

AI-AUGMENTED ENGINEERING DYNAMICS: A CONVERSATIONAL APPROACH

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Observe



Idealize



Model



Solve / Analyze



Validate



Report

The engineering workflow you will use throughout this book

by Taner Onsay

CHAPTER - 2

PART 1 · ≈ 30 MIN

From Straight Paths to Curved Paths

What changes when the path itself curves? The bicycle-wheel bead makes the question visible.

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A bead on a spinning wheel — what is moving, and what is changing?

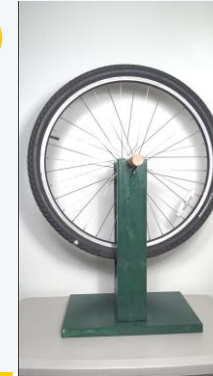
BICYCLE-WHEEL APPARATUS

Front wheel of a bicycle is mounted on the wooden V-notch stand. A $\frac{1}{2}$ -in-diameter silver bead is attached near the tire rim. The bead is approximately **12 in** from the center of the spindle.

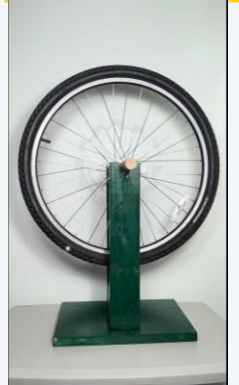


OBSERVE

Normal speed
30 fps



Slow Motion
120fps



What is moving?

One small object: the bead — a particle, as in Chapter 1.



What path does the bead trace?

A circle of fixed radius r about the spindle.



What is changing — and what is not?

Watch its speed. Watch its direction. Which one changes?

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PREDICT



**The wheel rotates at approximately constant angular speed.
The bead therefore moves at approximately constant speed.
Then, is the bead accelerating?**

Commit to an answer before we draw anything.

Vote: yes · no · only if the wheel speeds up. Then say in one sentence what "acceleration" means.

Observe



Idealize



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Solve / Analyze



Validate

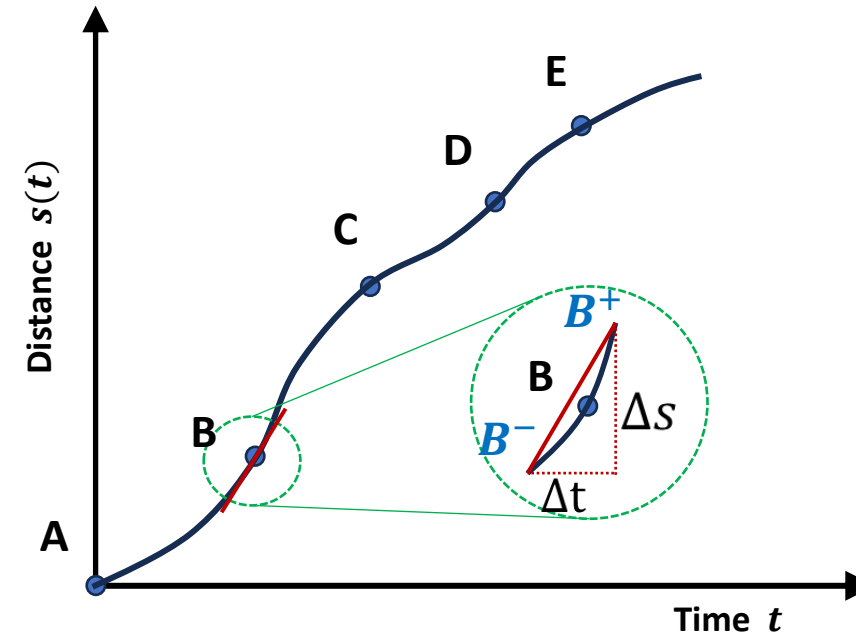


Report

On a curved road, we need a vector.



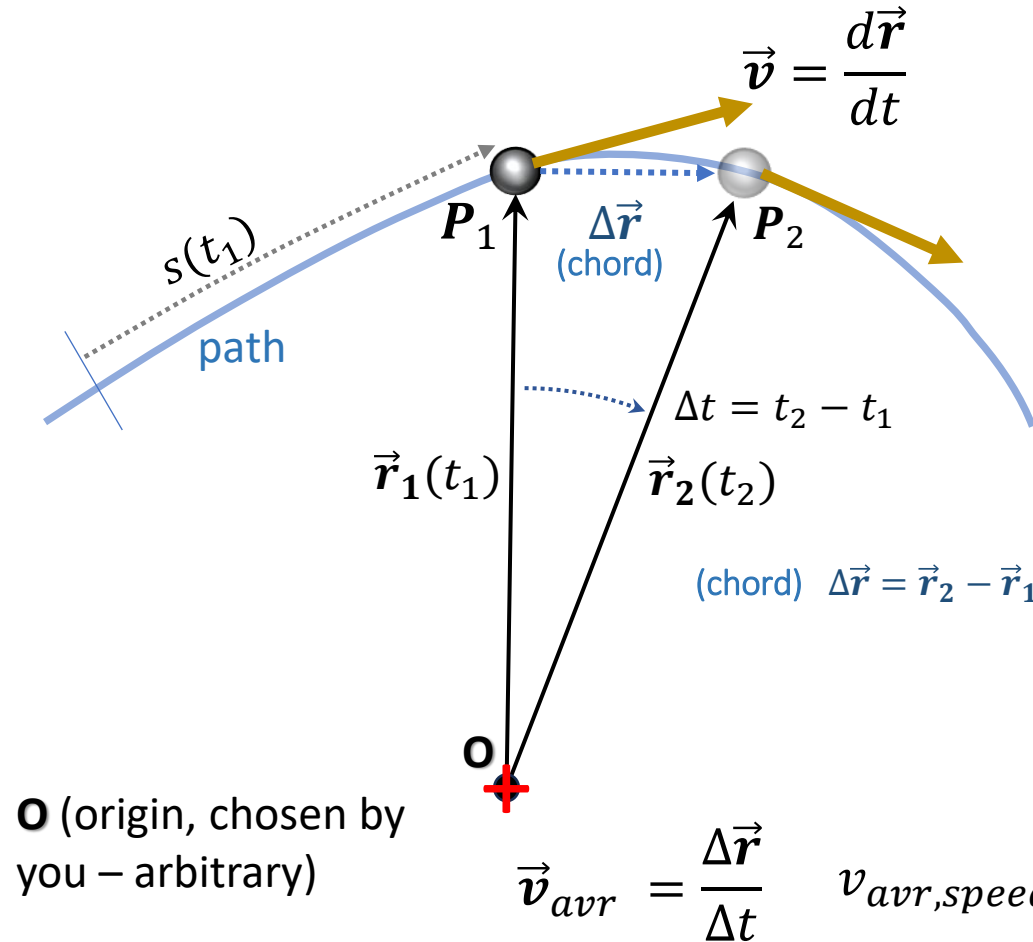
If we record distance traveled $s(t)$, what can we determine?
 We can obtain **speed** from the slope ds/dt .
 But can $s(t)$ alone tell us the direction of **velocity**?
 Can it tell us the complete **acceleration** vector on this curved road?





For motion along a straight line, one signed coordinate was enough to locate the particle.

On a curved path, position requires a vector.



Position is now a vector $\vec{r}(t)$

Drawn from an origin O that the engineer chooses. Its length and its direction both change with time.



Displacement $\Delta \vec{r}$ is a vector difference

The chord $\Delta \vec{r}$ from one position to the next. Distance along the path, $s(t)$, is still a scalar — they are not the same thing.



Velocity $\vec{v} = d\vec{r}/dt$ is tangent to the path

As $\Delta t \rightarrow 0$ the chord turns into the tangent. $|\vec{v}|$ is the speed (magnitude of the vector); the direction of $\vec{v}$ is the direction of travel. $\vec{v}_{avr}$ may not be tangent to the path



Average velocity & average speed:

In general, $|\vec{v}_{avr}| \leq v_{avr,speed}$; chord displacement and distance traveled are different.

Draw the velocity vector at each bead position

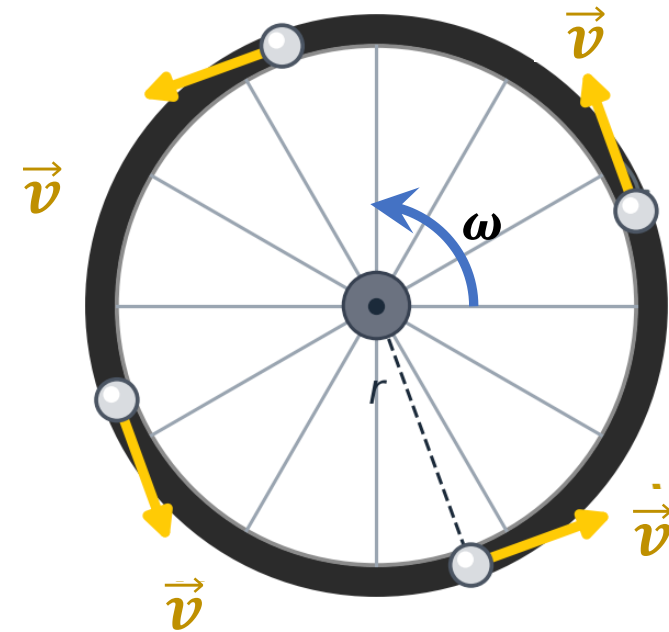
FREEZE-FRAME BEAD POSITION



time $t = t_1$

$t = t_2$

$t = t_3$

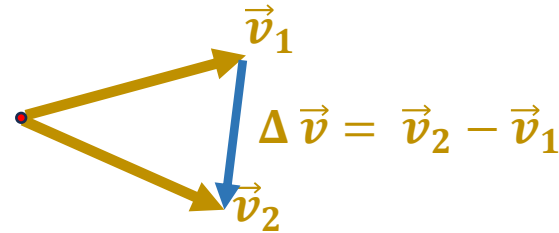
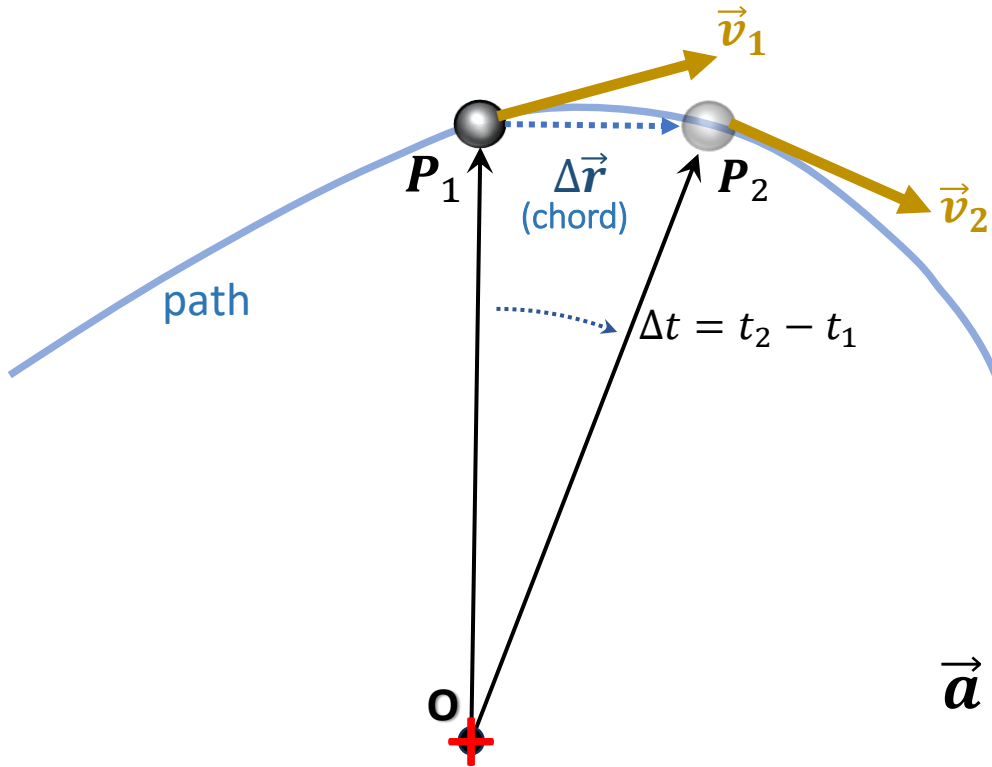


Approximately same speed at every instant.
Same velocity? No — the direction keeps turning.



Constructing Acceleration:

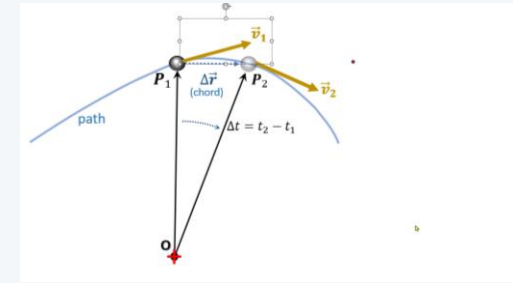
Slide the two velocity vectors to a common tail. For two nearby instants, $\Delta \vec{v}$ points approximately inward. In the limit $\Delta t \rightarrow 0$, the acceleration points toward the center.



$$\vec{a}_{avr} = \frac{\Delta \vec{v}}{\Delta t}$$

$$\vec{a} = \lim_{\Delta t \rightarrow 0} \frac{\Delta \vec{v}}{\Delta t} = \frac{d\vec{v}}{dt}$$

VIDEO: How $\Delta \vec{v}$ is generated



SAME DEFINITION AS
CHAPTER 1

$$\vec{a} = \frac{d\vec{v}}{dt}$$

...but $\vec{v}$ is a vector now. It can change in magnitude, in direction, or in both.

Constant speed does NOT mean zero acceleration. The velocity vector changed direction — and that change needs an acceleration.



Light braking, then stronger braking. What changed?

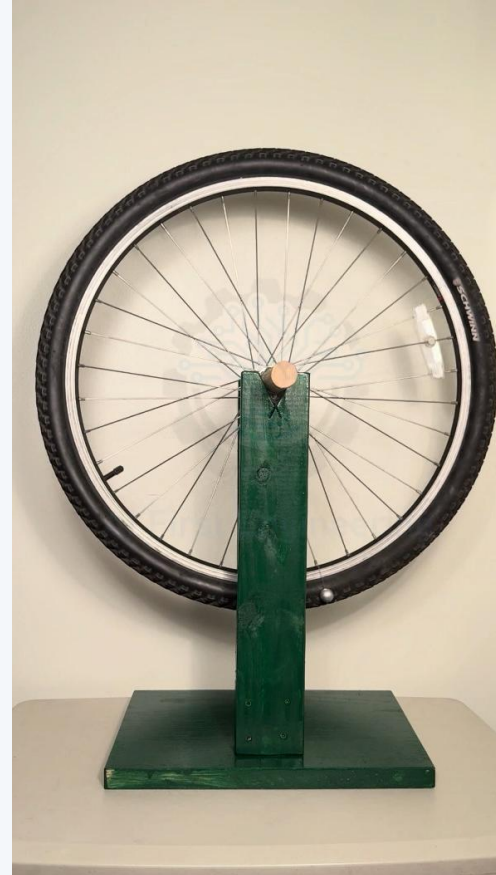
VIDEO: BRAKING

Normal
Speed
30 fps

Rubber friction element
pressed lightly against
the hub; **wheel slows
gradually.**



Slow
Motion
120fps



What is changing now that was not changing before?

The **speed**. The path is unchanged — still a circle of radius r .



Is the direction of $\vec{v}$ still changing?

Yes. There are now two contributions to acceleration at the same time: the speed is decreasing and the velocity direction is changing.

Observe

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Model

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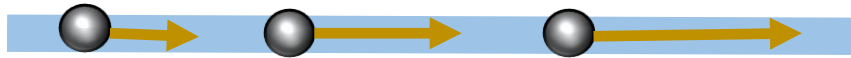
Validate

Report



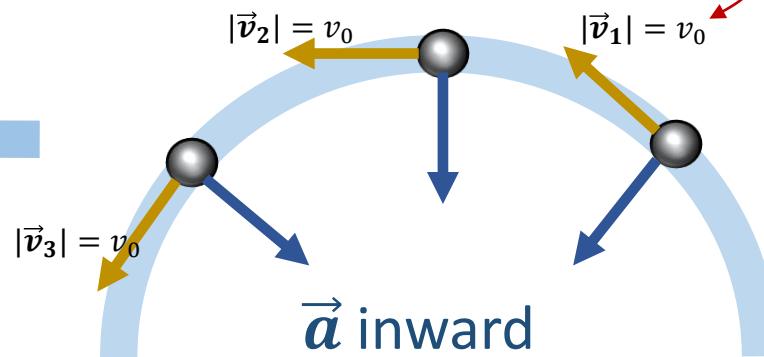
Acceleration can come from a change in speed, a change in direction, or both

SPEED CHANGES Straight Path

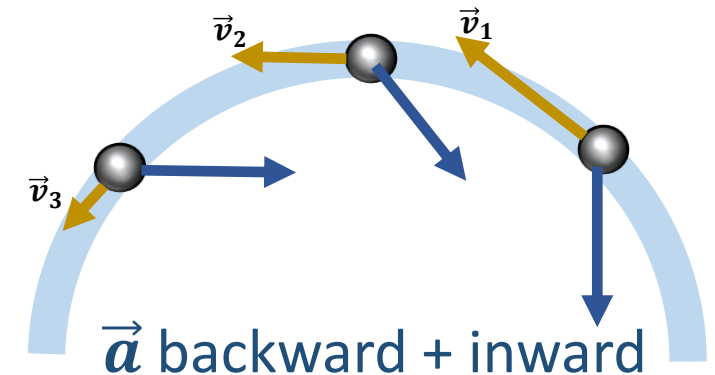


$\vec{a}$ in the direction of motion

DIRECTION CHANGE Curved Path, Constant Speed



SPEED & DIRECTION BOTH CHANGE Curved Path, Slowing down



1 Speed changes

Chapter 1: a car braking on a straight road. The acceleration is along the path.

2 Direction changes

The steady wheel. Speed constant, velocity vector turning. The acceleration points inward, across the path.

3 Both direction & speed change

The braking wheel. One part of $\vec{a}$ acts along the path (slowing), one part acts inward (turning).

Observe



Idealize

**Model**

Solve / Analyze



Validate

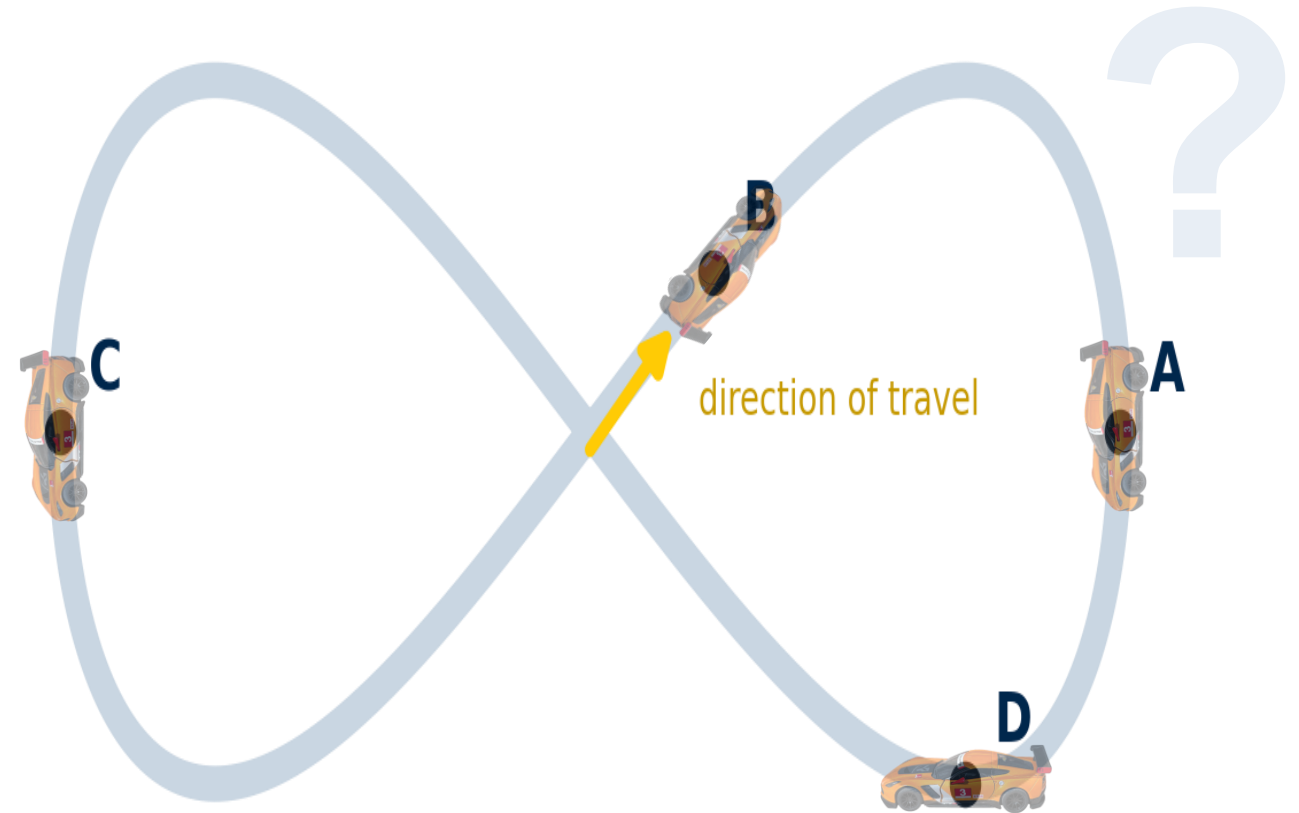


Report



THINK

A test vehicle drives a figure-8 at constant speed.
Where is $|\vec{a}|$ largest?
Where is it zero?



Mark your answers on the sketch before we discuss.

Points A–D. Then: the driver brakes at B — which way does the acceleration tilt now?

Observe

Idealize

Model

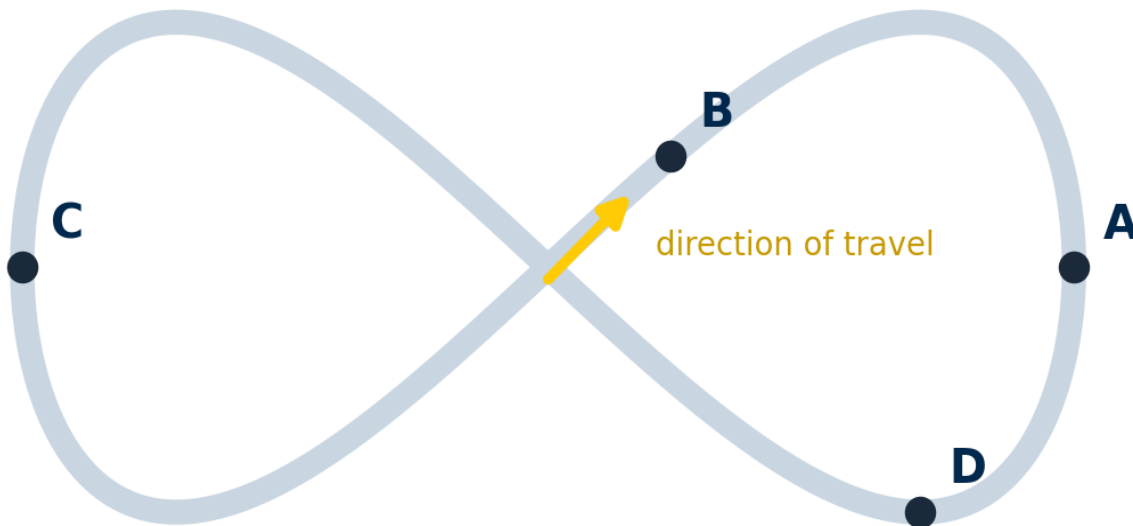
Solve / Analyze

Validate

Report



At constant speed: tighter bend → larger inward acceleration. Straight stretch → no inward acceleration. Braking → $\vec{a}$ tilts backward.



THE VECTOR CHAIN — CHAPTER 1, NOW WITH ARROWS

$$\vec{r}(t) \rightarrow \vec{v} = \frac{d\vec{r}}{dt} \rightarrow \vec{a} = \frac{d\vec{v}}{dt}$$

$\vec{v}$ is always tangent to the path.

$\vec{a}$ is generally NOT tangent to the path — it has an inward part whenever the path bends.

$|\vec{v}|$ is the speed. Constant $|\vec{v}|$ still allows $a \neq 0$.



Misconception to retire today

"Velocity points from the origin to the particle." No — $\vec{r}$ does that. $\vec{v}$ is tangent to the path, wherever the origin is.

Observe

Idealize

Model

Solve / Analyze

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Part 1 — what you can now explain and do



You can now EXPLAIN

- Why the velocity vector must be tangent to the path, whatever origin you chose
- Why a particle moving at constant speed on a curve is accelerating — and which way
- The three reasons for acceleration, with a physical example of each (straight-line braking, steady wheel, braking wheel)



You can now DO

- Draw $\vec{r}$, $\Delta\vec{r}$ and $\vec{v}$ on a trajectory sketch; distinguish path distance s from displacement magnitude $|\Delta\vec{r}|$
- Construct $\Delta\vec{v}$ from two nearby velocity vectors and read the direction of $\vec{a}$ from it
- Rank points qualitatively by inward acceleration at constant speed using relative curvature, and predict how $\vec{a}$ tilts when the speed changes

Next — Part 2: we can describe this motion with numbers using fixed x–y axes. Parts 4 and 5 will show two other descriptions of the SAME motion. AI as Tutor: "Explain, without equations, why a car rounding a bend at constant speed is accelerating — then ask me one question to check that I understood."

EXPLORE WITH AI — Go One Step Deeper



What we established

A particle can accelerate when its:

- speed changes,
- direction changes,
- or both.

Now use AI to extend your understanding.



AI EXPLORATION PROMPT.

“I am studying curvilinear particle motion in a 300-level Dynamics course. I understand that a particle can accelerate even when its speed is constant because its velocity direction changes. Give me a new physical example—not a bicycle wheel—and walk me through the velocity and acceleration directions at three points on the path. Ask me to predict each direction before revealing the answer.”



ENGINEER'S CHECK BOX:

- ☐ Don't just accept the answer. **Verify it.**
- ☐ Sketch the velocity vectors yourself.
- ☐ Is the velocity tangent to the path at each point?
- ☐ Does the proposed acceleration direction make physical sense?



Vectors in two minutes — magnitude, direction, unit vectors, differences



Scalar vs vector

Scalar: mass 5 kg, temperature 10 °C, **speed** 4 m/s.

Vector: position 5 m east, **velocity** 10 m/s upward, acceleration 9.81 m/s² downward.



Magnitude and unit vector

$|u|$ is the length (a scalar). The unit vector $\hat{u} = u/|u|$ carries only the direction. So $u = |u| \hat{u}$ — length times direction.



Components

$u = u_x i + u_y j$, $|u| = \sqrt{u_x^2 + u_y^2}$. The basis vectors i, j are fixed. In Parts 4–5 the basis vectors will move — watch for it.



Difference of two vectors

$u_2 - u_1$: slide both to a common tail, draw from the tip of u_1 to the tip of u_2 . This is exactly the Δv construction of Part 1.



Derivative of a vector

$du/dt = \lim \Delta u / \Delta t$. If $|u|$ is constant, du/dt can still be nonzero — it then points perpendicular to u . (This single fact powers Parts 4 and 5.)



Self-review with any AI assistant

"Quiz me on vector components and unit vectors, one problem at a time. Wait for my answer, then tell me if I am right and why."



Vector Reference Sheet (Optional)

Scalar: only magnitude no direction.

Examples:

Mass (e.g. $m = 5 \text{ kg}$)

Temperature (e.g. $T = 10^\circ \text{ F}$)

Speed (e.g. $v_{sp} = 4 \text{ m/s}$)

Vector : both magnitude and direction

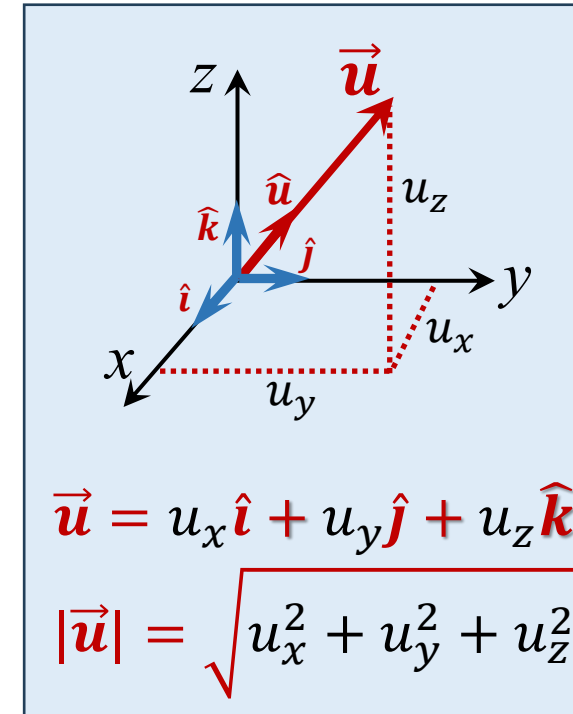
Examples:

Position (e.g., $\vec{r} = 5 \text{ m east}$)

Velocity (e.g., $\vec{v} = 10 \text{ m/s upward}$)

Acceleration (e.g., $\vec{a} = 9.81 \text{ m/s}^2 \text{ down}$)

Force (e.g., $\vec{F} = 20 \text{ N at } 30^\circ \text{ above horizontal}$)



Magnitude of a Vector: $|\vec{u}|$ is a scalar quantity

Unit Vector:

$$\hat{u} = \frac{\vec{u}}{|\vec{u}|}, \quad \text{then} \quad \vec{u} = |\vec{u}| \cdot \hat{u}$$