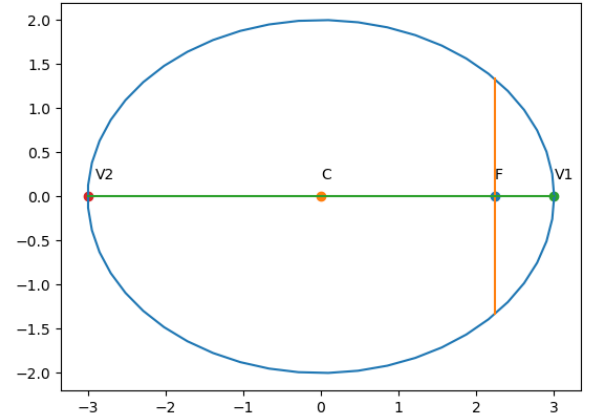


Fig. 12: Figure 1