

# Parametric and Polar Cheatsheet

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## 1 Parametric Intro

When you have parameters in terms of  $t$  to represent  $\langle x, y \rangle$  You represent the function as  $\langle x(t), y(t) \rangle$  and the derivative as  $\langle x'(t), y'(t) \rangle$ .

$$\frac{dy}{dx} = \frac{\frac{dy}{dt}}{\frac{dx}{dt}}$$
$$\frac{d^2y}{dx^2} = \frac{d}{dx}[f'(t)] = \frac{d}{dt}f'(t) * \frac{dt}{dx} = \frac{\frac{d}{dt}[\frac{dy}{dx}]}{\frac{dx}{dt}}$$

Speed:

$$\Delta r = \sqrt{x'(t)^2 + y'(t)^2}$$

If there is no change in  $y(t)$ :

$$\Delta r = \sqrt{x'(t)^2} = |x'(t)|$$

Distance:

$$r = \int \sqrt{x'(t)^2 + y'(t)^2} dt$$

## 2 Parametric Examples

1. Find the speed, acceleration, and distance of the following:

$$\vec{v} = \langle (t-1)e^{t^2}, \sin(t^{1.25}) \rangle$$
$$\text{speed} = \sqrt{((t-1)e^{t^2})^2 + \sin^2(t^{1.25})}$$
$$\text{distance} = \int \sqrt{((t-1)e^{t^2})^2 + \sin^2(t^{1.25})} dt$$

2. The parametric equation of a curve is given by  $\langle 2t-1, 3t^2+1 \rangle$ . What is the slope of the tangent line to the curve at  $t=2$ .

$$\frac{dy}{dx} = \frac{\frac{dy}{dt}}{\frac{dx}{dt}} = \frac{\frac{d}{dx}[3t^2+1]}{\frac{d}{dx}[2t-1]} = \frac{6t}{2} = \frac{12}{2} = 6$$

3. A parametric is given by  $\langle \cos t, \sin t \rangle$ . What is the speed of the particle at  $t = \frac{\pi}{4}$ ?

$$\frac{dy}{dx} = \frac{\frac{dy}{dt}}{\frac{dx}{dt}} = \frac{\frac{d}{dx}[\sin t]}{\frac{d}{dx}[\cos t]} = \frac{\cos t}{-\sin t} = -1$$
$$\text{speed} = \sqrt{\cos^2 t + \sin^2 t} = 1$$

4. A parametric is represented by  $\langle 5t, 4 - t^2 \rangle$ . At what value of  $t$  does the curve have a horizontal tangent line?

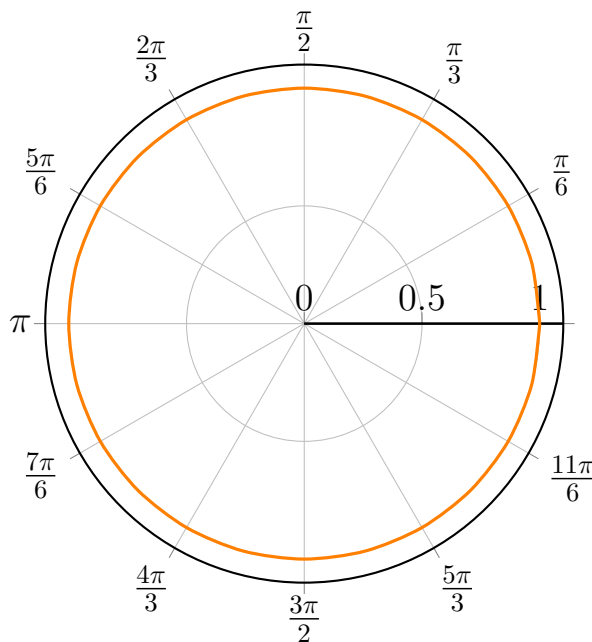
$$\frac{dy}{dt} = 0 = \frac{d}{dt}[4 - t^2] = -2t \implies t = 0$$

5. A parametric is represented  $\vec{v} = \langle 2t + 1, 3t^2 - 4t \rangle$ . What is the second derivative of  $y$  with respect to  $x$  at  $t = 2$ ?

$$\frac{\vec{v}'(t)}{\frac{dx}{dt}} = \frac{\frac{6t}{2}}{2} = 3$$

### 3 Polar

The polar axis defines functions for  $r(\theta)$  where radius is the distance from  $(0, 0)$  and  $\theta$  is



the angle with the horizontal.

A unit circle defined in Polar.

$$x = r \cos(\theta)$$

$$y = r \sin(\theta)$$

If we were to convert the unit circle to a parametric equation we would get  $\langle r \cos(\theta), r \sin(\theta) \rangle$ .

#### 3.1 Tangent Lines

Finding tangent lines of a Polar function is quite simple; just convert it to parametric.

Find the derivative of the following at  $\frac{3\pi}{4}$ :

$$\begin{aligned}
r(\theta) &= 4 \sin(2\theta) \\
r(\theta) \cos(\theta) &= 4 \sin(2\theta) \cos(\theta) \implies x = 4 \sin(2\theta) \cos(\theta) \\
y &= 4 \sin(2\theta) \sin(\theta) \\
\frac{dy}{dt} &= 4 \sin(2\theta) \cos(\theta) + 8 \sin(\theta) \cos(2\theta) \\
\frac{dx}{dt} &= -4 \sin(2\theta) \sin(\theta) + 8 \cos(\theta) \cos(2\theta) \\
\frac{dy}{dx} &= \frac{\sin(2\theta) \cos(\theta) + 2 \cos(2\theta) \sin(\theta)}{-\sin(2\theta) \sin(\theta) + 2 \cos(2\theta) \cos(\theta)} \\
\frac{\frac{\sqrt{2}}{2}}{\frac{\sqrt{2}}{2}} &= 1
\end{aligned}$$

### 3.2 Arc Length

Using a parametric to start with:

$$\begin{aligned}
\text{distance} &= \int \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2} dt \\
\text{distance} &= \int \sqrt{\left(\frac{dr}{d\theta} r \cos \theta\right)^2 + \left(\frac{dr}{d\theta} r \sin \theta\right)^2} d\theta \\
\text{distance} &= \int \sqrt{\left(-r \sin \theta + \frac{dr}{d\theta} \cos \theta\right)^2 + \left(r \cos \theta + \frac{dr}{d\theta} \sin \theta\right)^2} d\theta \\
\implies \int \sqrt{r^2 \sin^2 \theta - 2r \frac{dr}{d\theta} \sin \theta \cos \theta + \left(\frac{dr}{d\theta}\right)^2 \cos^2 \theta + r^2 \cos^2 \theta + 2r \frac{dr}{d\theta} \cos \theta \sin \theta + \left(\frac{dr}{d\theta}\right)^2 \sin^2 \theta} d\theta \\
&\implies \int \sqrt{r^2 \sin^2 \theta + \left(\frac{dr}{d\theta}\right)^2 \cos^2 \theta + r^2 \cos^2 \theta + \left(\frac{dr}{d\theta}\right)^2 \sin^2 \theta} d\theta \\
&\implies \int \sqrt{r^2 (\sin^2 \theta + \cos^2 \theta) + \left(\frac{dr}{d\theta}\right)^2 (\cos^2 \theta + \sin^2 \theta)} d\theta \\
&\implies \int \sqrt{r^2 + \left(\frac{dr}{d\theta}\right)^2} d\theta
\end{aligned}$$

### 3.3 $e^{-\theta}$

Find arc length:

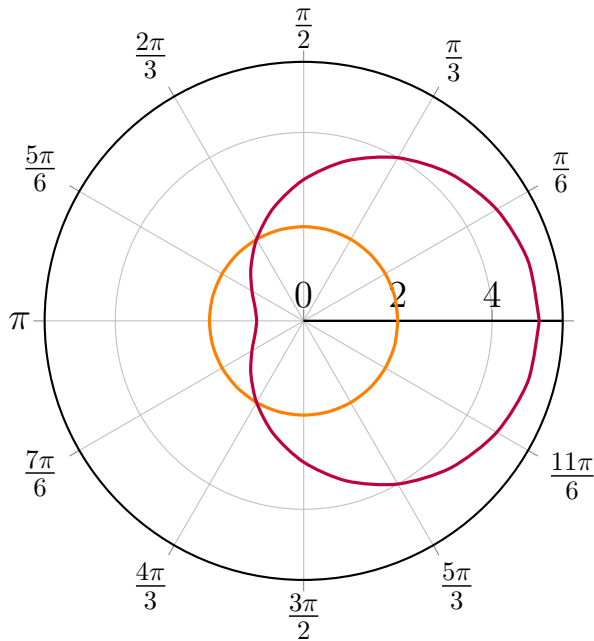
$$\begin{aligned}
 r = e^{-\theta} = \frac{1}{e^{\theta}} &\Rightarrow \int_0^{\infty} \sqrt{\left(\frac{1}{e^{\theta}}\right)^2 + \left(\frac{-1}{e^{\theta}}\right)^2} d\theta \\
 &\Rightarrow \int_0^{\infty} \sqrt{\frac{1}{e^{2\theta}} + \frac{1}{e^{2\theta}}} d\theta \\
 &\Rightarrow \int_0^{\infty} \sqrt{\frac{2}{e^{2\theta}}} d\theta \Rightarrow \sqrt{2} \int_0^{\infty} \sqrt{\frac{1}{e^{2\theta}}} d\theta \Rightarrow \sqrt{2} \int_0^{\infty} \left(\frac{1}{e^{2\theta}}\right)^{\frac{1}{2}} d\theta \Rightarrow \sqrt{2} \int_0^{\infty} e^{-\theta} d\theta \Rightarrow -\sqrt{2}e^{-\theta} \Big|_0^{\infty} \\
 &= \sqrt{2}
 \end{aligned}$$

### 3.4 Area in the Curve

A polar graph can be thought in terms of mini-sectors in the way an integral is thought of in rectangles.

$$\begin{aligned}
 A_{\text{arc}} &= \frac{\theta}{2\pi} \pi r^2 = \frac{1}{2} r^2 \theta \\
 A_{r(\theta)} &= \int \frac{1}{2} r^2 d\theta
 \end{aligned}$$

### 3.5 Examples



Find the area inside.

$$A = \frac{\pi 2^2}{2} + \frac{1}{2} \int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} (3 + 2 \cos \theta)^2 d\theta$$

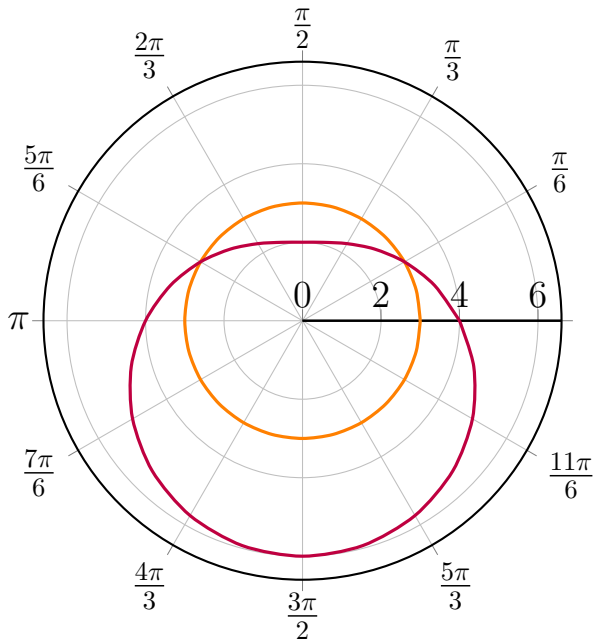
Solve  $\frac{dr}{dt}$  and  $\frac{dy}{dt}$  for  $t = \theta = \frac{\pi}{3}$ .

$$\frac{dr}{dt} = -2 \sin \theta = -\sqrt{3}$$

$$r \sin \theta = 3 \sin \theta + 2 \cos \theta \sin \theta$$

$$\implies y = 3 \sin \theta + \sin 2\theta$$

$$\frac{dy}{dt} = 3 \cos \theta + 2 \sin 2\theta = 3 * \frac{1}{2} + \sqrt{3}$$



They intersect at  $\theta = \frac{\pi}{6}$  and  $\theta = \frac{5\pi}{6}$ .

$$A = \int_0^{\frac{\pi}{6}} 3^2 d\theta + \int_{\frac{\pi}{6}}^{\frac{5\pi}{6}} (4 - 2 \sin \theta)^2 d\theta + \int_{\frac{5\pi}{6}}^{2\pi} 3^2 d\theta$$