MAT232 - Lecture 5

Advanced Curve Analysis: Polar Derivatives and Conic Sections

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Contents

Definitions and Theorems

Straight from the textbook — no fluff, just what we need.

Quick recap before diving into the lecture.

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1 Conic Sections and Their Properties

1.1 Theorem 1.10: Equations of Hyperbolas

Theorem

Equation of a Hyperbola in Standard Form
Consider the hyperbola with center (h, k), a horizontal major axis, and a vertical minor axis. Then the equation of this hyperbola is

$$\frac{(x-h)^2}{a^2} - \frac{(y-k)^2}{b^2} = 1 \tag{1}$$

and the foci are located at $(h \pm c, k)$, where $c^2 = a^2 + b^2$. The equations of the asymptotes are given by

$$y = k \pm \frac{b}{a}(x-h).$$

The equations of the directrices are

$$x = h \pm \frac{a^2}{c}.$$

If the major axis is vertical, then the equation of the hyperbola becomes

$$\frac{(y-k)^2}{a^2} - \frac{(x-h)^2}{b^2} = 1 \tag{2}$$

and the foci are located at $(h, k \pm c)$, where $c^2 = a^2 + b^2$. The equations of the asymptotes are given by

$$y = k \pm \frac{a}{b}(x-h).$$

The equations of the directrices are

$$y = k \pm \frac{a^2}{c}.$$

A hyperbola is called *horizontal* if its transverse axis is horizontal, and *vertical* if its transverse axis is vertical. The general form of the equation of a hyperbola is

$$Ax^2 + By^2 + Cx + Dy + E = 0,$$

where A and B have opposite signs. To convert the equation to standard form, use the method of completing the square.

Example 1.21

Put the equation $9x^2 - 16y^2 + 36x + 32y - 124 = 0$ into standard form and graph the resulting hyperbola. What are the equations of the asymptotes?

Checkpoint 1.20

Put the equation $4y^2 - 9x^2 + 16y + 18x - 29 = 0$ into standard form and graph the resulting hyperbola.

Hyperbolas have unique reflective properties. A ray directed toward one focus of a hyperbola is reflected by a hyperbolic mirror toward the other focus. This property is illustrated in the following figure.

Figure 1: A hyperbolic mirror used to collect light from distant stars.

This property is utilized in radio direction finding, telescope mirror construction, and modeling cometary trajectories in hyperbolic paths.

1.2 Eccentricity and Directrix

Definition

The eccentricity e of a conic section is defined as the ratio of the distance from any point on the conic to its focus and the perpendicular distance from that point to the nearest directrix. The value of e determines the type of conic section:

- If $e = 1$, the conic is a parabola.
- If $e < 1$, it is an ellipse.
- If $e > 1$, it is a hyperbola.

The eccentricity of a circle is zero.

Example 1.22

Determine the eccentricity of the ellipse described by the equation

$$\frac{(x-3)^2}{16} + \frac{(y+2)^2}{25} = 1.$$

Checkpoint 1.21

Determine the eccentricity of the hyperbola described by the equation

$$\frac{(y-3)^2}{49} - \frac{(x+2)^2}{25} = 1.$$

1.3 Polar Equations of Conic Sections

The polar equation of a conic section is given by

$$r = \frac{ep}{1 \pm e\cos\theta} \quad \text{or} \quad r = \frac{ep}{1 \pm e\sin\theta}.$$

Theorem

Theorem 1.11 Polar Equation of Conic Sections

For a conic section with focal parameter p, the equations in polar form are:

$$r = \frac{ep}{1 \pm e\cos\theta} \quad \text{(horizontal axis)},$$

$$r = \frac{ep}{1 \pm e\sin\theta} \quad \text{(vertical axis)}.$$

Here, e is the eccentricity. The type of conic can be identified as follows:

- $e = 1$: parabola,
- $0 < e < 1$: ellipse,
- $e > 1$: hyperbola.

Example 1.23

Graph the conic section described by

$$r = \frac{3}{1 + 2\cos\theta}.$$

Checkpoint 1.22

Identify and graph the conic section described by

$$r = \frac{4}{1 - 0.8\sin\theta}.$$

1.4 General Equations of Degree Two

A general equation of degree two can be written as

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0.$$

The discriminant $4AC - B^2$ is used to identify the type of conic:

- $4AC - B^2 > 0$: ellipse,
- $4AC - B^2 = 0$: parabola,
- $4AC - B^2 < 0$: hyperbola.

Example 1.24

Identify the conic section and calculate the angle of rotation for the equation

$$13x^2 - 6\sqrt{3}xy + 7y^2 - 256 = 0.$$

Let's Get Started

Time to dive into the lecture notes.

Grab your pen or pencil, and let's break this down step by step.

Review from the Previous Lecture

Remark

In the previous lecture, we covered important foundational concepts related to polar coordinates and their derivatives. Here's a brief summary:

- **Derivative of $r = f(\theta)$ in Cartesian Coordinates:**

$$\frac{dy}{dx} = \frac{\frac{dy}{d\theta}}{\frac{dx}{d\theta}} = \frac{\frac{dr}{d\theta}\sin\theta + r\cos\theta}{\frac{dr}{d\theta}\cos\theta - r\sin\theta}$$

  This formula helps us compute the slope of the tangent line for polar curves when converted to Cartesian coordinates.

- **Equation of a Circle:**

$$(x-h)^2 + (y-k)^2 = r^2$$

  Here:

  - r: Radius of the circle
  - (h, k): Centre of the circle

Note

Reminder: Term Test 1 is scheduled for **Thursday, January 30th, 2025 (Week 4)**. Make sure to review polar derivatives, transformations, and conic sections!

Exploring Common Curve Shapes

Parabola

Definition

A **parabola** is a symmetric curve defined by the quadratic equation:

$$y = ax^2 + bx + c, \quad a \neq 0$$

To rewrite this equation in vertex form, we complete the square:

$$y = A(x - B)^2 + C$$

Here:

- A: Determines the direction and "width" of the parabola.

$$A > 0 \implies \text{The parabola opens upwards.}$$

$$A < 0 \implies \text{The parabola opens downwards.}$$

- (B, C): Represents the vertex of the parabola.
  - B: Horizontal position of the vertex.
  - C: Vertical position of the vertex.

Algorithm

Vertex Formula: To find the vertex when given the standard form $y = ax^2 + bx + c$, use the formulas:

$$B = -\frac{b}{2a}, \quad C = f(B)$$

where $f(B)$ is the value of the quadratic function evaluated at $x = B$.

...cont'd...

Definition

...cont'd...

Illustration

Below are examples of parabolas showcasing key features:

Figure 2: A parabola opening down, labeled with its vertex and axis of symmetry.

Figure 3: Generic parabolas showing upwards and downwards directions of opening.

Example: Sketching the Region of a Set

Example

Sketch the region of the set defined by

$$R = \{(x, y) \mid y \geqslant x^2 + 1\}$$

Solution

Consider the graph for the function $y = x^2 = 1$:

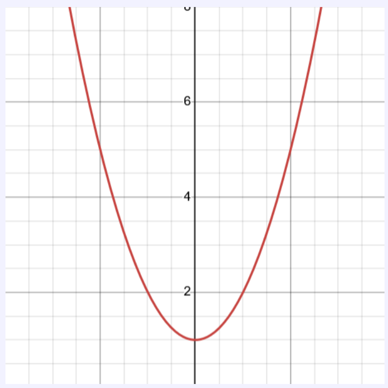

Figure 4: Graph of $y = x^2 + 1$.

Notice that

$$\begin{aligned} & y = x^2 + 1 \\ \implies & 0 \geqslant (-2)^2 + 1 \\ \implies & 0 \geqslant 5, \text{ which is not true.} \end{aligned}$$

Then, notice that

$$\begin{aligned} & 2 \geqslant 0^2 + 1 \\ \implies & 2 \geqslant 1, \text{ which is true!} \end{aligned}$$

Here is the region being considered:

Figure 5: Sample image illustrating the concept.

Ellipse

Definition

The equation of an ellipse is defined by

$$\frac{(x-h)^2}{a^2} + \frac{(y-k)^2}{b^2} = 1.$$

Note

Recall the equation of the circle, which is based on the equation of the ellipse when $a = b = 1$:

$$\text{Circle:} \quad (x-h)^2 + (y-k)^2 = r^2,$$

where (h, k) is the centre, a represents the x-axis radius, and b represents the y-axis radius.

Example of Skecthing an Ellipse

Example

Sketch the region of the set defined by

$$A = \{(x, y) \mid x^2 + 4y^2 > 4\}.$$

Solution

Notice that

$$x^2 + 4y^2 = 4.$$

This means the centre is at $(0, 0)$. Also,

$$\frac{x^2}{4} + \frac{y^2}{1} = 1$$

provides that the x-axis radius is $a = 2$ and the y-axis radius is $b = 1$.

Here is the corresponding illustration:

self-note: add the illustratoin from the lecture note from your camera roll

Figure 6: Illustration of ellipse.

Note

Note that dashed lines are used to denote that the edge of the ellipse is **not included** in the region A.

Check the point $(0, 0)$:

$$0^2 + 4 \cdot 0^2 > 4$$

$$\implies 0 > 4,$$

which is not true.

Therefore, the inside of the ellipse is **not** to be shaded in.

Check the point $(3, 0)$:

$$3^2 + 4 \cdot 0^2 > 4$$

Introducing the Hyperbola

Definition

The equation of a hyperbola is defined by

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$$

Illustration

self-note: add the image of the corresponding illustration here (see the lecture note)

Figure 7: Sample image illustrating the concept.

$$\frac{y^2}{b^2} - \frac{x^2}{a^2} = 1$$

Illustration

self-note: add the image of the corresponding illustration here (see the lecture note)

Figure 8: Sample image illustrating the concept.

Welcome to Linear Algebra...

well... not really!

Section 2.1/2.2: Welcome to 3D Space!

Remark

Recall that the cartesian coordinate system considers the 2-dimensional realm: a system in $\mathbb{R}^2$.

Illustration

self-note: add the cartesian plane — the typical one in 2D

Figure 9: Sample image illustrating the concept.

Now, check out the cartesian coordinate system being introduced in MAT232, considering the 3-dimensional realm; $\mathbb{R}^3$:

Illustration

self-note: add the illustration for the 3D cartesian plane, the z-axis in addition to the x- and y-axis.

Figure 10: Sample image illustrating the concept.

Note

<u>In 2D:</u>

Notice that $\mathbb{R}^2 = \mathbb{R} \times \mathbb{R}$, where the first $\mathbb{R}$ represents the x-values and the second $\mathbb{R}$ represents the y-values.

<u>Now, in 3D:</u>

Notice that $\mathbb{R}^3 = \mathbb{R} \times \mathbb{R} \times \mathbb{R}$.

- The first $\mathbb{R}$ represents the x-values;
- The second $\mathbb{R}$ represents the y-values;
- The third $\mathbb{R}$ represents the z-values.

Example of Plotting in a 3D Cartesian Plane

Example

Plot the points $(-1, 2, -3)$ and $(2, -4, 2)$.

Illustration

self-note: add the illustration here!!

Figure 11: Sample image illustrating the concept.

Follow the line segments denoted in ***purple*** *for an interpretation guide of how the three components contribute to the final point destination, for* $(-1, 2, -3)$.

Follow the line segments denoted in ***green*** *for an interpretation guide of how the three components contribute to the final point destination, for* $(2, -4, 2)$.

Interpreting Planes

Concept

Notice that in a 2D world, there is no notion of height when considering the x, y-plane. In a 3D world, $z = 0$.

Now, have a look at the basic planes for a 3D cartesian graph:

The xy plane:

$$x = 0 \qquad (x, y, 0)$$

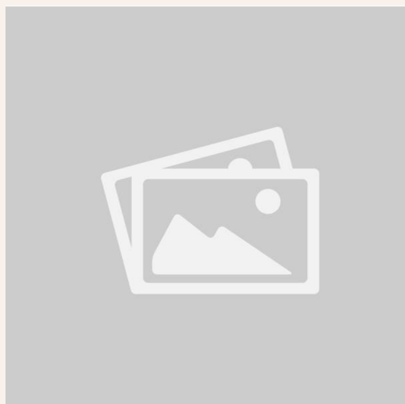

Figure 12: Sample image illustrating the concept.

The yz plane:

$$x = 0 \qquad (0, y, z)$$

Figure 13: Sample image illustrating the concept.

The xz plane:

$$x = 0 \qquad (x, 0, z)$$

Let's Try Going from 2D to 3D

Example

Consider the graph defined by $y = 2$ on a 2D cartesian graph:

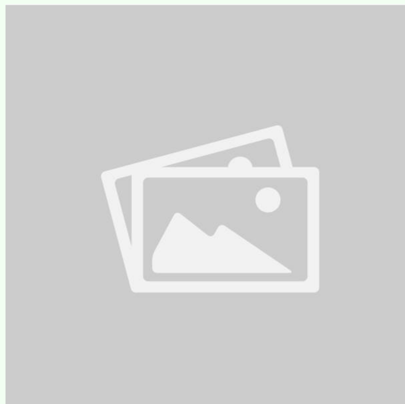

Figure 15: Sample image illustrating the concept.

Here's how that would look like in a 3D cartesian space:

Figure 16: Sample image illustrating the concept.

Example

Consider the graph of a circle defined by

$$x^2 + y^2 = 4.$$

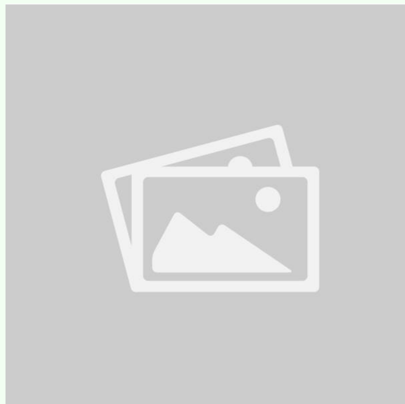

Figure 17: Sample image illustrating the concept.

If this circle is brought to the 3D world, stretched along the z-axis, for any values of z, then a cylinder is created (the cirle is the cross-section shape).

Figure 18: Sample image illustrating the concept.

Next Lecture: We Discuss Vectors!

Lecture Title

Note

This template is designed for MAT232 lecture notes. Replace this content with your specific lecture details.

Key Concepts

Definition

A **parametric equation** is a set of equations that express the coordinates of the points of a curve as functions of a variable, called a parameter.

Examples

Example

Example 1: Consider the parametric equations:

$$x = t, \quad y = t^2, \quad t \in \mathbb{R}.$$

- At $t = 0$, $(x, y) = (0, 0)$.
- At $t = 1$, $(x, y) = (1, 1)$.

This describes a parabola.

Figure 19: Sample image illustrating the concept.

Theorems and Proofs

Theorem

Theorem: If $x(t)$ and $y(t)$ are differentiable functions, the slope of the curve is given by:

$$\frac{dy}{dx} = \frac{\frac{dy}{dt}}{\frac{dx}{dt}}, \quad \text{provided } \frac{dx}{dt} \neq 0.$$

Figure 20: Graphical representation of the theorem.

Additional Notes

Note

Always check the domain of the parameter t when solving problems involving parametric equations.