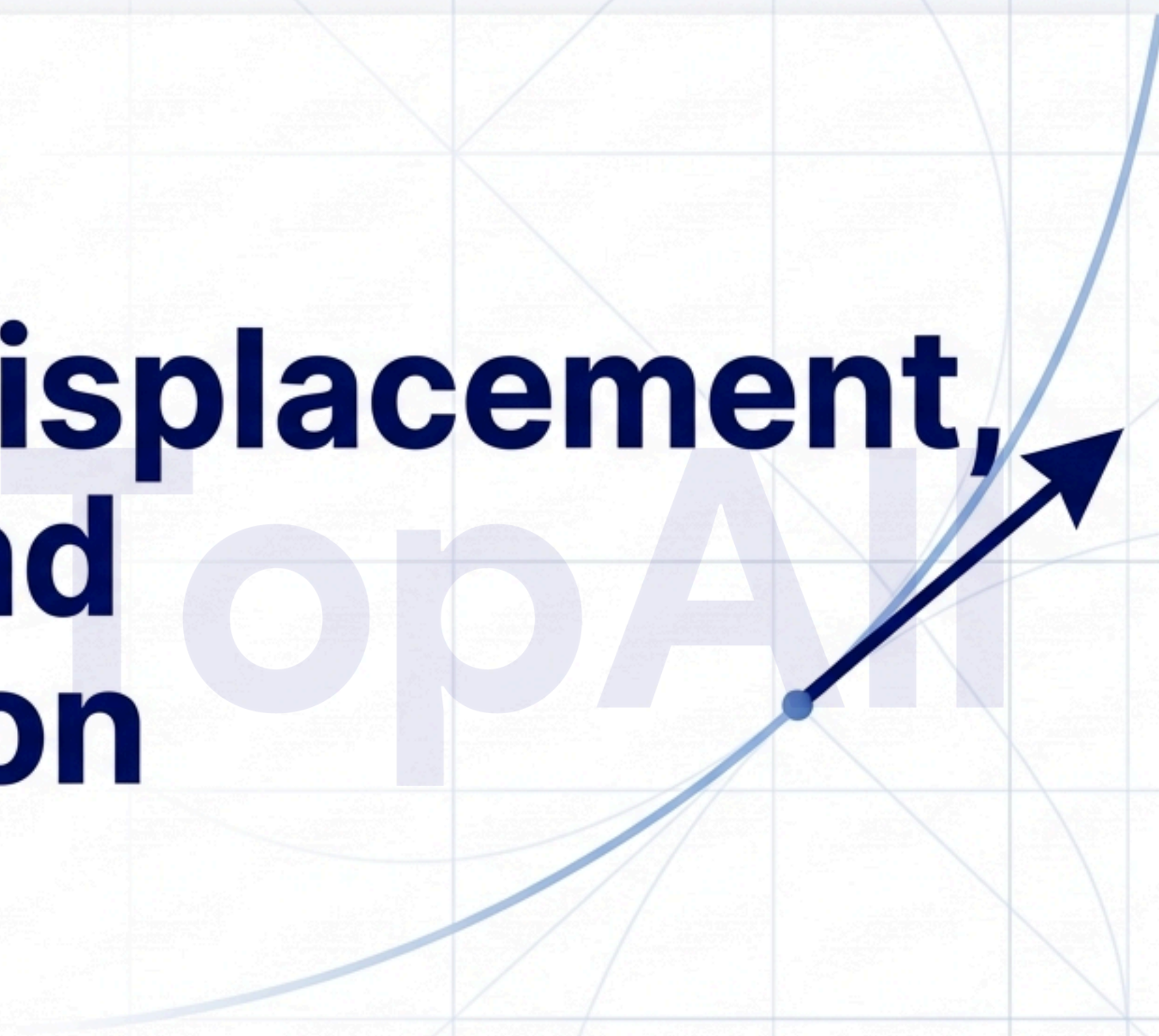
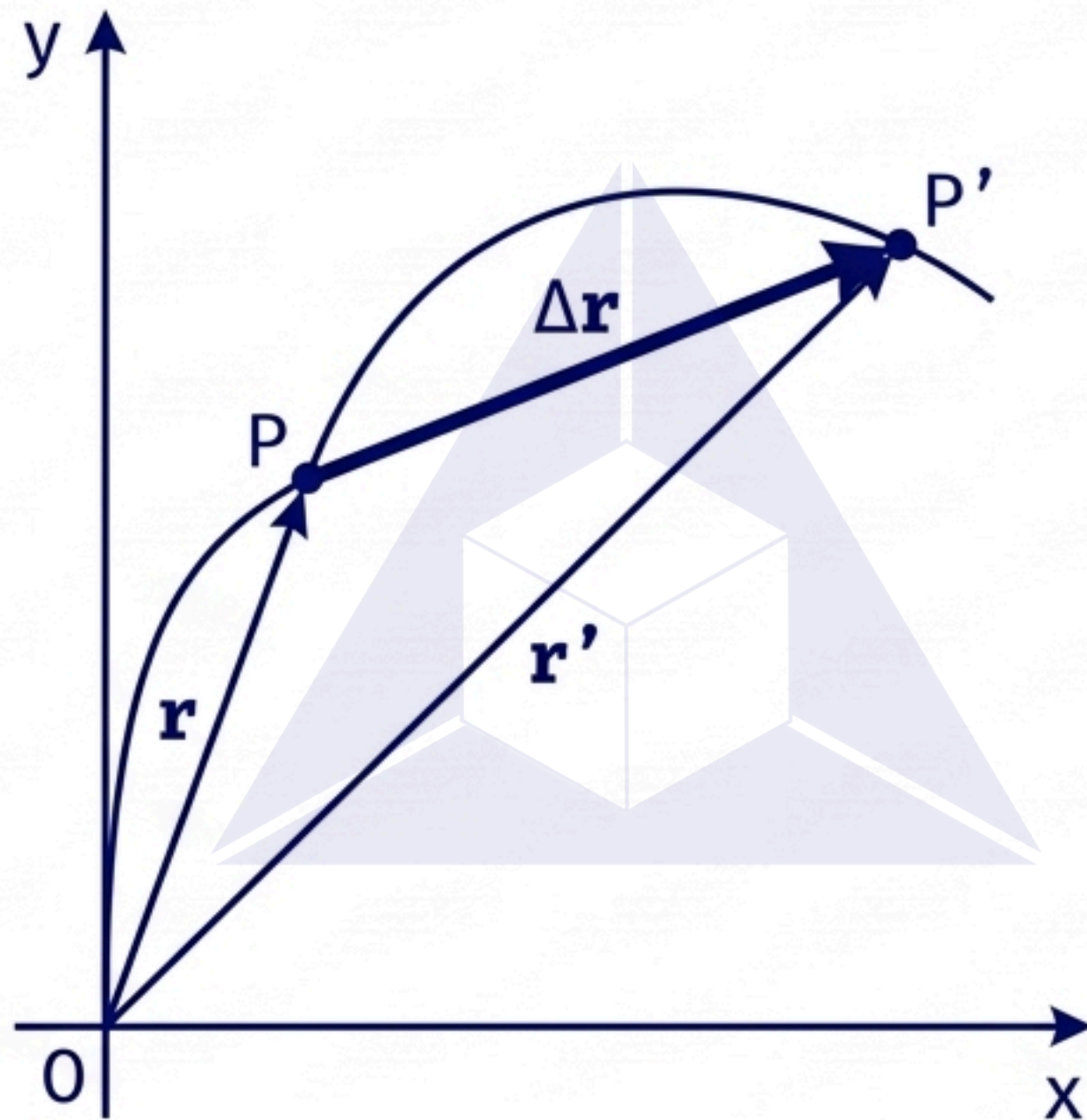


Motion in a Plane · Concept 6

Position, Displacement, Velocity and Acceleration in a Plane





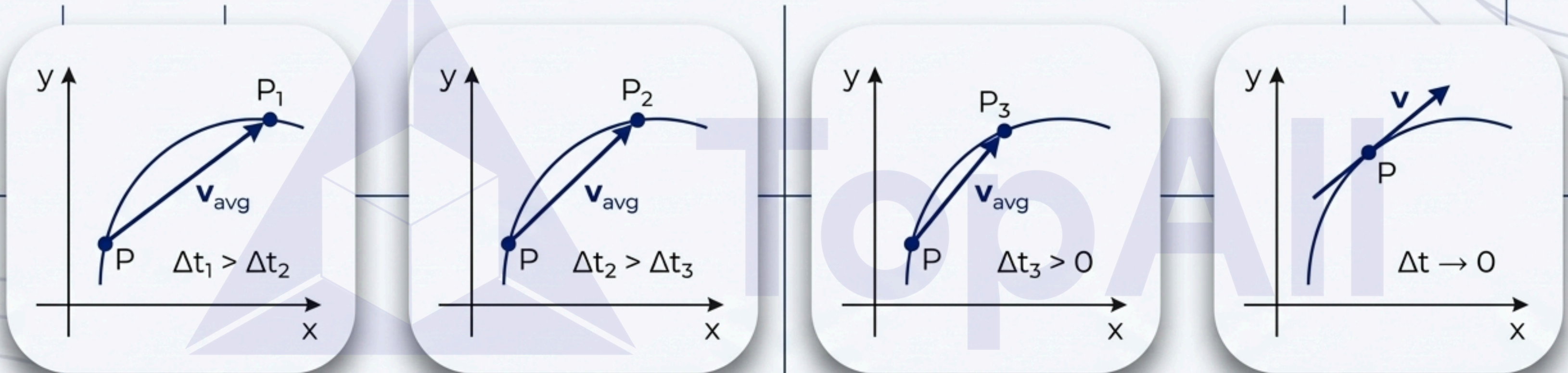
Defining the Vectors

Position is defined by coordinates; displacement is the straight-line vector between initial and final positions, entirely independent of the actual path taken.

Position: $\mathbf{r} = x\hat{i} + y\hat{j}$
 Displacement: $\Delta\mathbf{r} = \mathbf{r}' - \mathbf{r}$
 Component Form: $\Delta\mathbf{r} = \hat{i}\Delta x + \hat{j}\Delta y$
 (where $\Delta x = x' - x$, $\Delta y = y' - y$)

Average to Instantaneous Velocity

As the time interval approaches zero, the average velocity vector aligns perfectly with the tangent to the path.



Average: $\mathbf{v}_{\text{avg}} = \frac{\Delta \mathbf{r}}{\Delta t} = (\Delta x / \Delta t) \hat{i} + (\Delta y / \Delta t) \hat{j}$

Instantaneous: $\mathbf{v} = \lim_{\Delta t \rightarrow 0} \Delta \mathbf{r} / \Delta t = d\mathbf{r} / dt$



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Components of Velocity

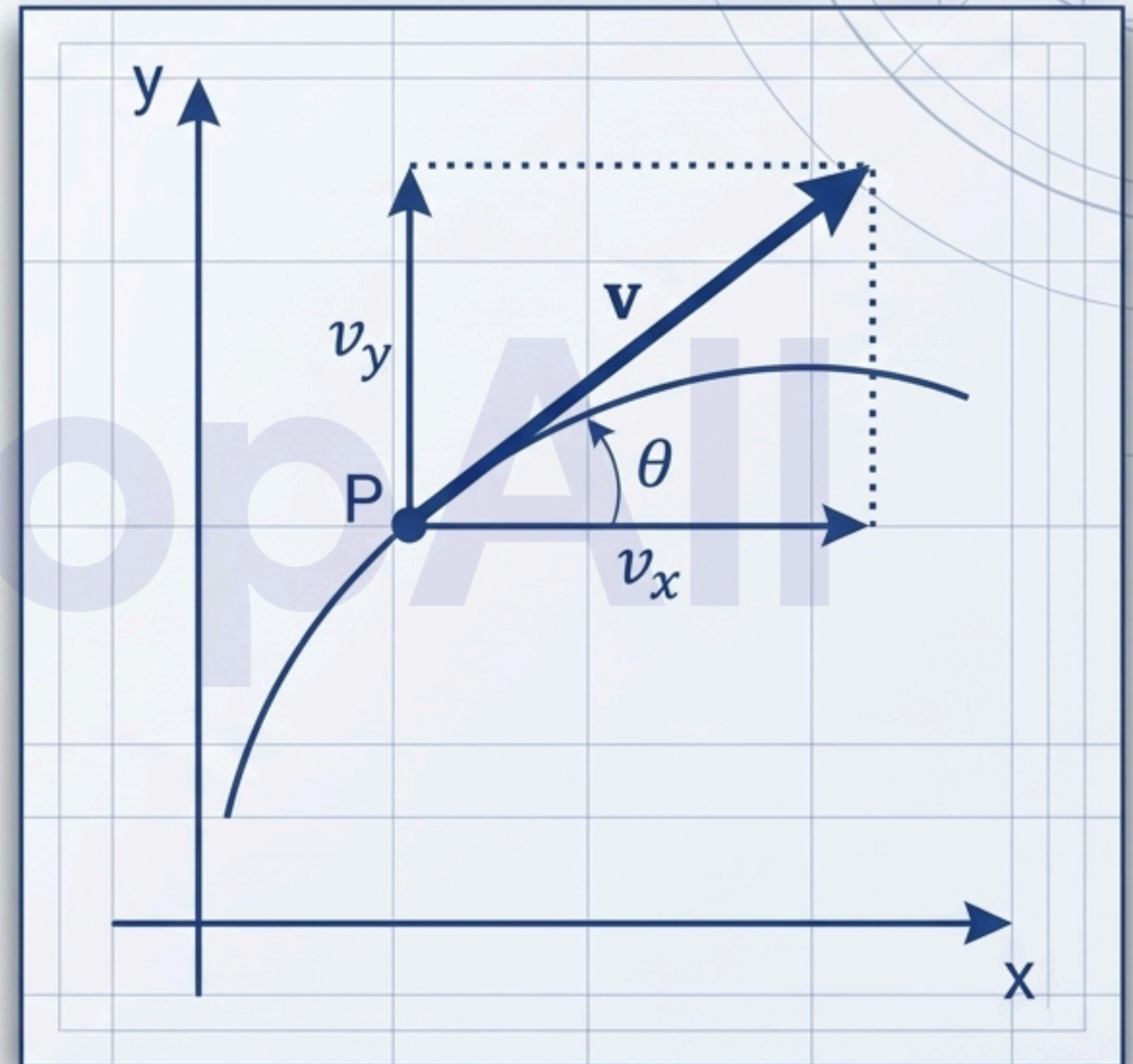
The instantaneous velocity in a plane behaves as two independent, simultaneous 1D motions along the x and y axes.

Vector: $\mathbf{v} = v_x \hat{\mathbf{i}} + v_y \hat{\mathbf{j}}$

Components: $v_x = \frac{dx}{dt}$, $v_y = \frac{dy}{dt}$

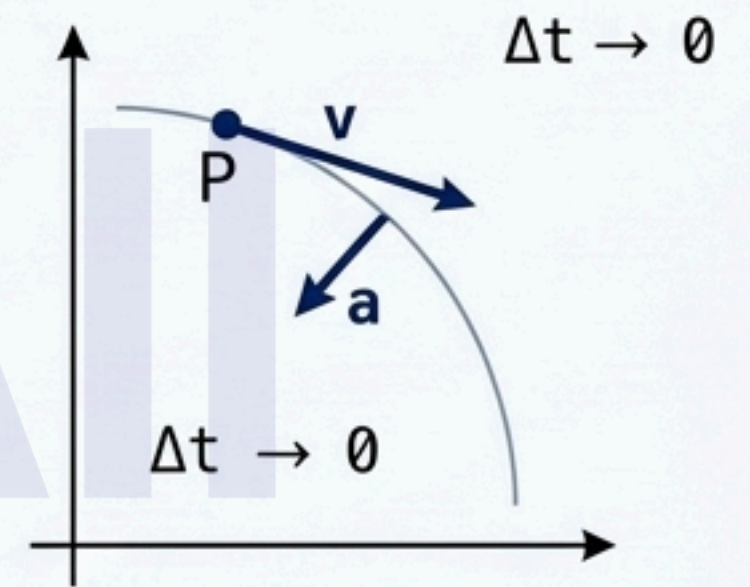
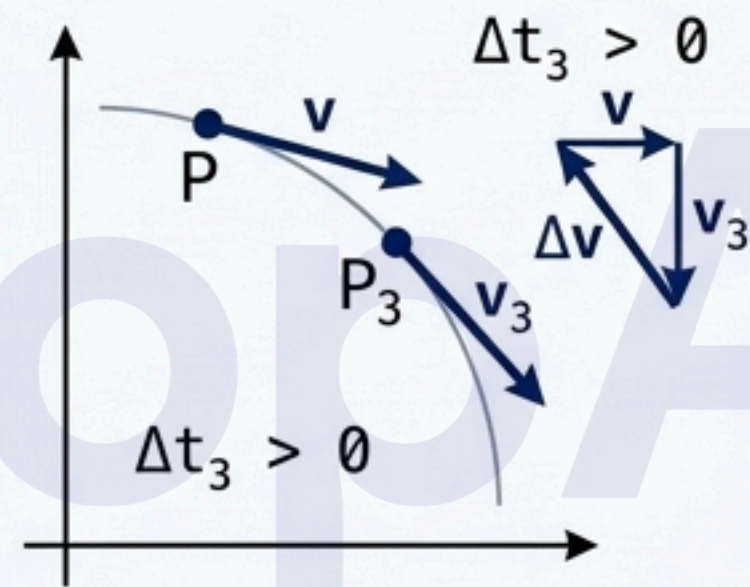
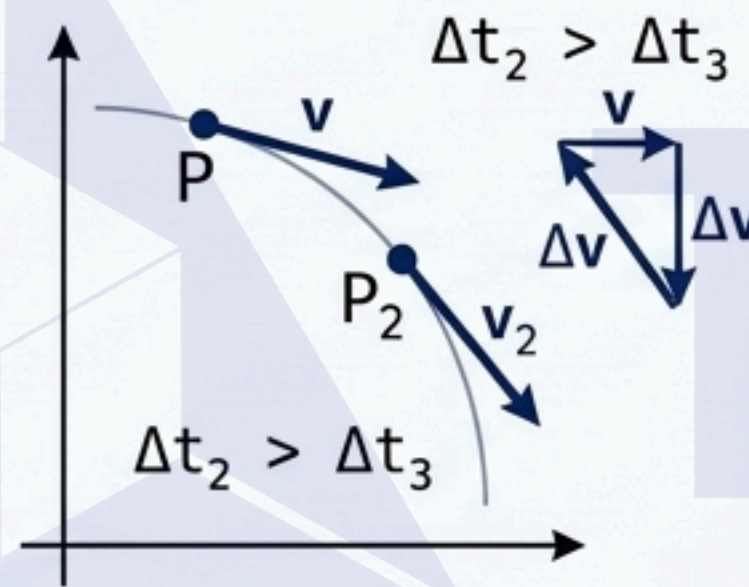
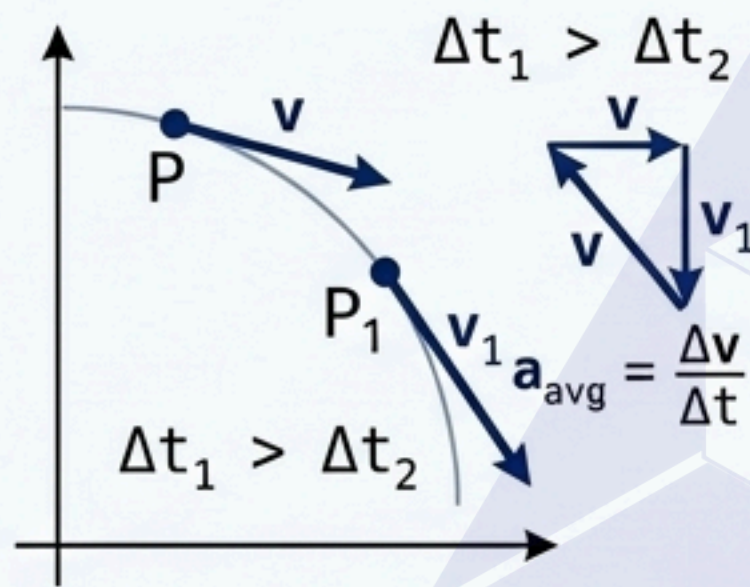
Magnitude: $|\mathbf{v}| = \sqrt{v_x^2 + v_y^2}$

Direction: $\theta = \tan^{-1} \left(\frac{v_y}{v_x} \right)$



Average to Instantaneous Acceleration

Acceleration tracks the change in velocity. Notice how $\Delta \mathbf{v}$ (and thus $\mathbf{a}$) points inward as the object turns, not necessarily along the path.



$$\mathbf{a}_{avg} = \Delta \mathbf{v} / \Delta t$$

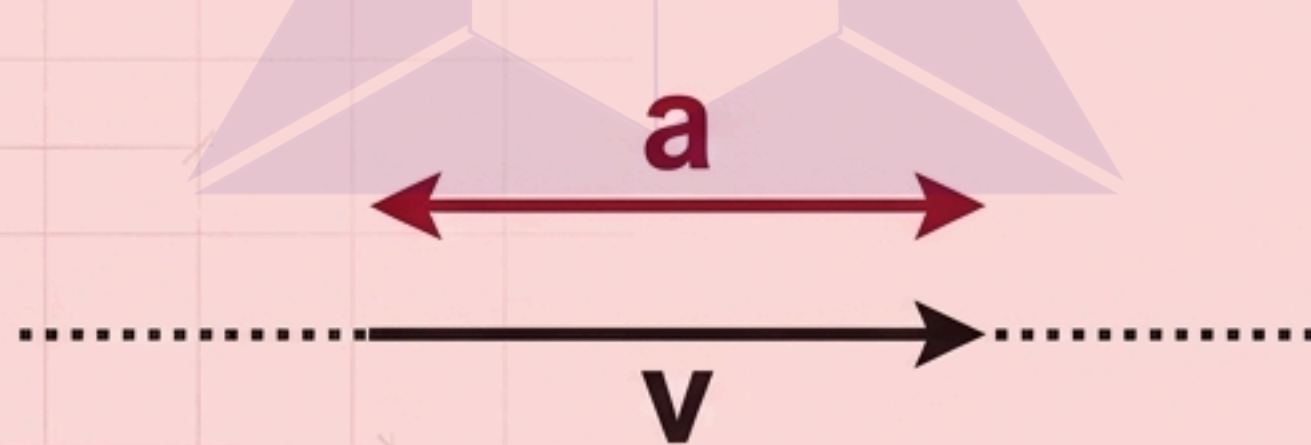
$$\mathbf{a} = \lim(\Delta t \rightarrow 0) \Delta \mathbf{v} / \Delta t = d\mathbf{v} / dt$$

$$\mathbf{a} = a_x \hat{\mathbf{i}} + a_y \hat{\mathbf{j}} \quad (\text{where } a_x = dv_x/dt, a_y = dv_y/dt)$$

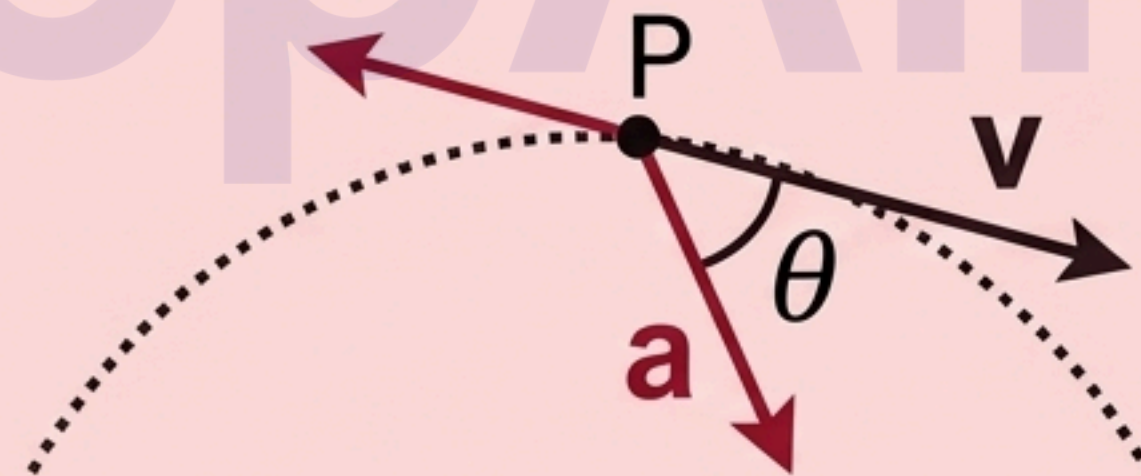


TRAP ALERT

In a plane, velocity and acceleration can point anywhere between 0° and 180° apart — unlike in 1D, where they're always collinear.



1D Motion



2D Motion

Worked Example 3.4

The position of a particle is given by $\mathbf{r} = 3.0t\hat{\mathbf{i}} + 2.0t^2\hat{\mathbf{j}} + 5.0\hat{\mathbf{k}}$ (m). Find $\mathbf{v}(t)$, $\mathbf{a}(t)$, and the magnitude/direction of $\mathbf{v}(t)$ at $t = 1.0\text{s}$.

Solution Steps

$$\mathbf{v} = d\mathbf{r}/dt = 3.0\hat{\mathbf{i}} + 4.0t\hat{\mathbf{j}}$$

$$\mathbf{a} = d\mathbf{v}/dt = 4.0\hat{\mathbf{j}}$$

$$\text{At } t = 1.0\text{s: } \mathbf{v} = 3.0\hat{\mathbf{i}} + 4.0\hat{\mathbf{j}}$$

$$\text{Magnitude: } |\mathbf{v}| = \sqrt{(3^2 + 4^2)} = 5.0 \text{ m/s}$$

$$\text{Direction: } \theta = \tan^{-1}(4/3) \approx 53^\circ \text{ with x-axis.}$$



Key Takeaways

Velocity is always tangent to the path;
acceleration need not align with it in 2D/3D motion.

$$\mathbf{v} = d\mathbf{r}/dt, \quad \mathbf{a} = d\mathbf{v}/dt$$



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