Today: Section 3.4

Today: Section 3.4

Motion in a circle

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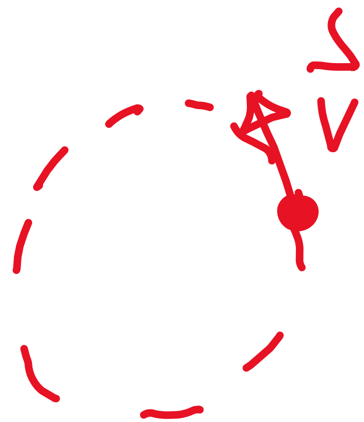
Motion in a circle



Today: Section 3.4

HW#3 Due tonight

Today: Section 3.4

HW#3 Due tonight

Monday: Section 3.5

Today: Section 3.4

HW#3 Due tonight

Monday: Section 3.5

Relative Motion

Today: Section 3.4

HW#3 Due tonight

Monday: Section 3.5

HW#4 Due Wednesday

ASU

Today: Section 3.4

HW#3 Due tonight

Monday: Section 3.5

HW#4 Due Wednesday

Date of Exam #1

ASU

Uniform Circular Motion

Uniform Circular Motion

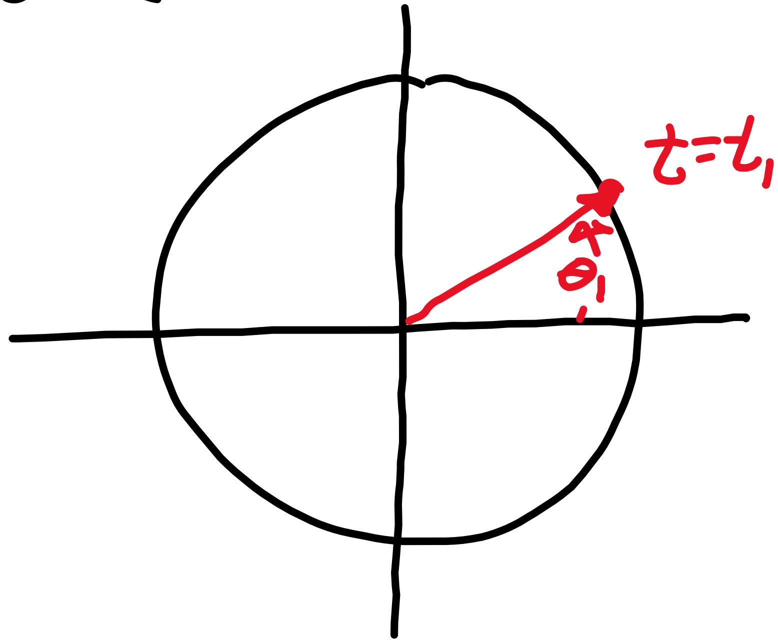
1st we will look at a mathematic description not given by the book

Uniform Circular Motion

1st we will look at a mathematic description not given by the book & then revert back to the treatment given in the text

Uniform Circular Motion

Uniform ⇒ constant speed



Uniform Circular Motion

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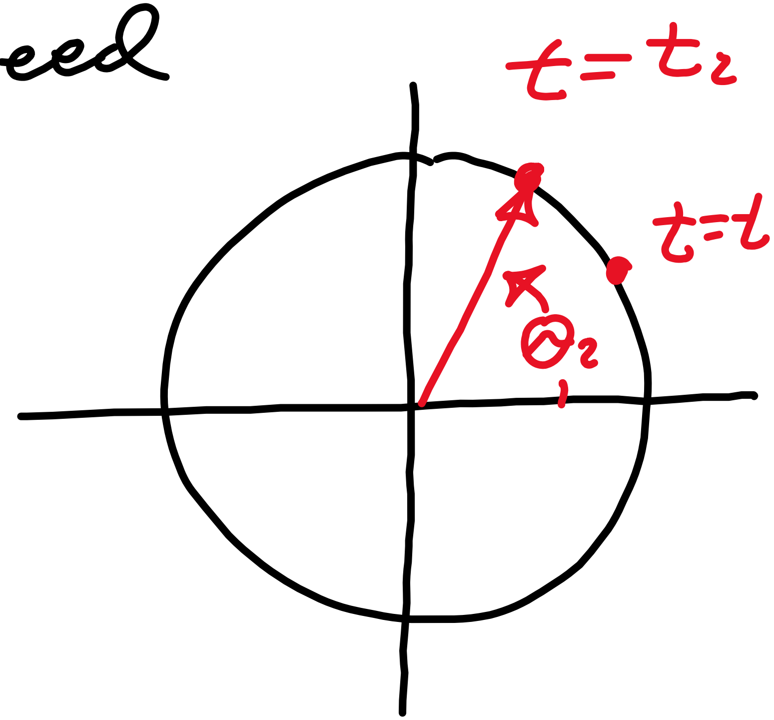

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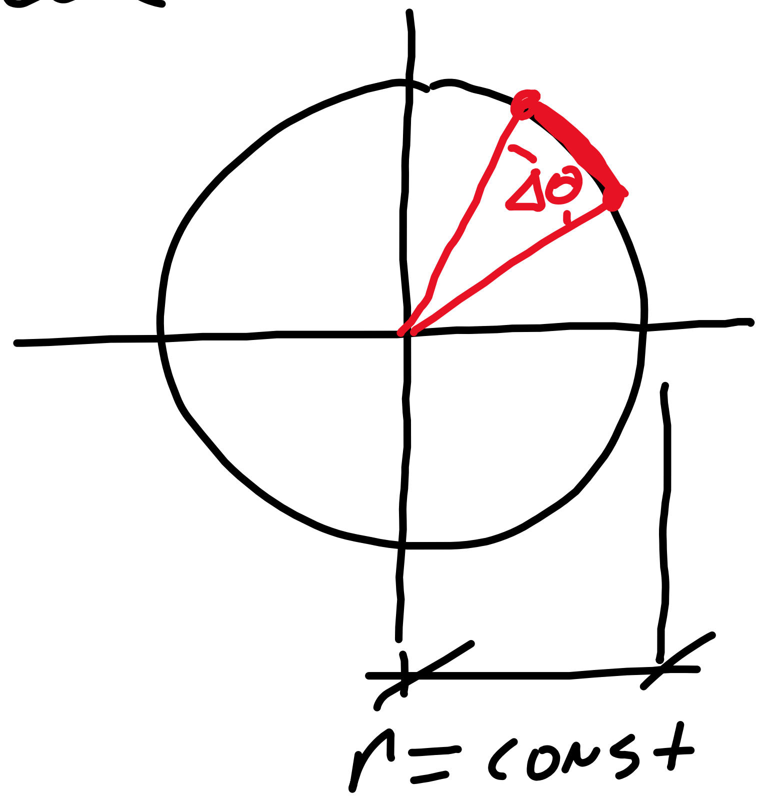

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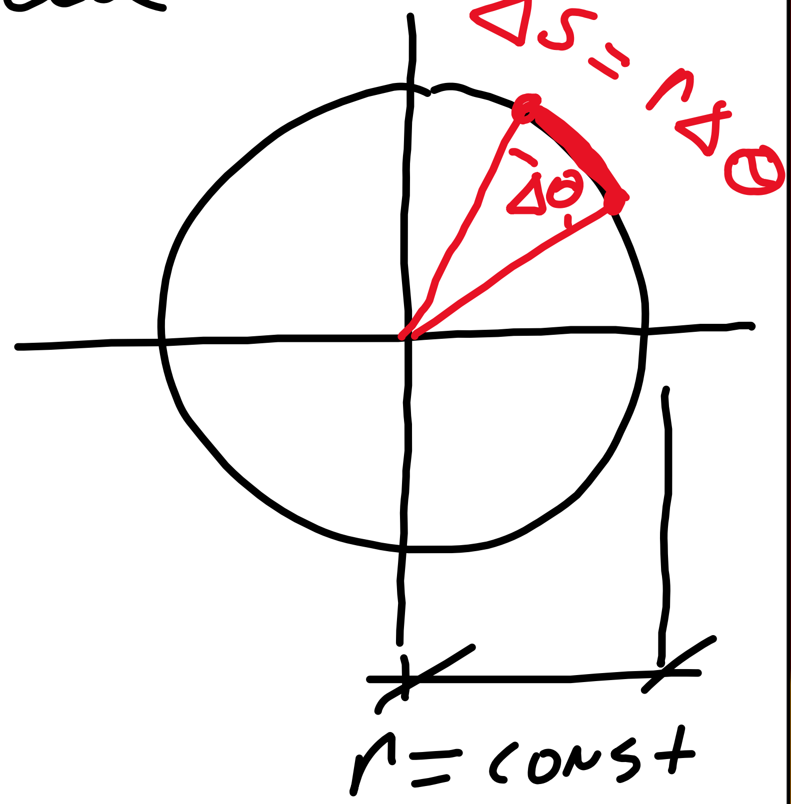

Uniform Circular Motion

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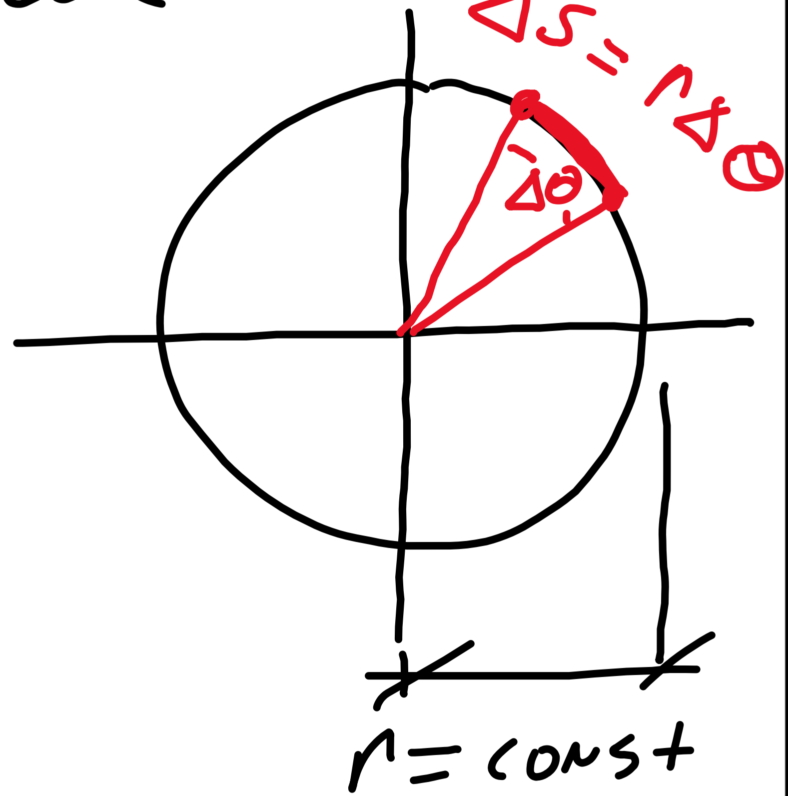
$$\frac{\Delta s}{\Delta t} = r \frac{\Delta \theta}{\Delta t}$$



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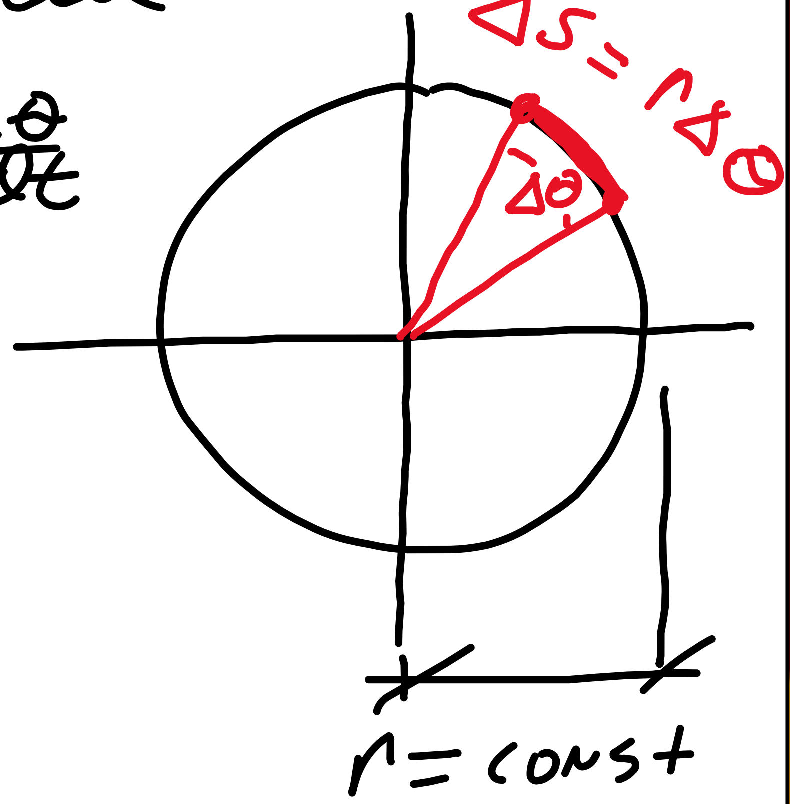

Uniform Circular Motion

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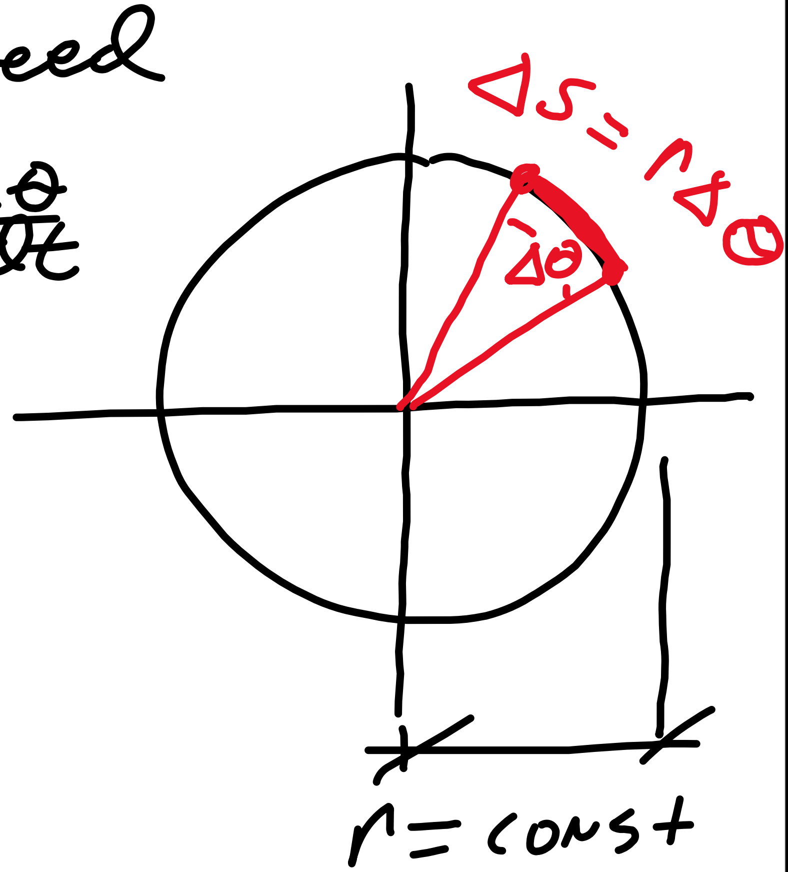

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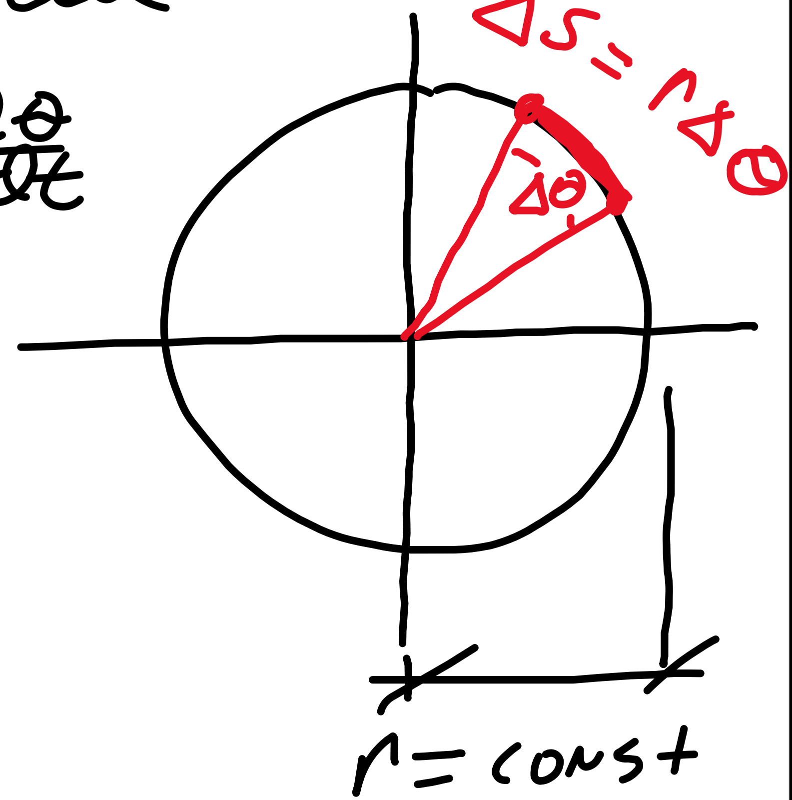

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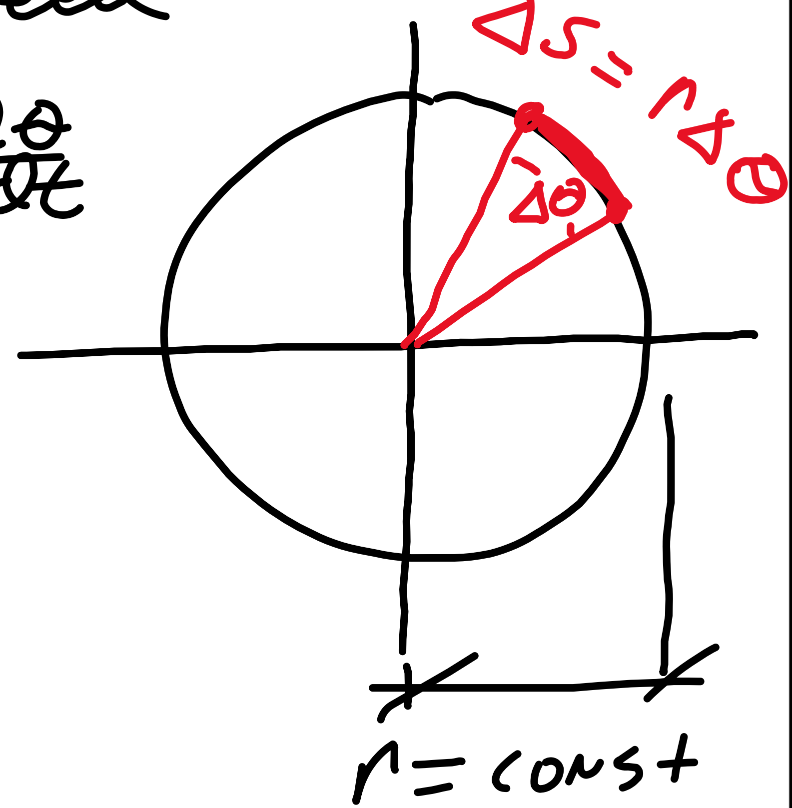

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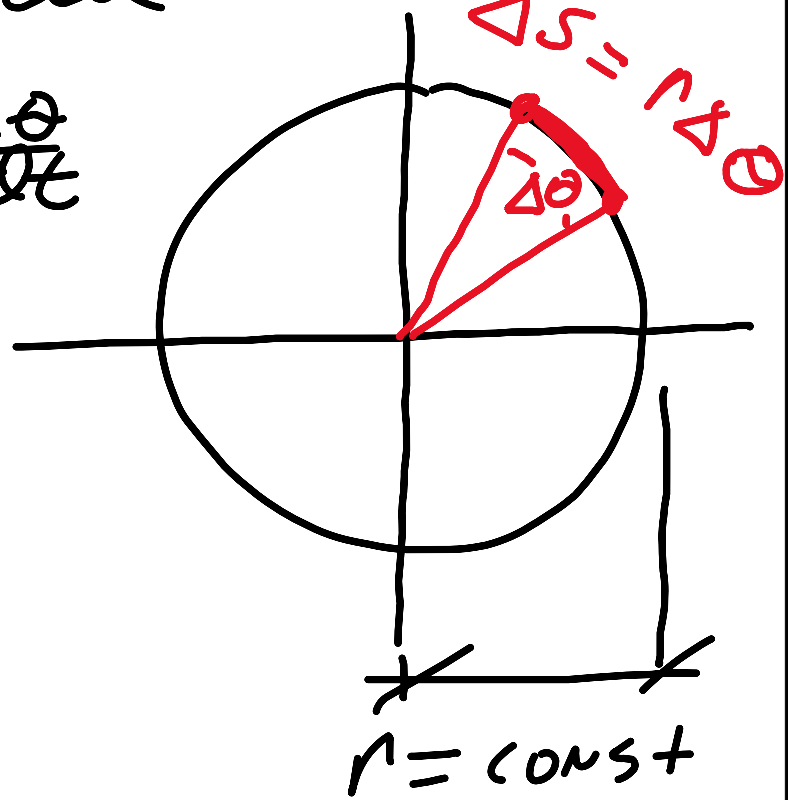

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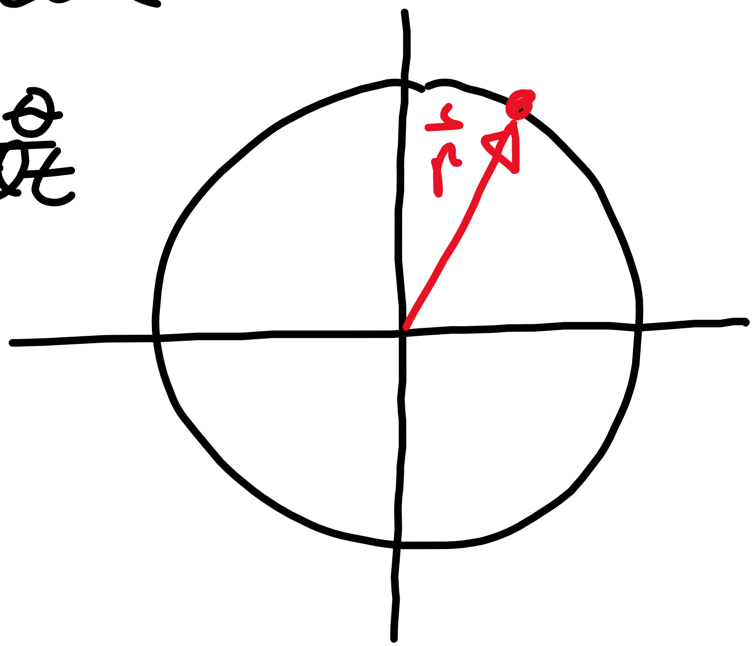

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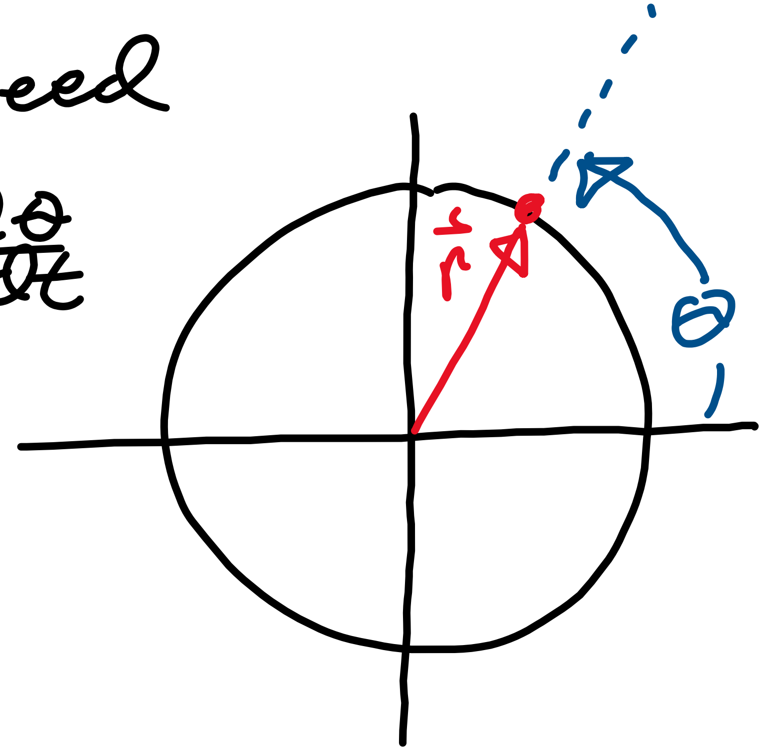

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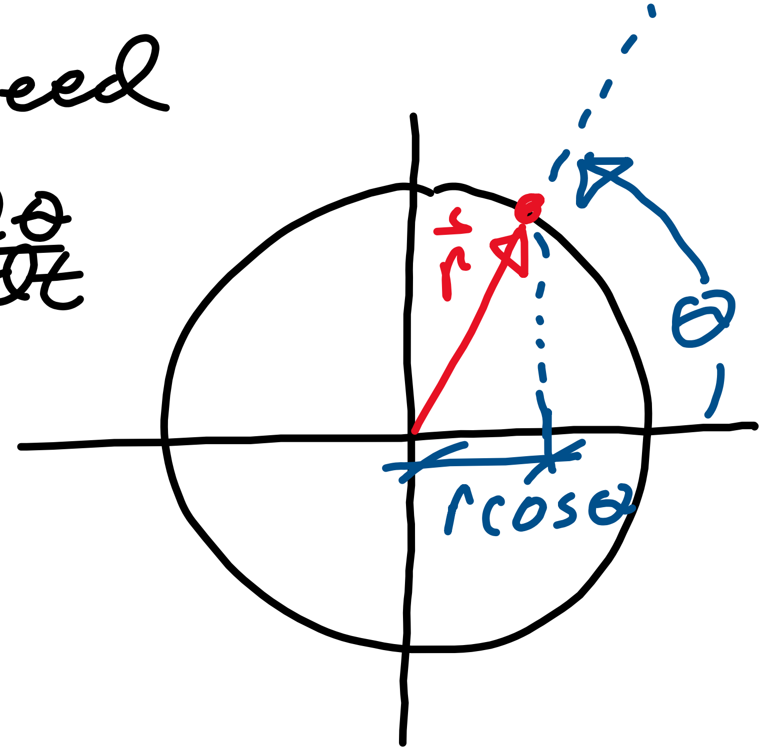

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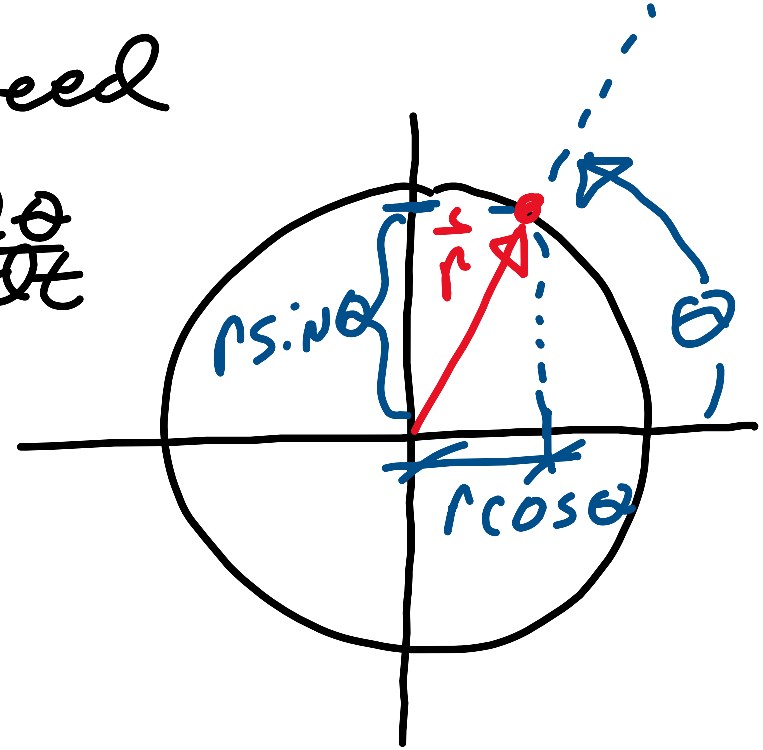

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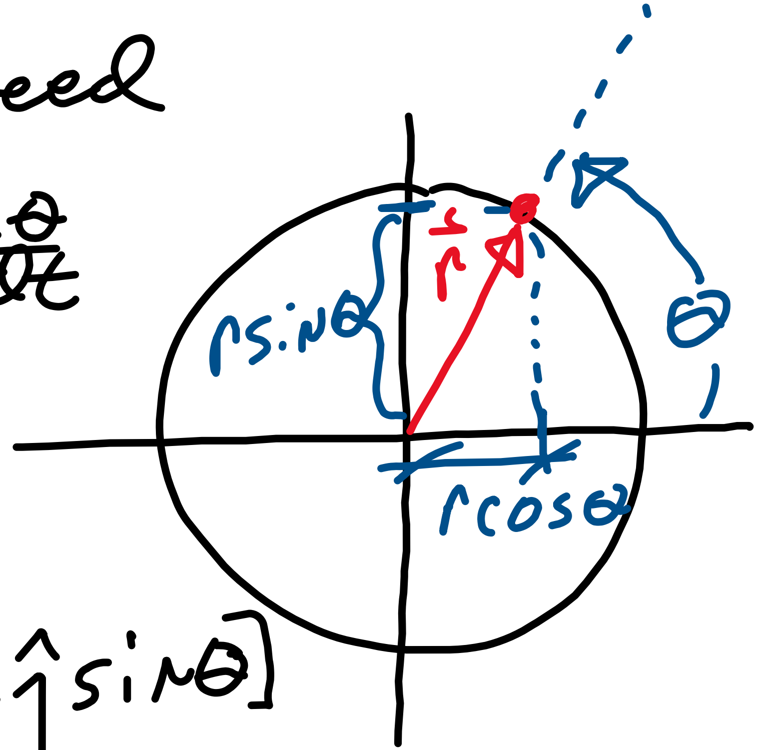

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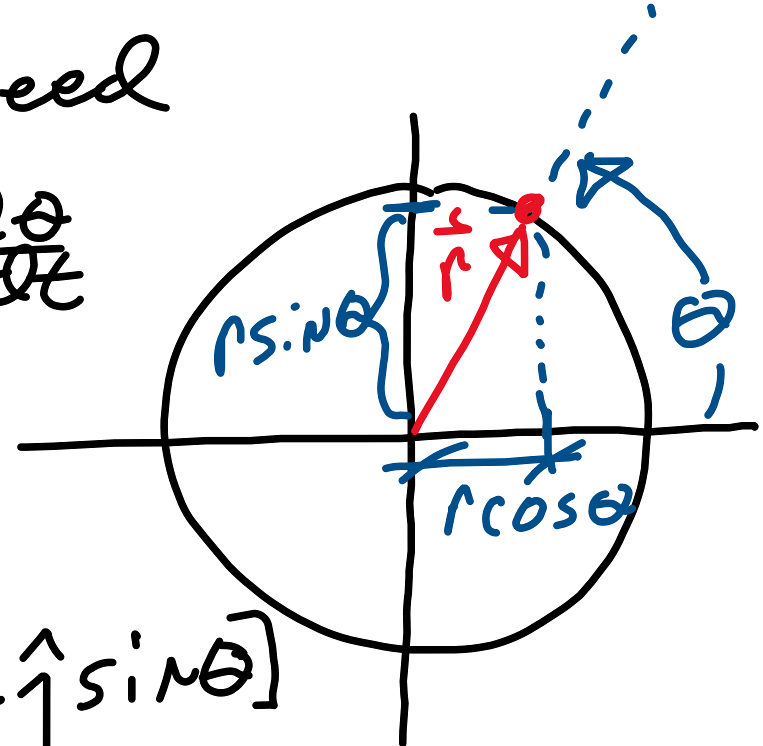

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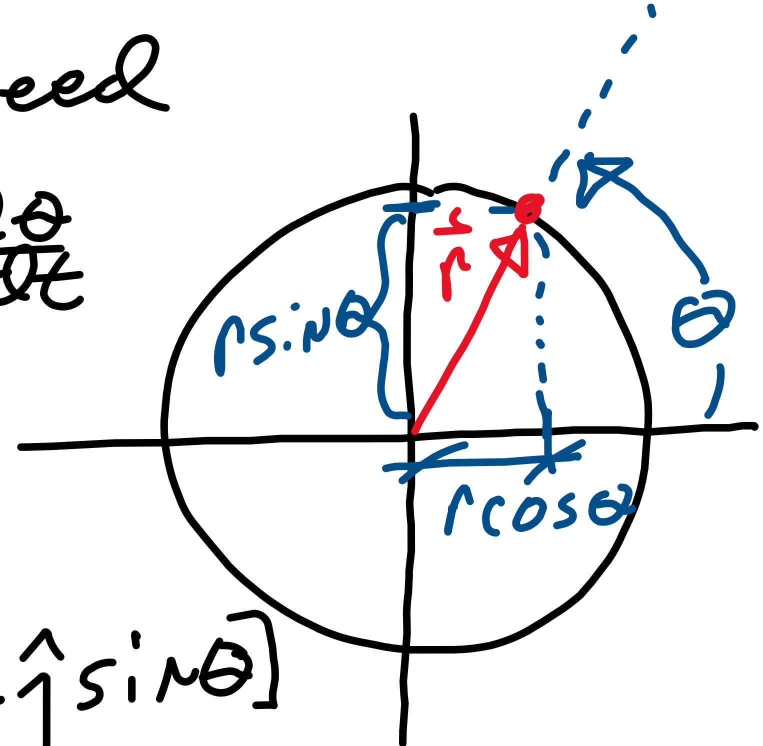

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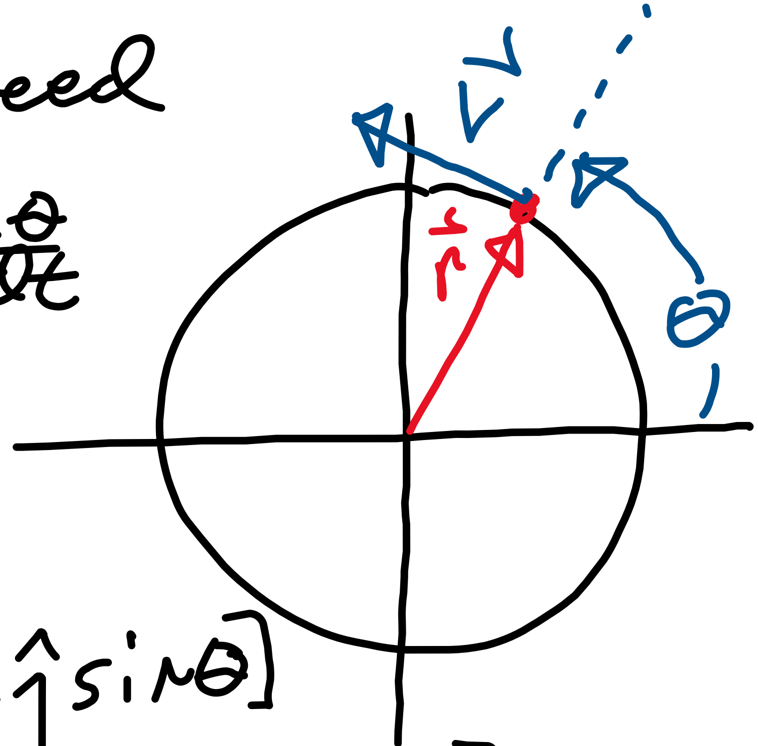

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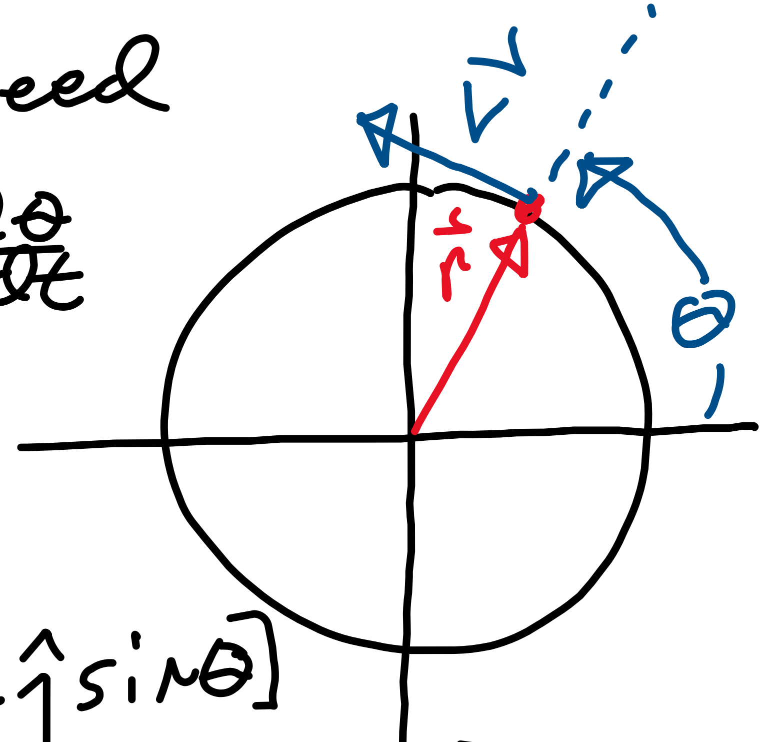

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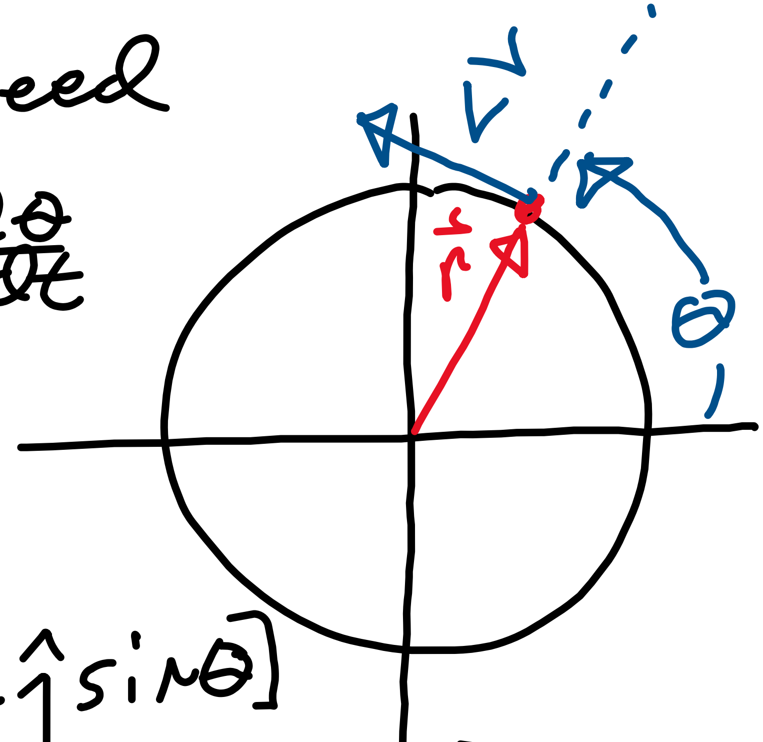

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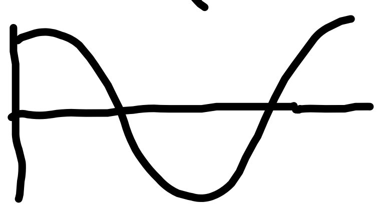

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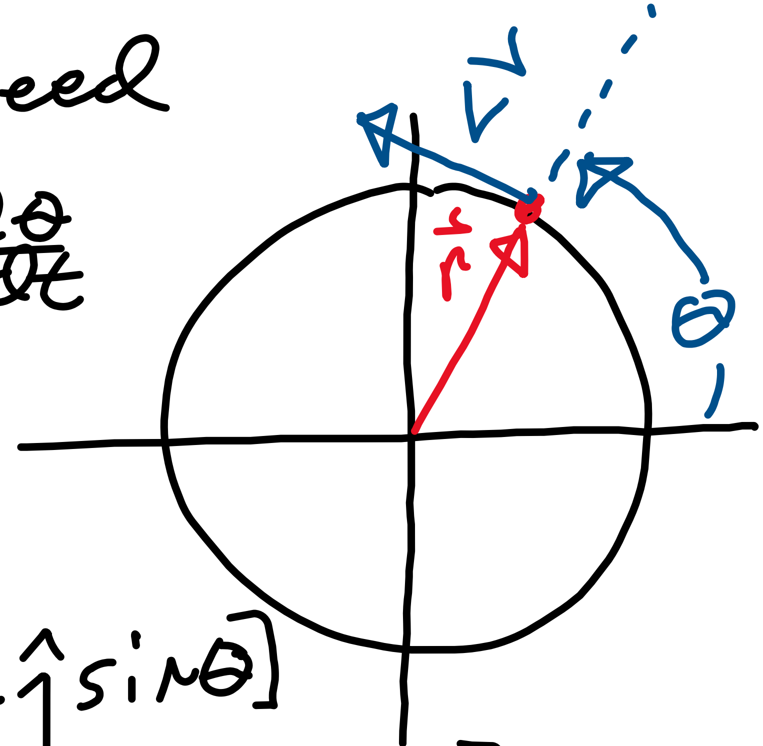

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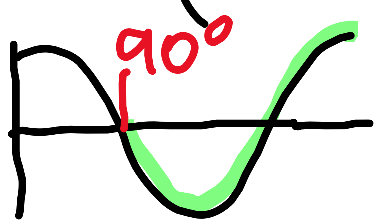

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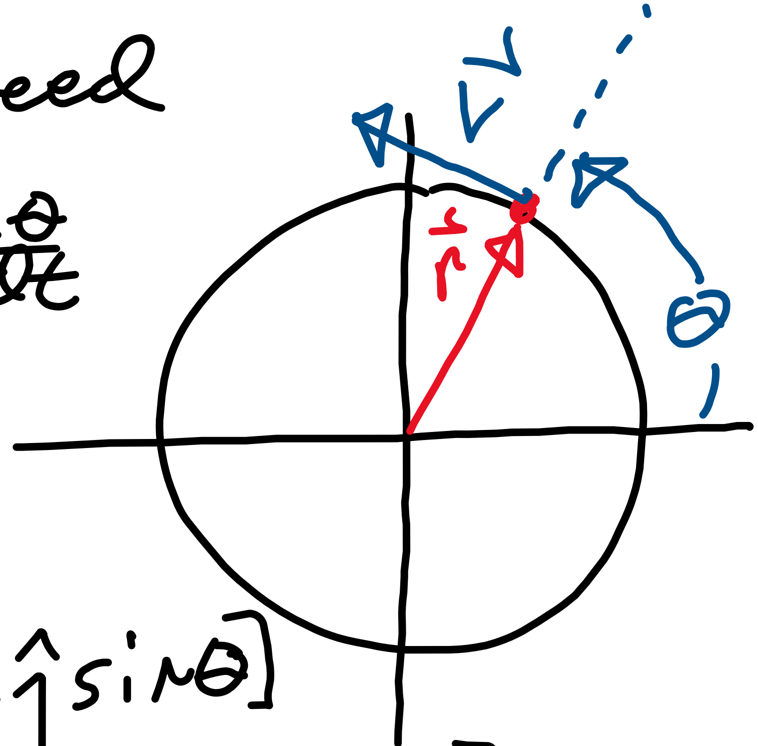

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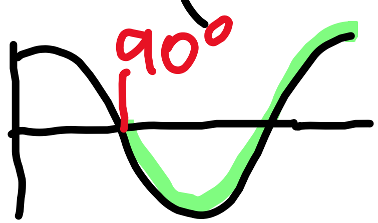

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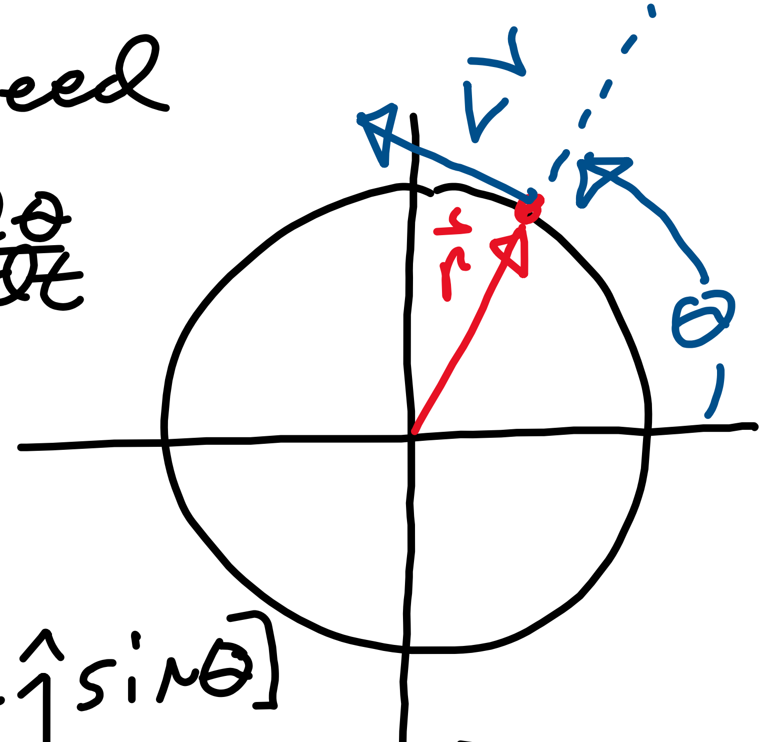

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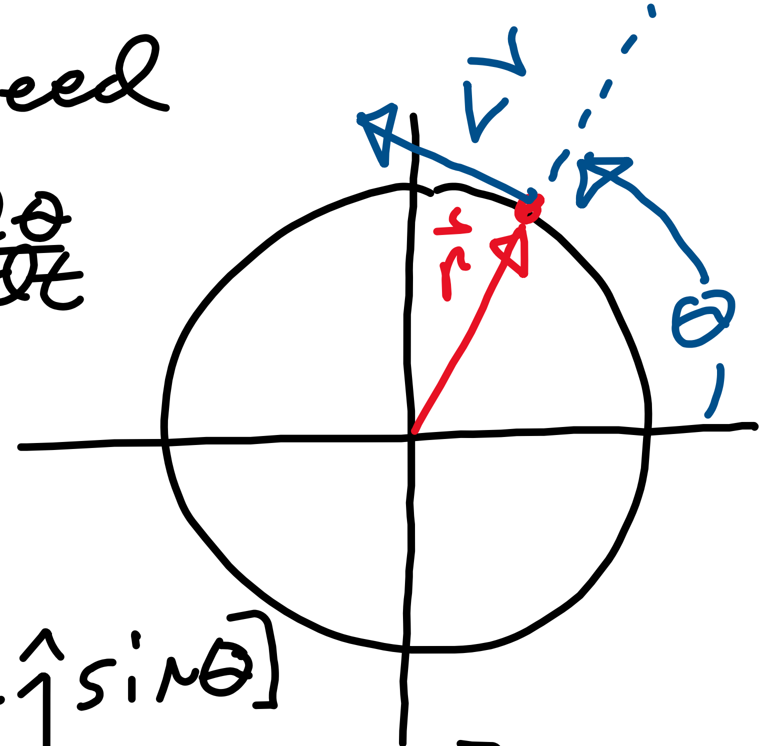

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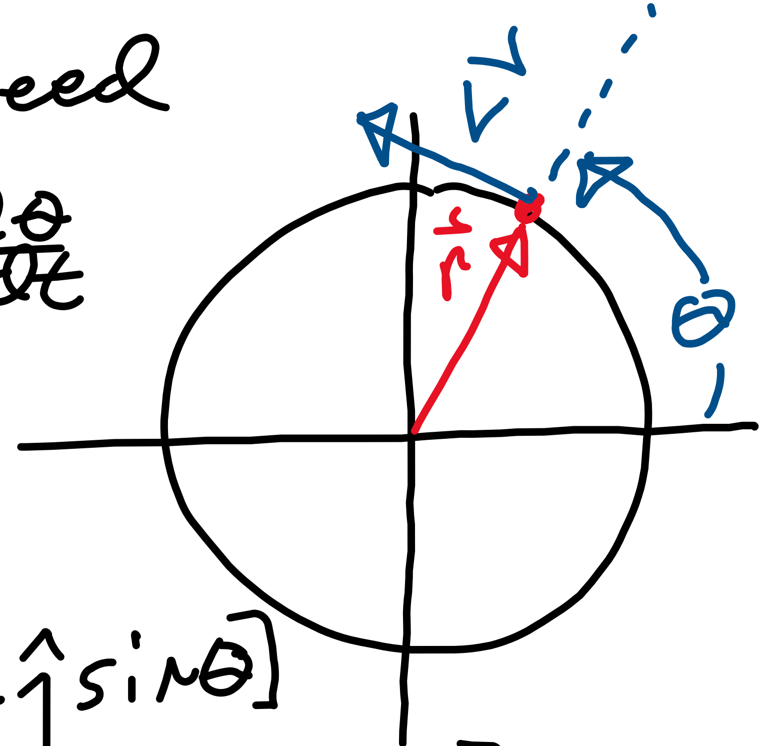

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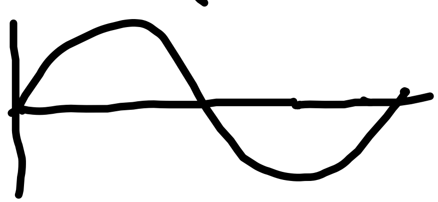

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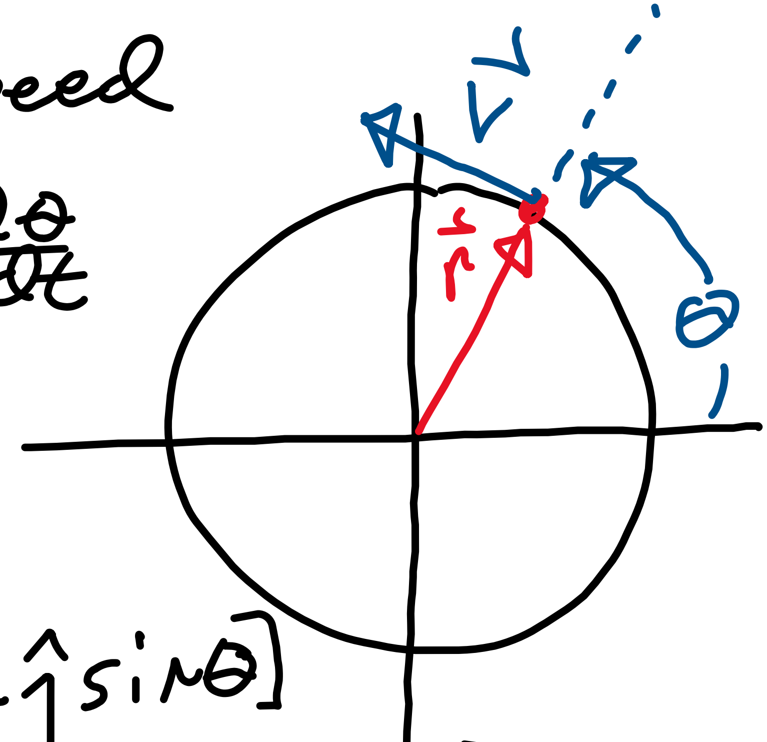

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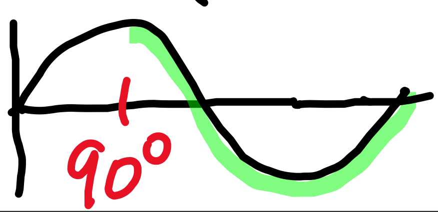

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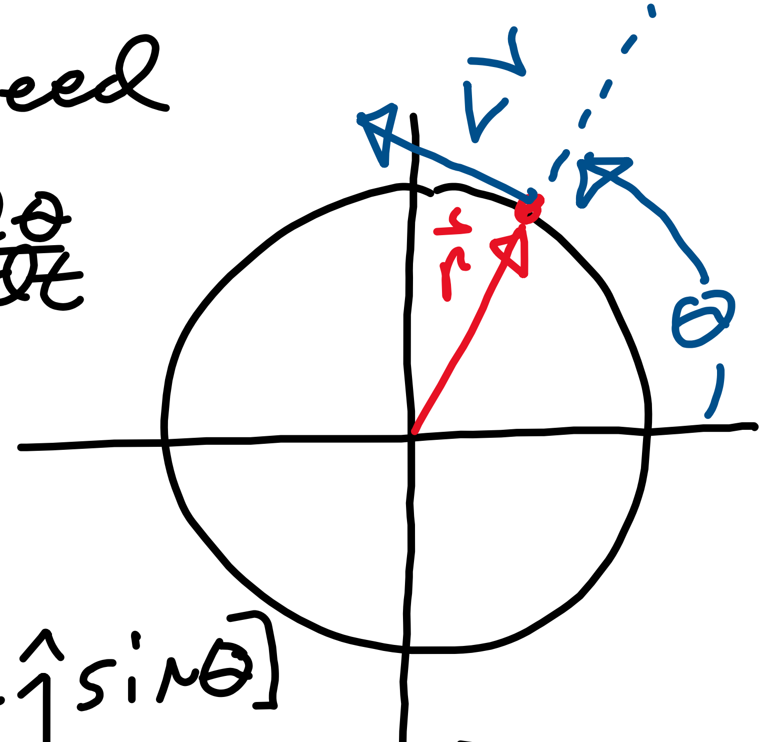

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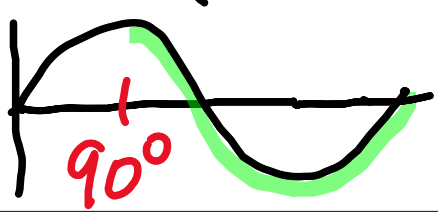

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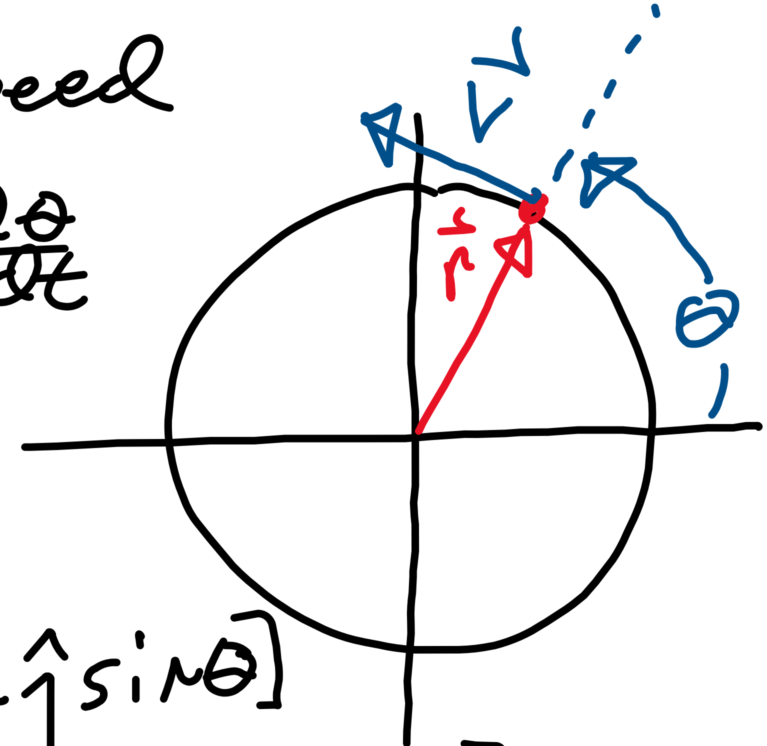

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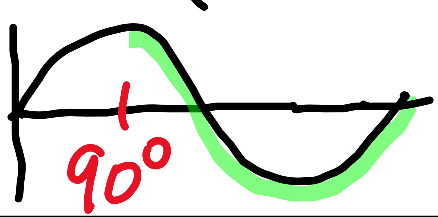

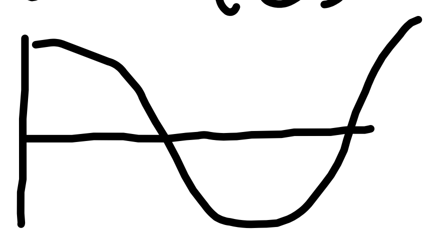

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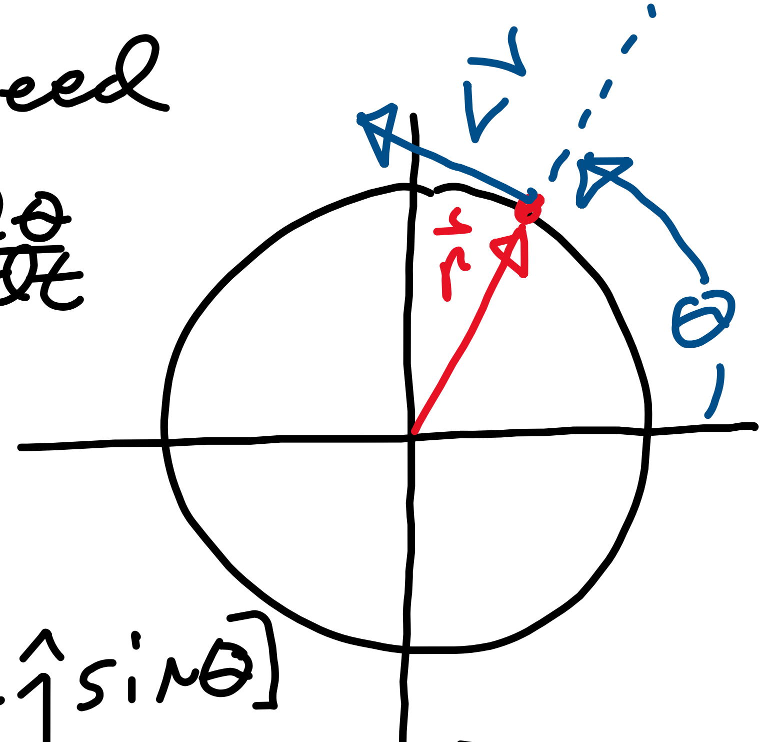

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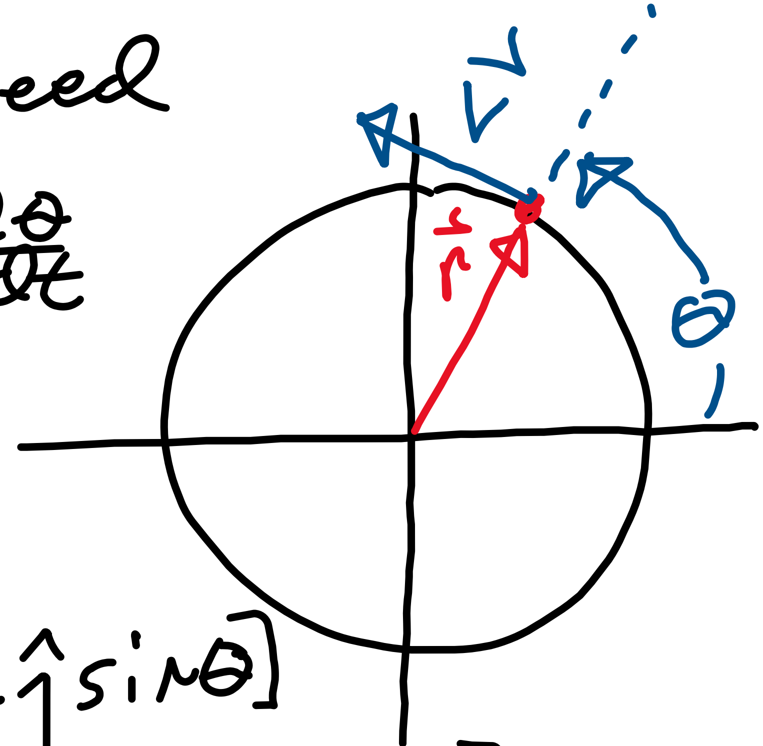

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What about $\vec{v}$?

$$\vec{v} = \frac{d\vec{r}}{dt} = r\frac{d}{dt}\left[\hat{i}\cos\theta + \hat{j}\sin\theta\right]$$

$$= \left(r\frac{d\theta}{dt}\right)\left[-\hat{i}\sin\theta + \hat{j}\cos\theta\right]$$

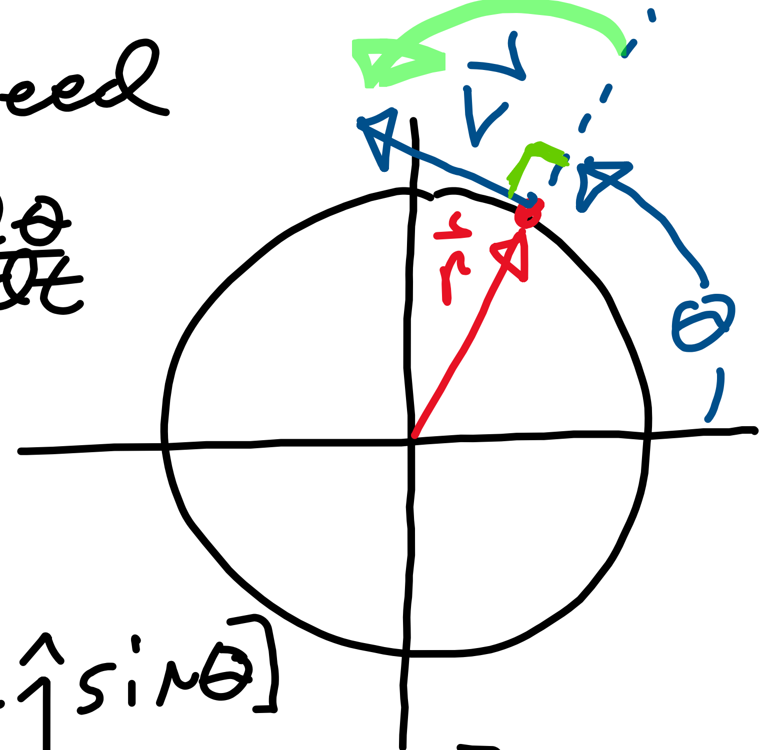
So $\vec{v}$ is rotated 90° relative to $\vec{r}$

Uniform Circular Motion

Uniform ⇒ constant speed

$$\frac{\Delta s}{\Delta t} = r\frac{\Delta\theta}{\Delta t} \Rightarrow \frac{ds}{dt} = r\frac{d\theta}{dt}$$

& $v = \frac{ds}{dt} \Rightarrow v = r\frac{d\theta}{dt}$



What about $\vec v$?

$$\vec v = \frac{d\vec r}{dt} = r\frac{d}{dt}\left[\hat i\cos\theta + \hat j\sin\theta\right]$$

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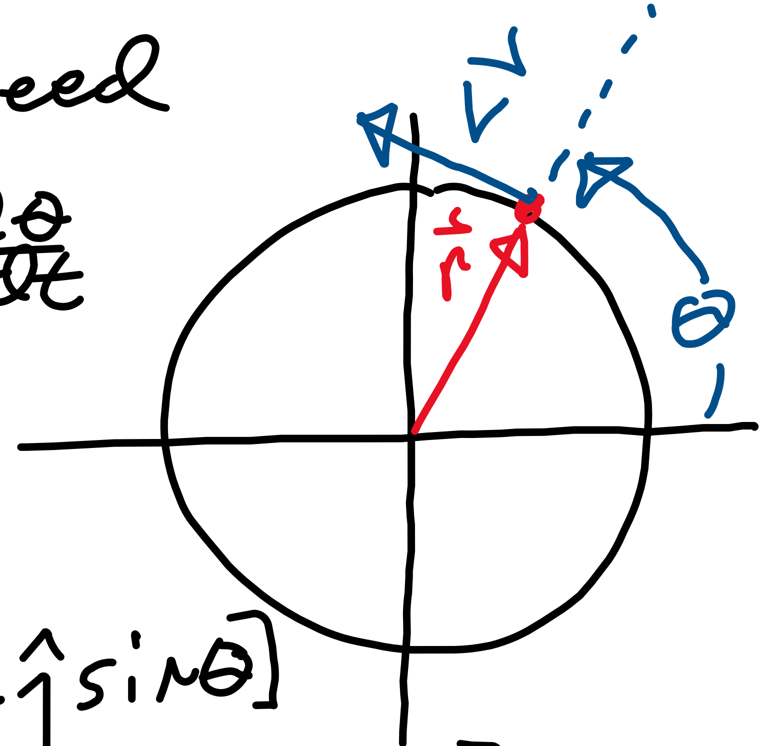
Uniform Circular Motion

Uniform ⇒ constant speed



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What about $\vec{a}$

Uniform Circular Motion

Uniform $\Rightarrow$ constant speed

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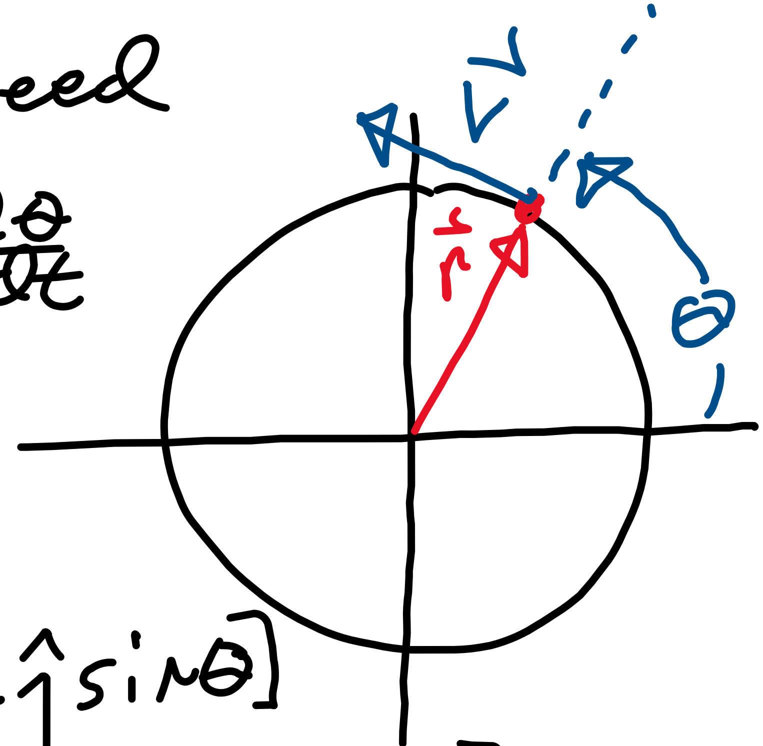
$$\text{\& } v = \frac{ds}{dt} \Rightarrow v = r\frac{d\theta}{dt}$$



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$$\vec{a} = \frac{d\vec{v}}{dt} = \left[r\left(\frac{d\theta}{dt}\right)^2\right]\left[-\hat{i}\cos\theta - \hat{j}\sin\theta\right]$$

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Uniform $\Rightarrow$ constant speed

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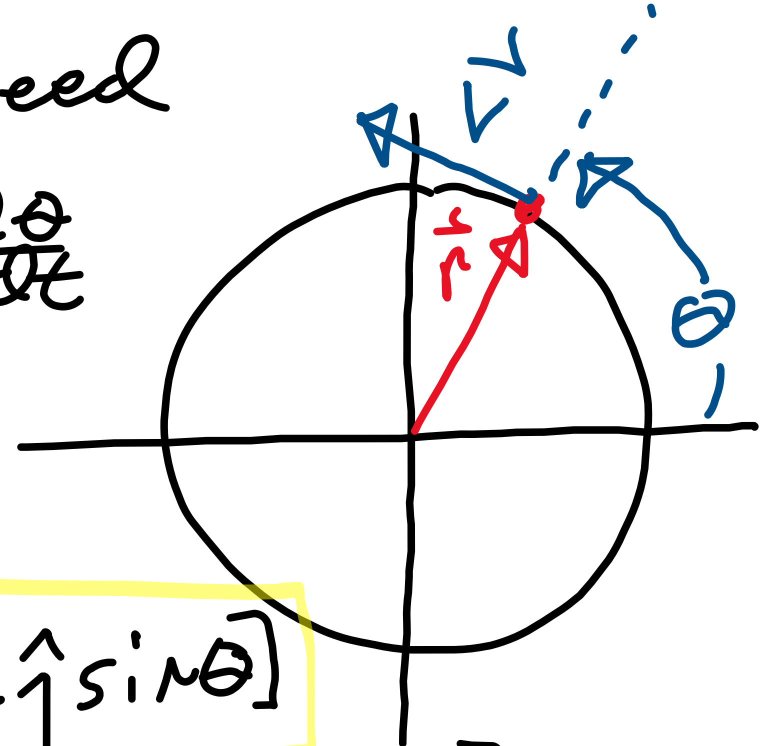

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ASU

Uniform Circular Motion

Uniform ⇒ constant speed

$\frac{\Delta s}{\Delta t} = r\frac{\Delta\theta}{\Delta t} \Rightarrow \frac{ds}{dt} = r\frac{d\theta}{dt}$

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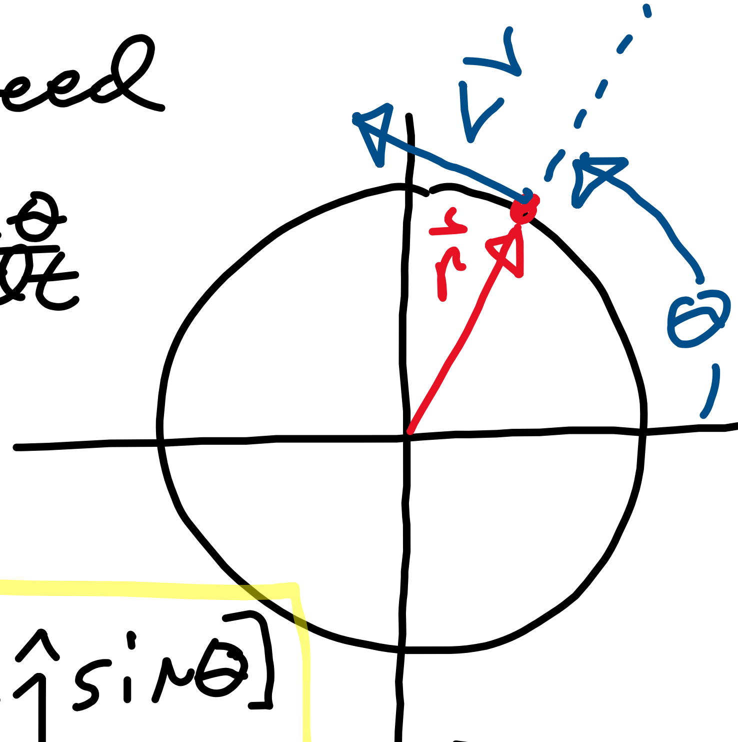

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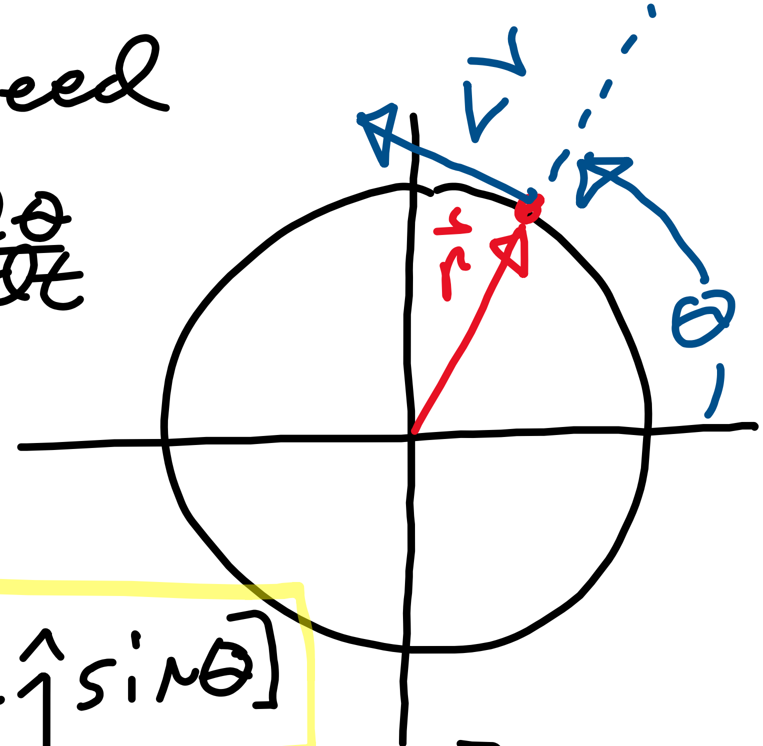

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$$\vec{a} = \frac{d\vec{v}}{dt} = \left[r\left(\frac{d\theta}{dt}\right)^2\right]\left[-\hat{i}\cos\theta - \hat{j}\sin\theta\right]$$

$\vec{a}$ is rotated 90° relative to $\vec{v}$

Uniform Circular Motion

Uniform $\Rightarrow$ constant speed

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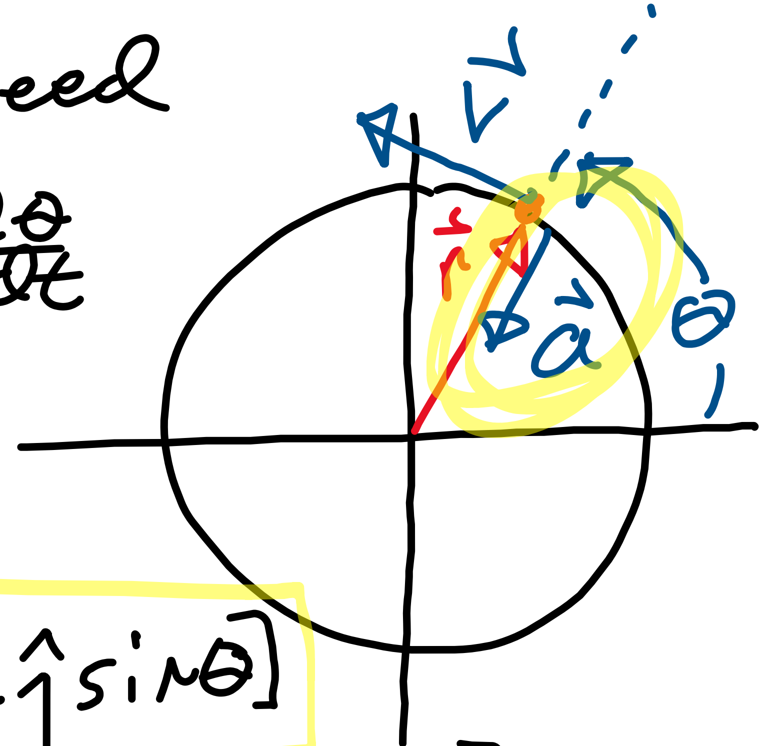

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Uniform Circular Motion

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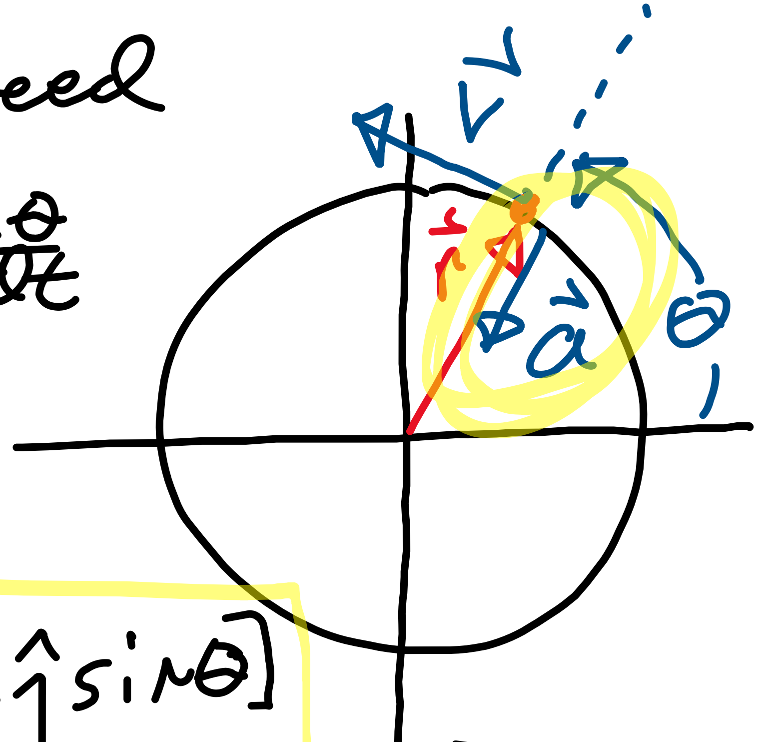

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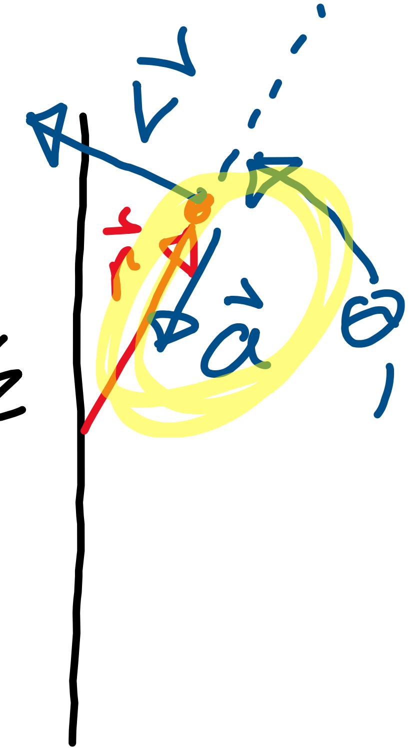
→ points inward towards center

Uniform Circular Motion

Uniform ⇒ constant speed

$$\frac{\Delta s}{\Delta t} = r\frac{\Delta\theta}{\Delta t} \Rightarrow \frac{ds}{dt} = r\frac{d\theta}{dt}$$

so $$a_\perp = r\left(\frac{d\theta}{dt}\right)^2\left[\cos^2\theta + \sin^2\theta\right]^{1/2}$$



Uniform Circular Motion

Uniform $\Rightarrow$ constant speed

$$\frac{\Delta s}{\Delta t} = r\frac{\Delta\theta}{\Delta t} \Rightarrow \frac{ds}{dt} = r\frac{d\theta}{dt}$$

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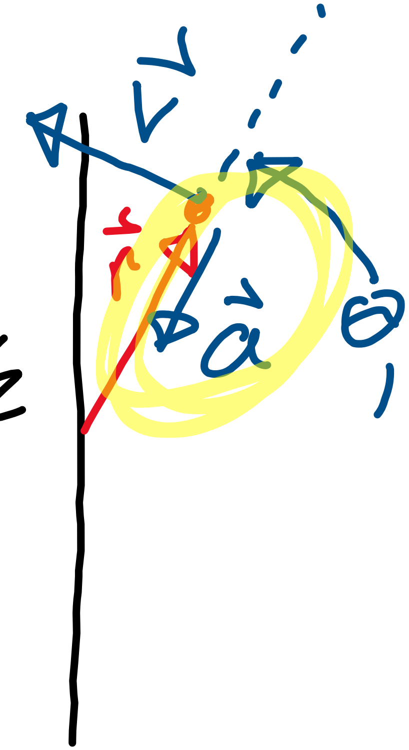

Uniform Circular Motion

Uniform $\Rightarrow$ constant speed

$$\frac{\Delta s}{\Delta t} = r\frac{\Delta\theta}{\Delta t} \Rightarrow \frac{ds}{dt} = r\frac{d\theta}{dt}$$

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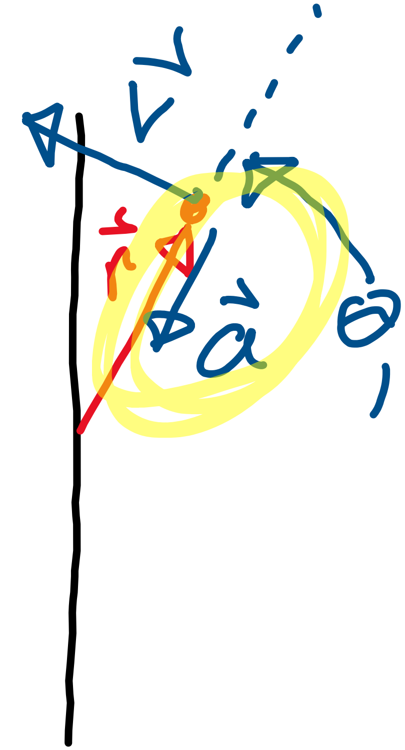


Uniform Circular Motion

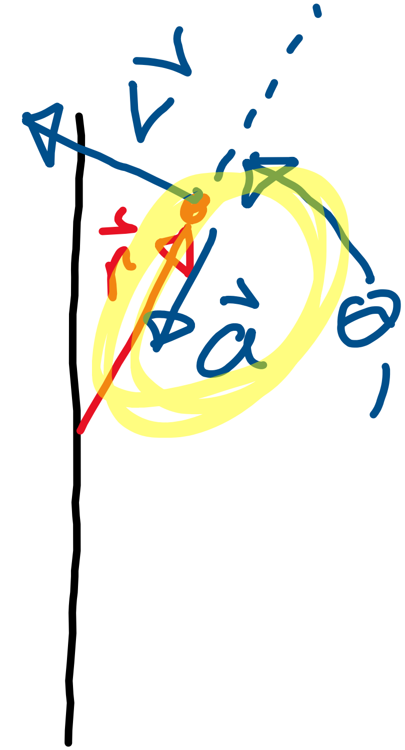
Uniform ⇒ constant speed

$$\frac{\Delta s}{\Delta t} = r\frac{\Delta\theta}{\Delta t} \Rightarrow \frac{ds}{dt} = r\frac{d\theta}{dt}$$

so $a_\perp = r\left(\frac{d\theta}{dt}\right)^2$

But

$$r\frac{d\theta}{dt} = v$$



ASU

Uniform Circular Motion

Uniform ⇒ constant speed

$$\frac{\Delta s}{\Delta t} = r\frac{\Delta\theta}{\Delta t} \Rightarrow \frac{ds}{dt} = r\frac{d\theta}{dt}$$

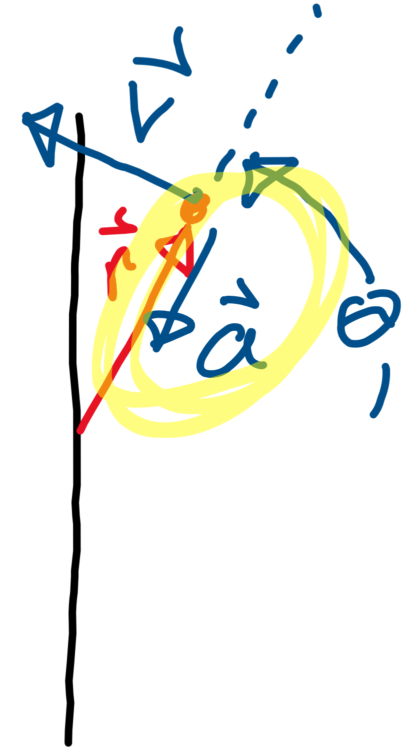
so $a_\perp = r\left(\frac{d\theta}{dt}\right)^2$

But

$$r\frac{d\theta}{dt} = v$$

so

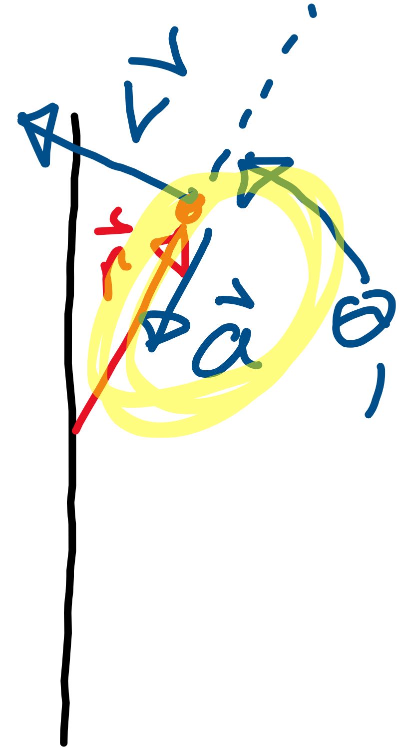
$$\frac{v^2}{r} = r\left(\frac{d\theta}{dt}\right)^2$$



Uniform Circular Motion

Uniform ⇒ constant speed

$$\frac{\Delta s}{\Delta t} = r\frac{\Delta\theta}{\Delta t} \Rightarrow \frac{ds}{dt} = r\frac{d\theta}{dt}$$



so $a_\perp = r\left(\frac{d\theta}{dt}\right)^2$

But

$$r\frac{d\theta}{dt} = v$$

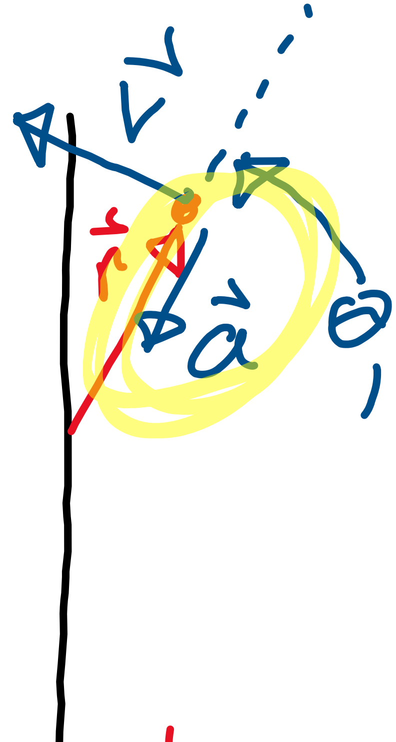
so

$$\frac{v^2}{r} = r\left(\frac{d\theta}{dt}\right)^2$$

$$\Rightarrow \boxed{a_\perp = \frac{v^2}{r}}$$

Uniform Circular Motion

Uniform ⇒ constant speed



$$\frac{\Delta s}{\Delta t} = r\frac{\Delta \theta}{\Delta t} \Rightarrow \frac{ds}{dt} = r\frac{d\theta}{dt}$$

so $a_\perp = r\left(\frac{d\theta}{dt}\right)^2$

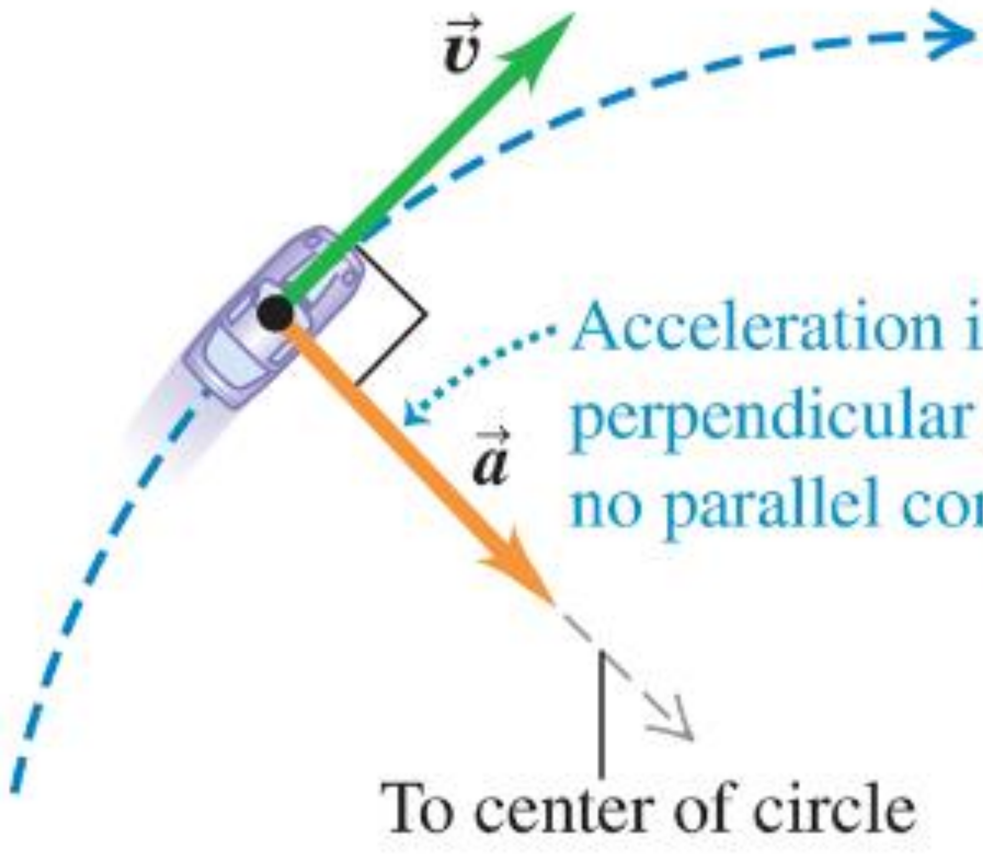
But $r\frac{d\theta}{dt} = v$

so $\frac{v^2}{r} = r\left(\frac{d\theta}{dt}\right)^2$

$$\Rightarrow \boxed{a_\perp = \frac{v^2}{r}}$$

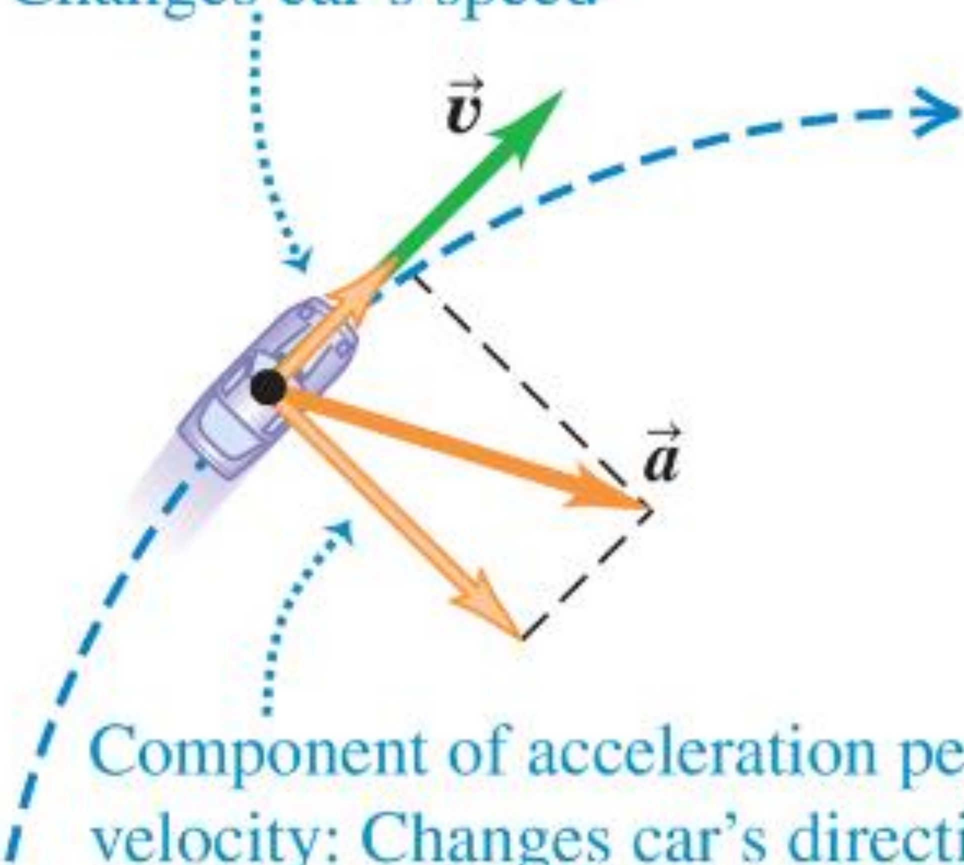
Back to the text

(a) **Uniform circular motion:** Constant speed along a circular path



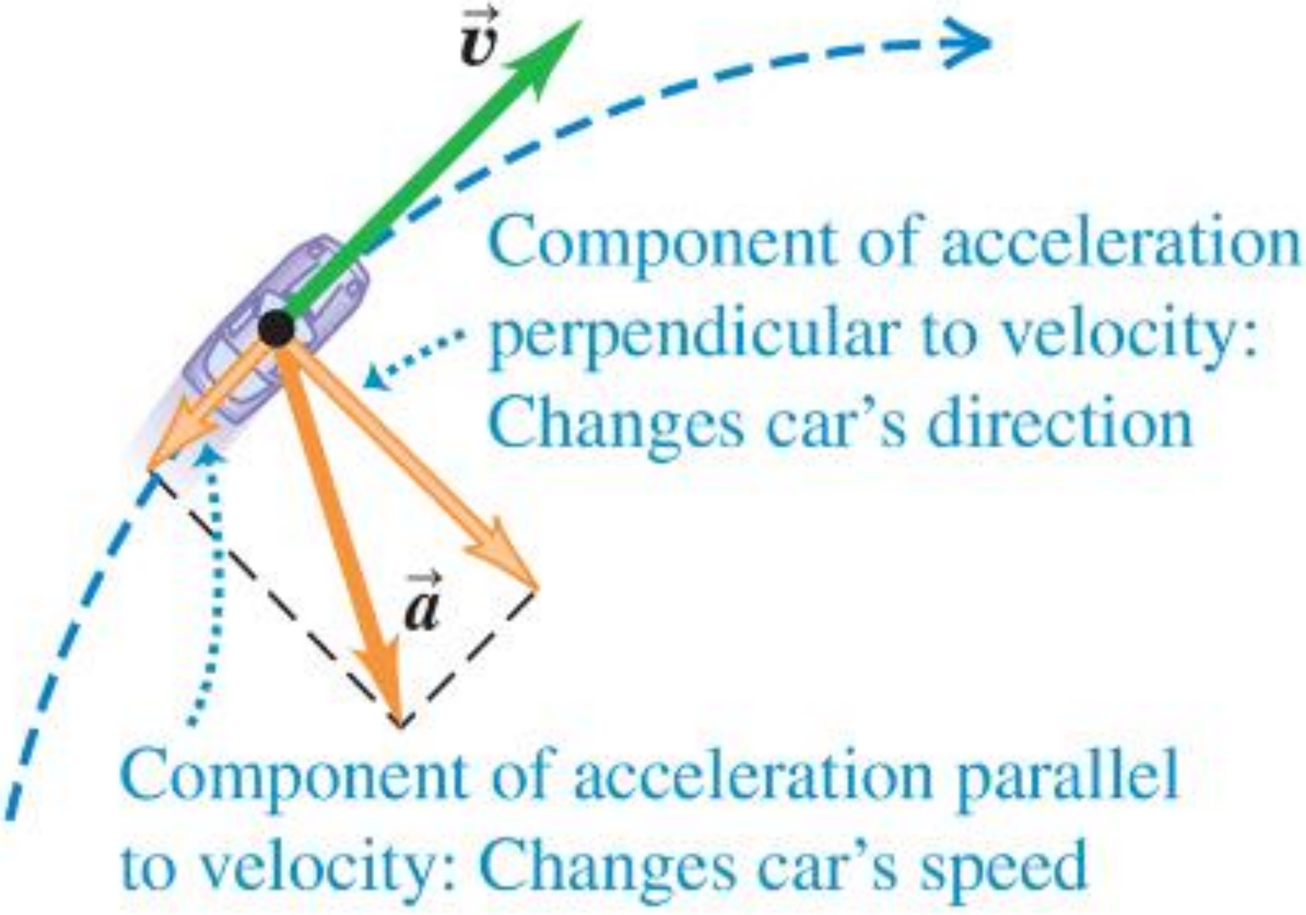
(b) Car speeding up along a circular path

Component of acceleration parallel to velocity: Changes car's speed

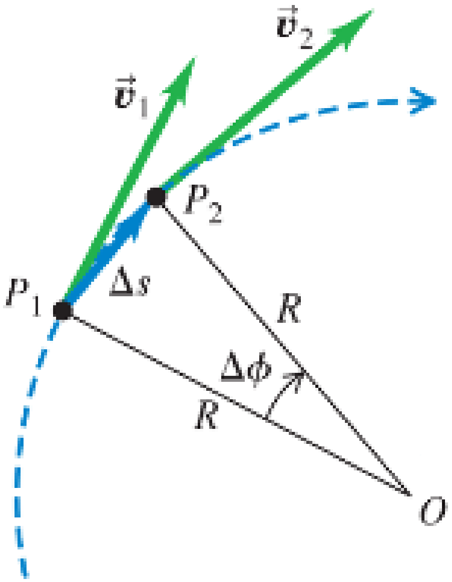


Component of acceleration perpendicular to velocity: Changes car's direction

(c) Car slowing down along a circular path



(a) A particle moves a distance Δs at constant speed along a circular path.



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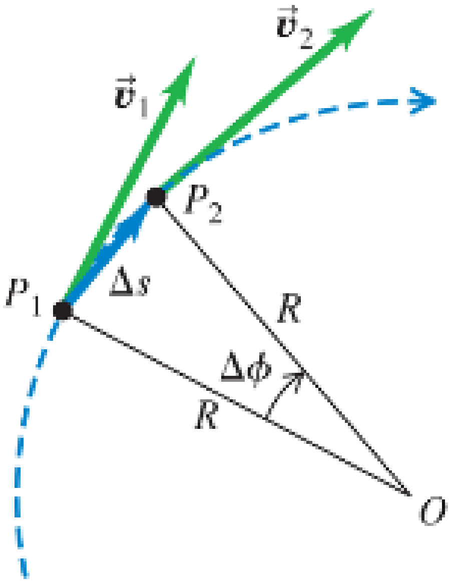
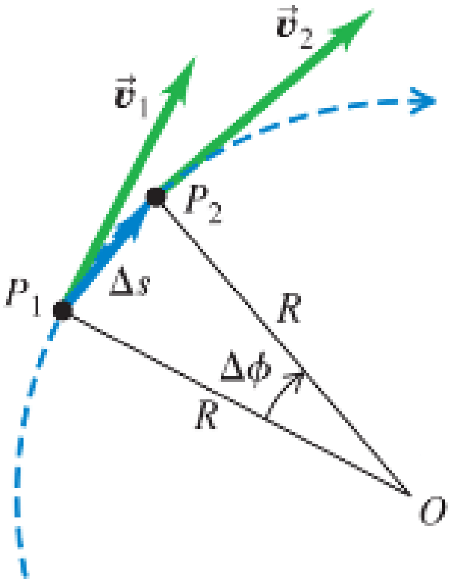


path length

Δs

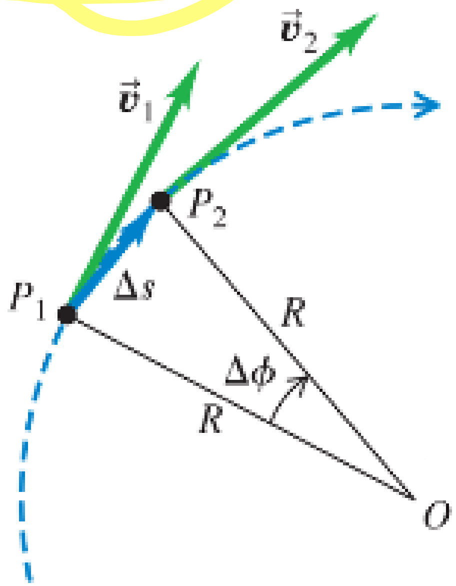
(a) A particle moves a distance Δs at constant speed along a circular path.



path length

$\Delta s = R\Delta\varphi$

(a) A particle moves a distance Δs at constant speed along a circular path.

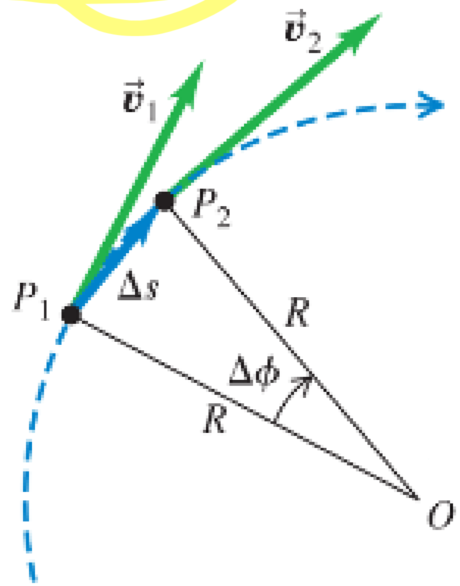


path length

$$\Delta s = R\Delta\phi$$

Constant speed

(a) A particle moves a distance Δs at constant speed along a circular path.



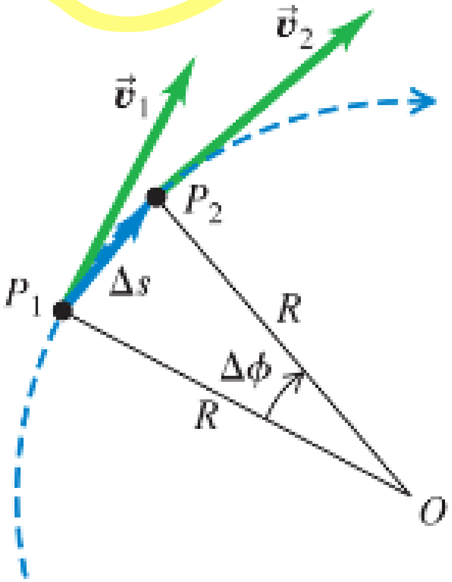
path length

$$\Delta s = R\Delta\phi$$

Constant speed so

$$v = \frac{\Delta s}{\Delta t} = \text{constant}$$

(a) A particle moves a distance Δs at constant speed along a circular path.



path length

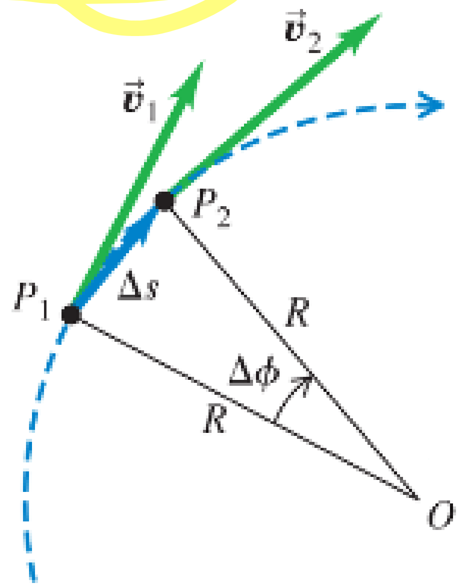
$\Delta s = R\Delta\phi$

Constant speed so

$v = \frac{\Delta s}{\Delta t} = \text{constant}$

But

(a) A particle moves a distance Δs at constant speed along a circular path.



path length

$\Delta s = R\Delta\phi$

Constant speed so

$v = \frac{\Delta s}{\Delta t} = \text{constant}$

But NOT constant velocity $\vec{v}$

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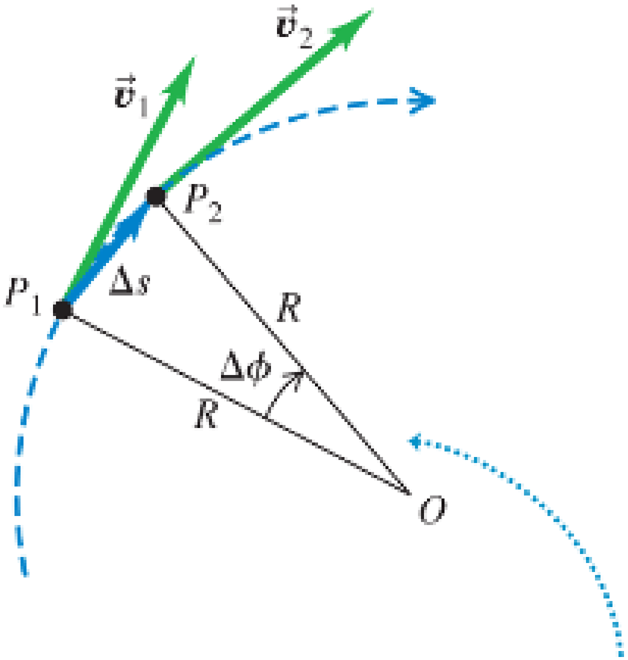
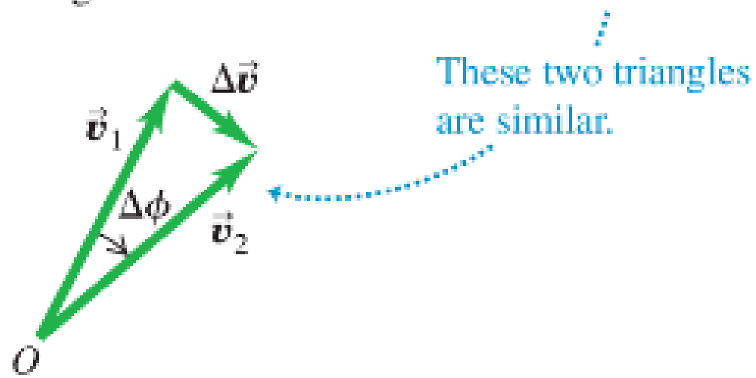


(b) The corresponding change in velocity $\Delta\vec{v}$. The average acceleration is in the same direction as $\Delta\vec{v}$.



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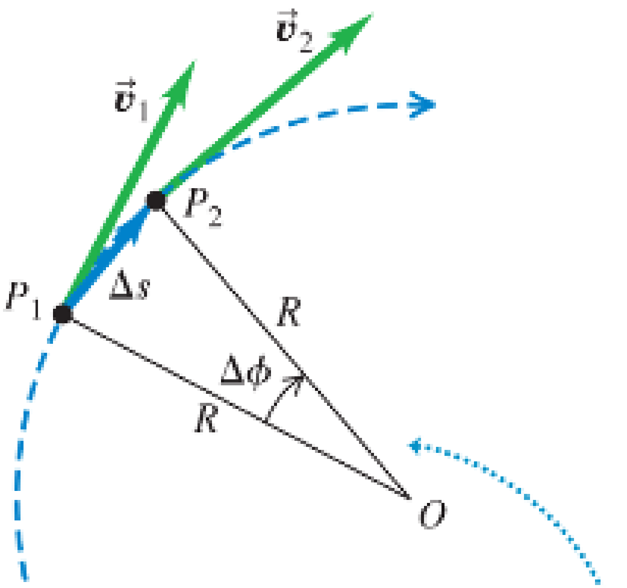

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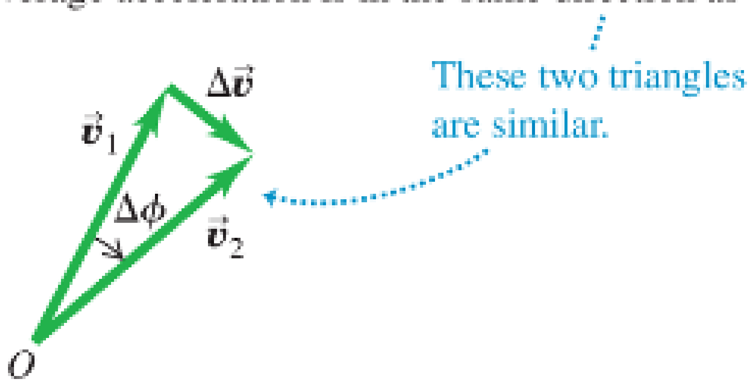

since

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

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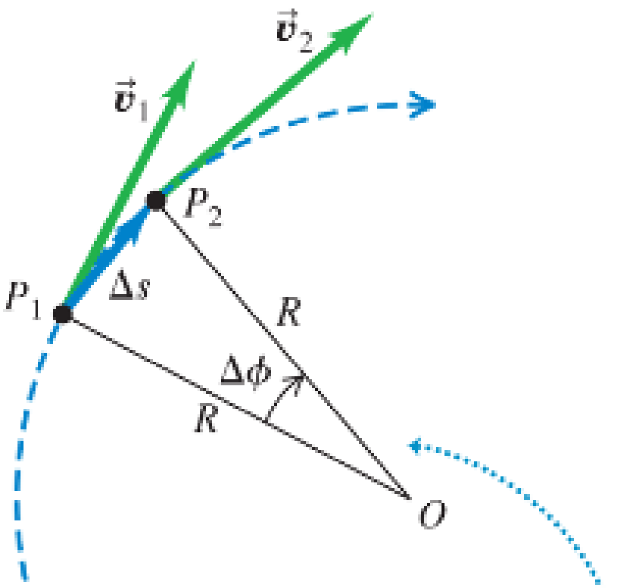

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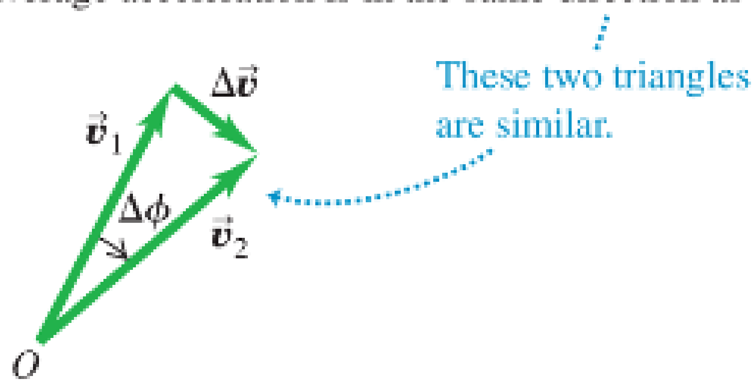

since

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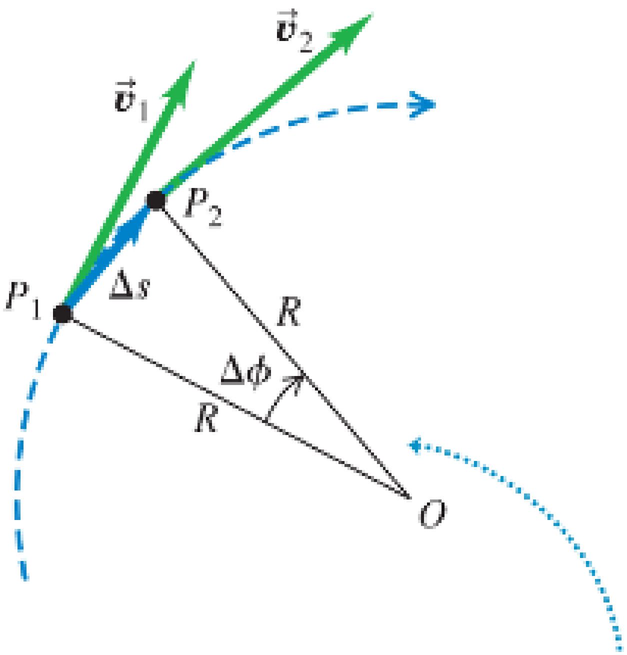
scalar

(a) A particle moves a distance Δs at constant speed along a circular path.



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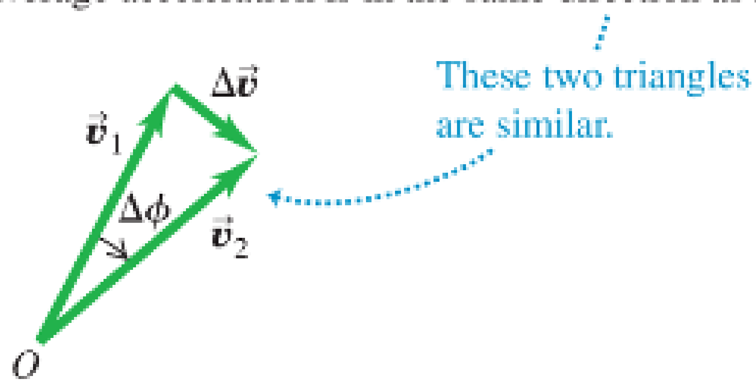
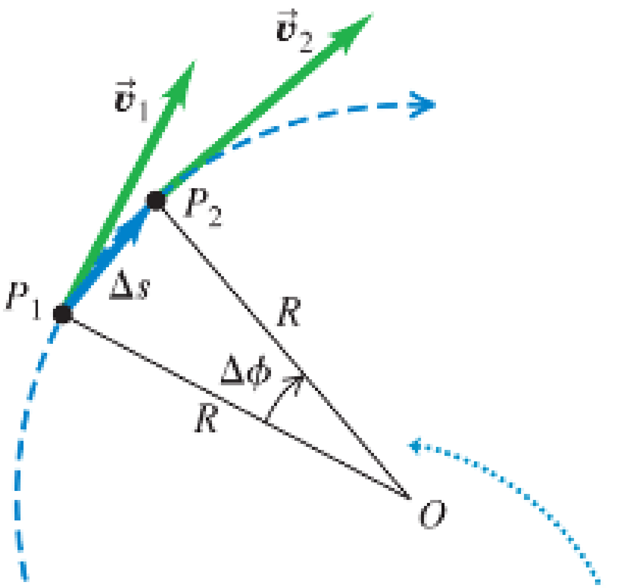


since $\vec{a} = \frac{\Delta \vec{V}}{\Delta t}$ then

$\vec{a}$ is in direction

of $\Delta \vec{V}$

(a) A particle moves a distance Δs at constant speed along a circular path.



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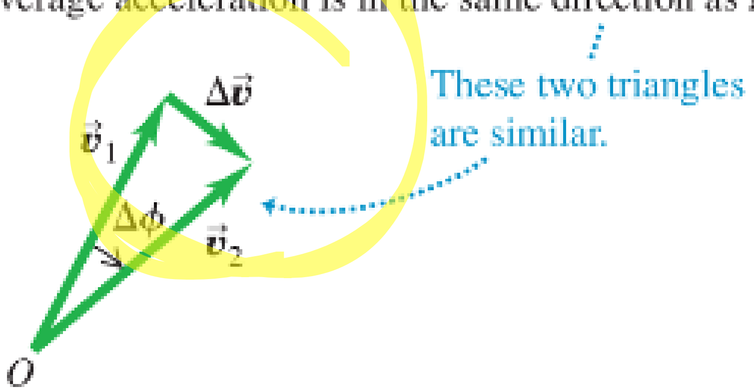

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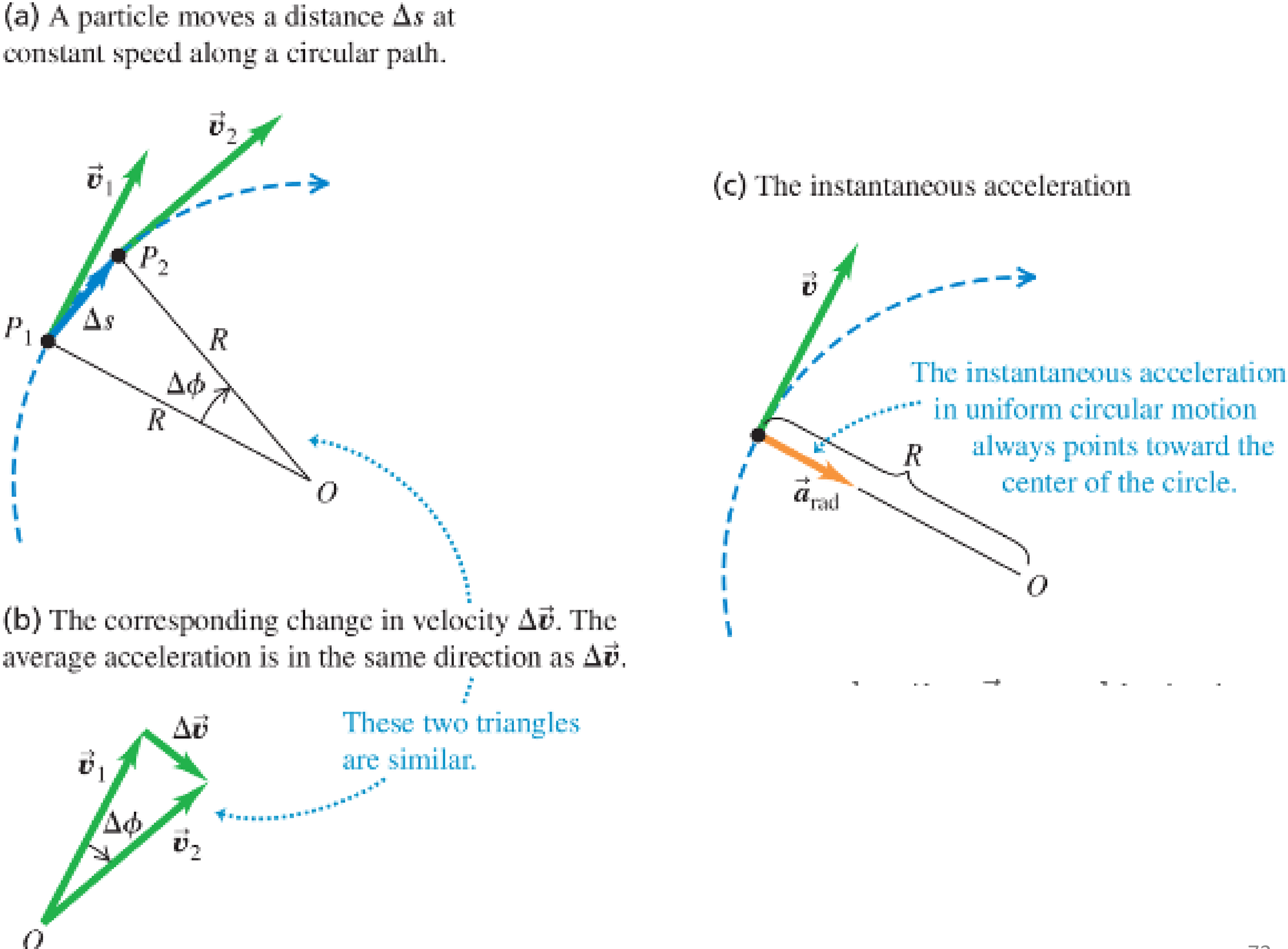
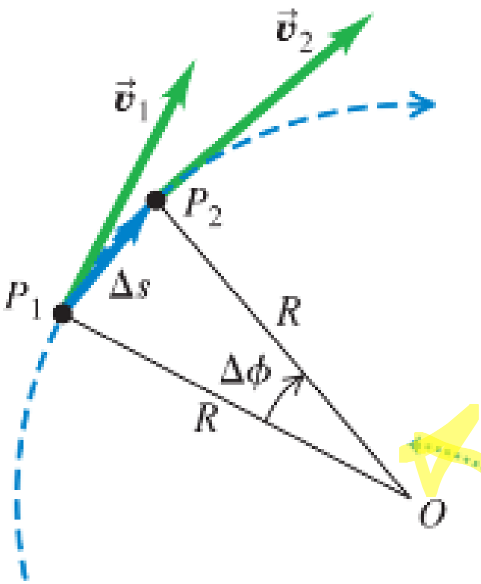

(a) A particle moves a distance Δs at constant speed along a circular path.
$\vec{v}_2$
$\vec{v}_1$
P_2
P_1
Δs
R
Δϕ
R
O
(b) The corresponding change in velocity $\Delta\vec{v}$. The average acceleration is in the same direction as $\Delta\vec{v}$.
$\Delta\vec{v}$
$\vec{v}_1$
Δϕ
$\vec{v}_2$
O
These two triangles are similar.
(c) The instantaneous acceleration
$\vec{v}$
The instantaneous acceleration in uniform circular motion always points toward the center of the circle.
R
$\vec{a}_{rad}$
O

Similar triangles

(a) A particle moves a distance Δs at constant speed along a circular path.



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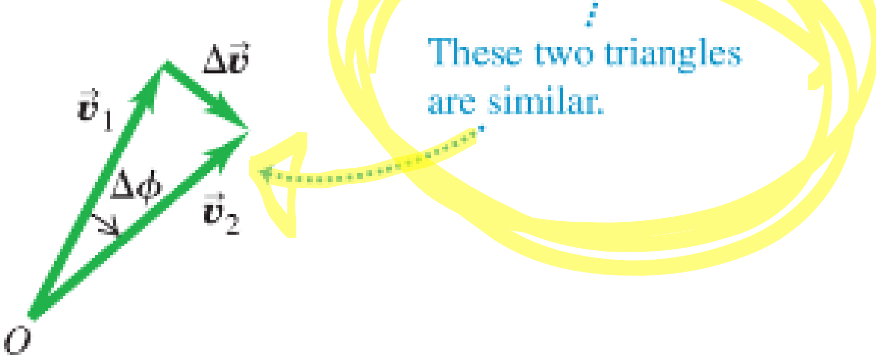
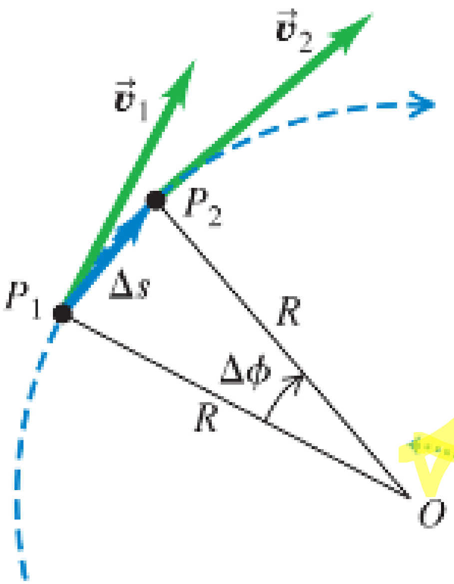


Similar triangles

so $|\Delta \vec{v}|$

(a) A particle moves a distance Δs at constant speed along a circular path.



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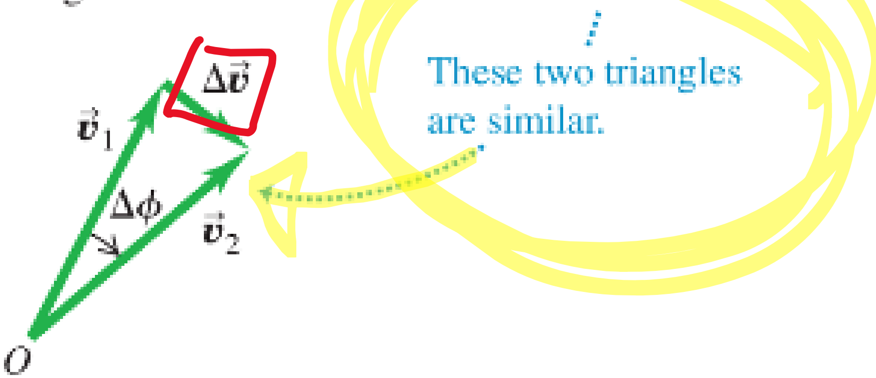
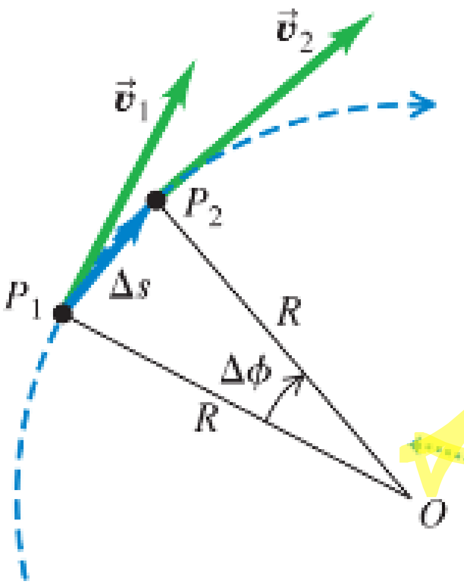


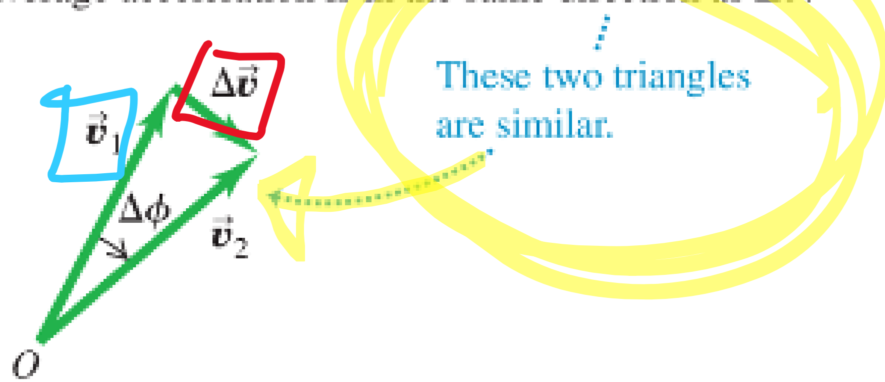
Similar triangles

so $\frac{|\Delta \vec{v}|}{v_1}$

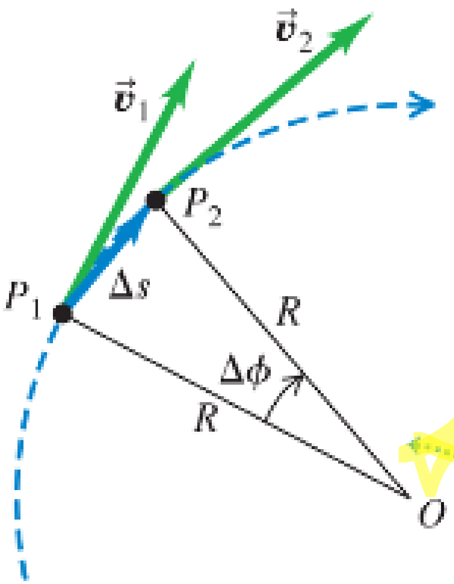
(a) A particle moves a distance Δs at constant speed along a circular path.



(b) The corresponding change in velocity $\Delta\vec{v}$. The average acceleration is in the same direction as $\Delta\vec{v}$.



(a) A particle moves a distance Δs at constant speed along a circular path.



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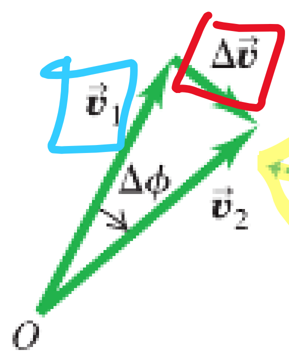

These two triangles are similar.

Similar triangles

so $\frac{|\Delta\vec{v}|}{v_1} =$

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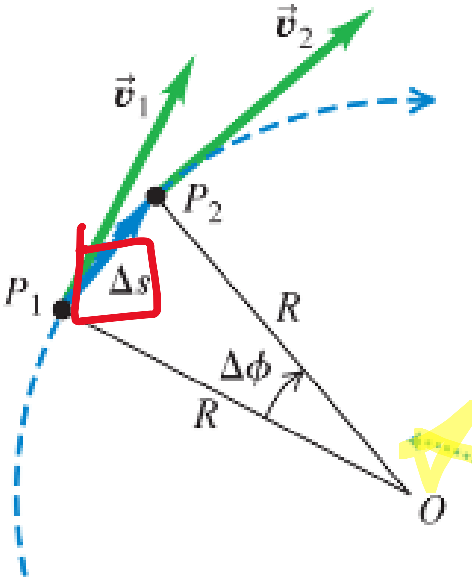

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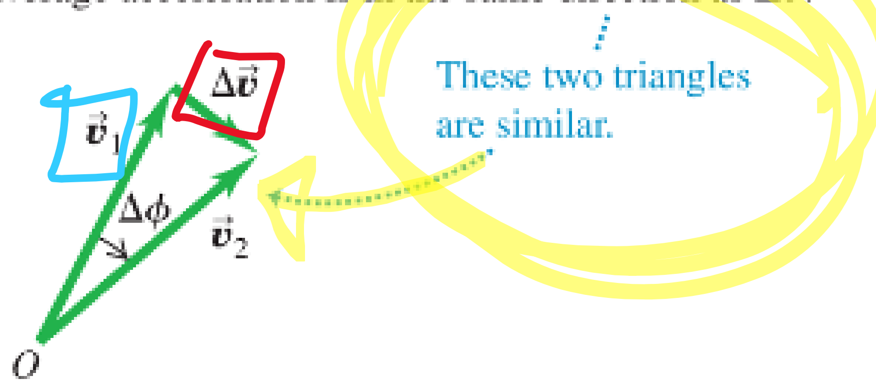


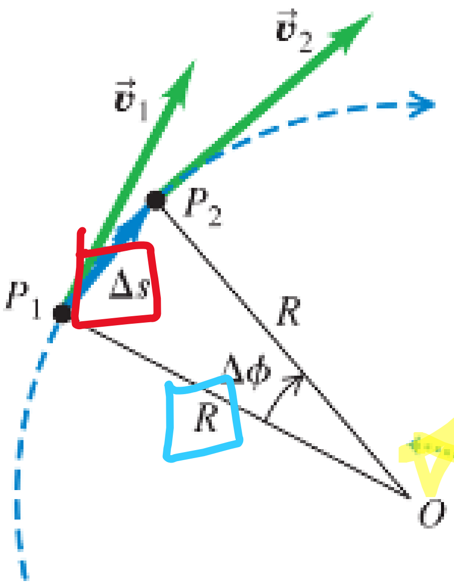
Similar triangles

so $\frac{|\Delta \vec{V}|}{V_1} = \Delta s$

Similar triangles

so $\dfrac{|\Delta \vec{v}|}{v_1} = \dfrac{\Delta s}{R}$

(a) A particle moves a distance Δs at constant speed along a circular path.



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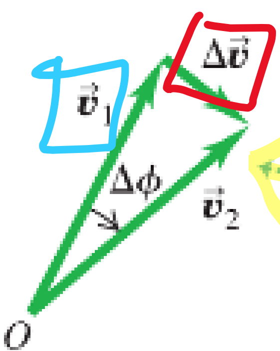

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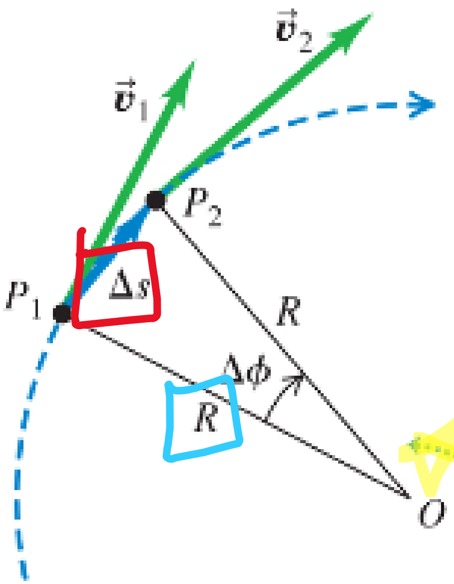

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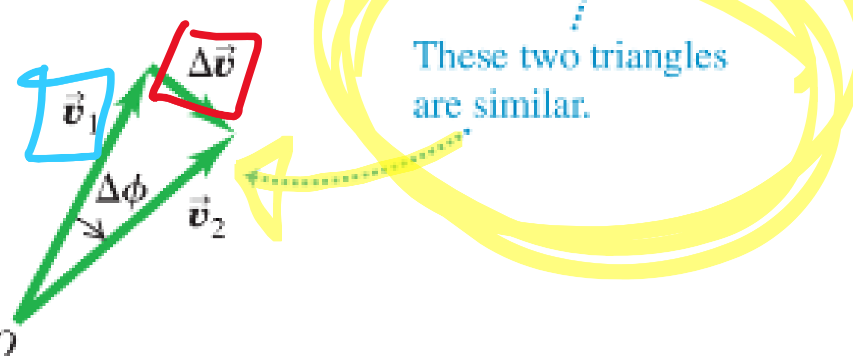

Similar triangles

so $\dfrac{|\Delta\vec{v}|}{v_1} = \dfrac{\Delta s}{R} \Rightarrow$

$|\Delta\vec{v}| = v_1 \Delta s / R$

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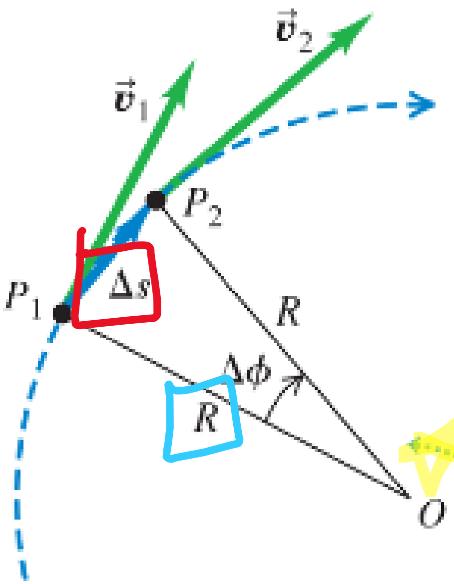

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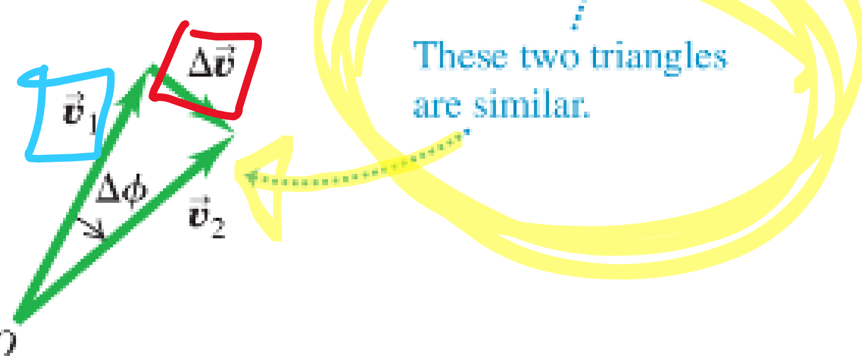

Similar triangles

so $\frac{|\Delta\vec{v}|}{V_1} = \frac{\Delta s}{R} \Rightarrow$

$|\Delta\vec{v}| = V_1 \Delta s/R$ & since

$a = \frac{|\Delta\vec{v}|}{\Delta t}$

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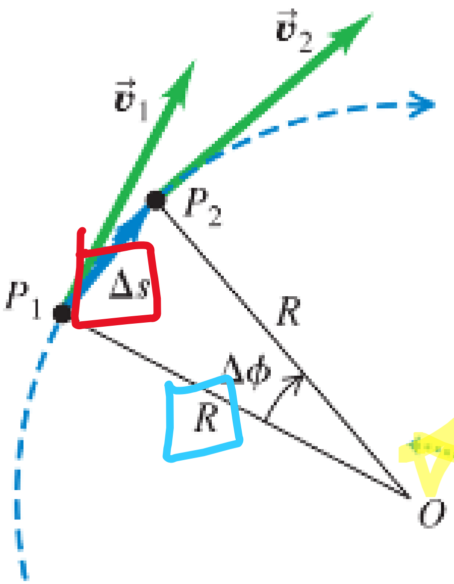

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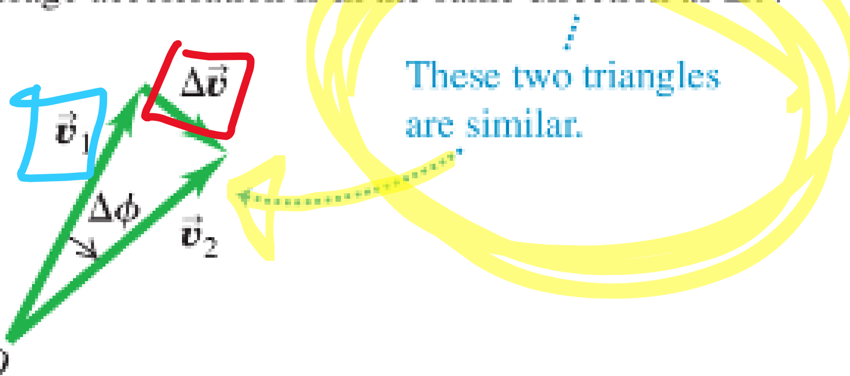

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$a = \dfrac{v_1 \Delta s}{R \Delta t}$

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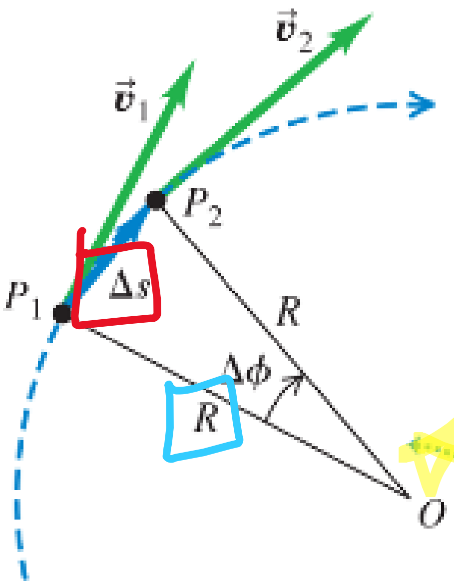

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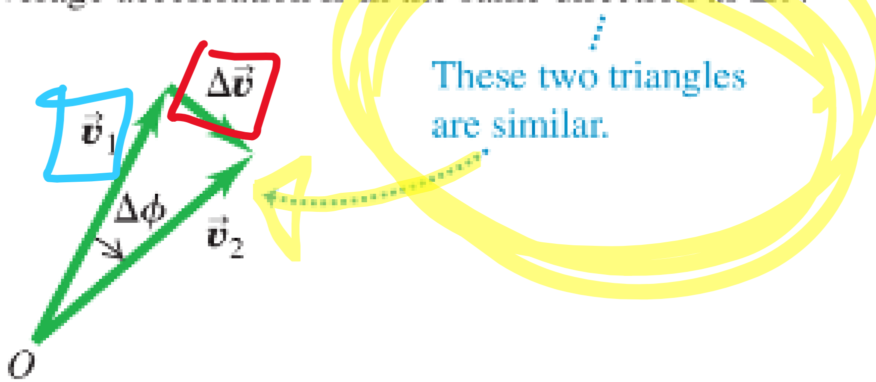

Similar triangles

so $\frac{|\Delta\vec{v}|}{v_1} = \frac{\Delta s}{R} \Rightarrow$

$|\Delta\vec{v}| = v_1 \Delta s / R$ & since

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$a = \frac{v_1 \Delta s}{R \Delta t}$ But $\frac{\Delta s}{\Delta t} = v$

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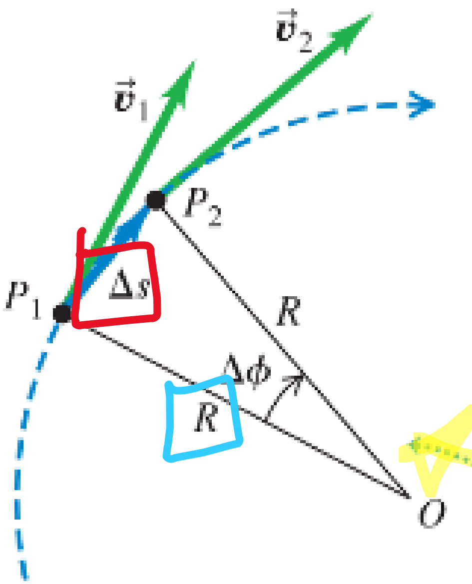
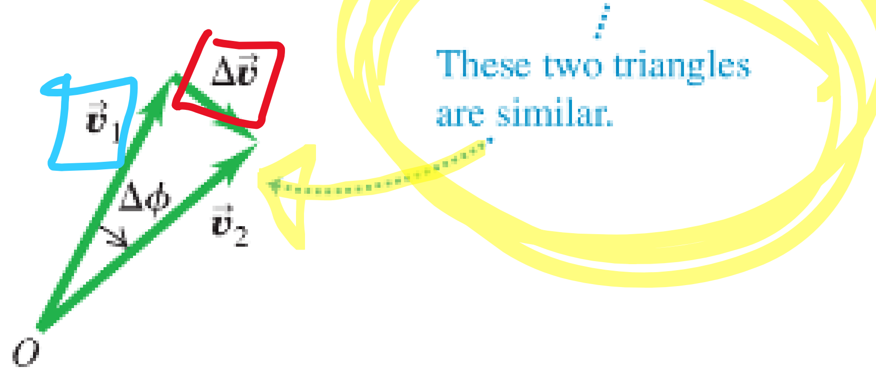


(b) The corresponding change in velocity $\Delta\vec{v}$. The average acceleration is in the same direction as $\Delta\vec{v}$.



Similar triangles

so $\dfrac{|\Delta\vec{v}|}{v_1} = \dfrac{\Delta s}{R} \Rightarrow$

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$a = \dfrac{v_1 \Delta s}{R \Delta t}$ But $\dfrac{\Delta s}{\Delta t} = v$

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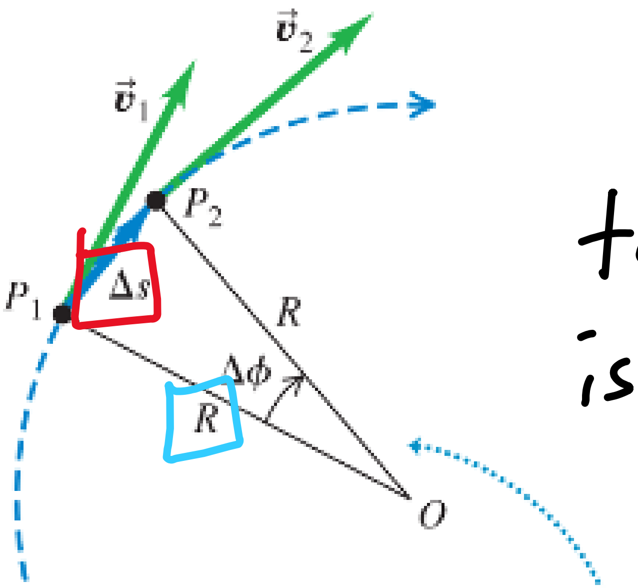
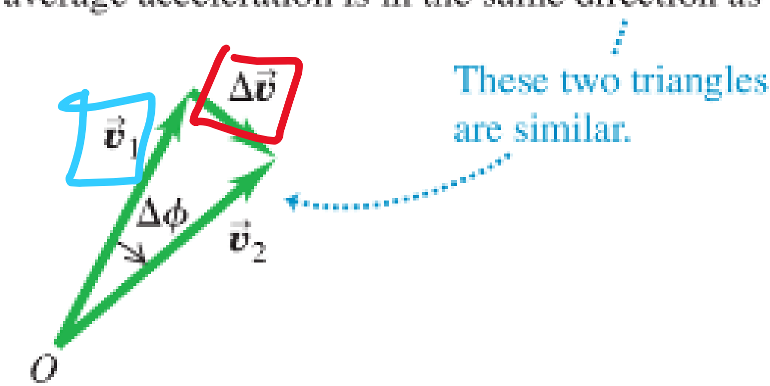


(b) The corresponding change in velocity $\Delta\vec{v}$. The average acceleration is in the same direction as $\Delta\vec{v}$.



Note: we will write $a_{rad} = \frac{v^2}{R}$ to remind us that this is only for the radial [a_{rad} or $a_\perp$] part of the acceleration

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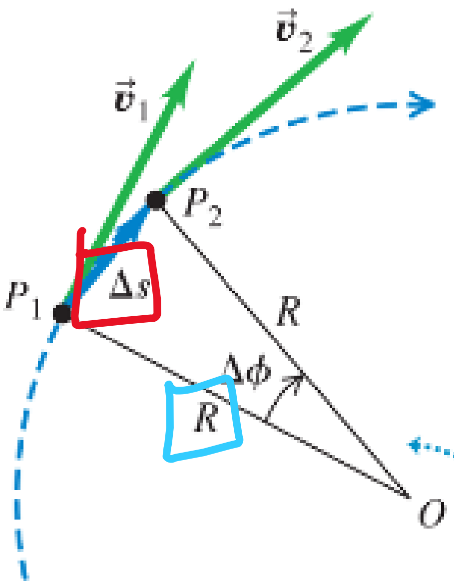
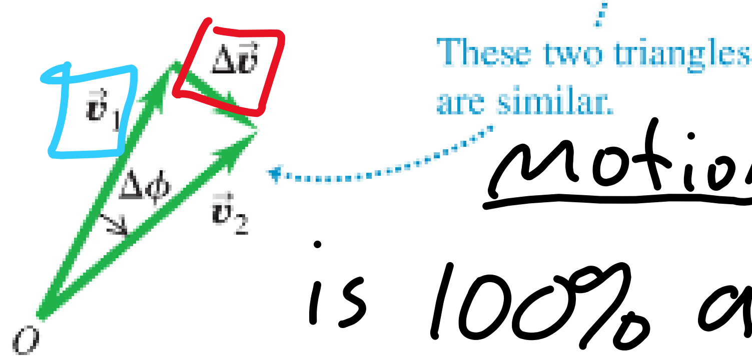


(b) The corresponding change in velocity $\Delta\vec{v}$. The average acceleration is in the same direction as $\Delta\vec{v}$.



Note: we will write $a_{rad} = \frac{v^2}{R}$ to remind us that this is only for the radial [a_{rad} or $a_{\perp}$] part of the acceleration when uniform circular motion the acceleration is 100% a_{rad}

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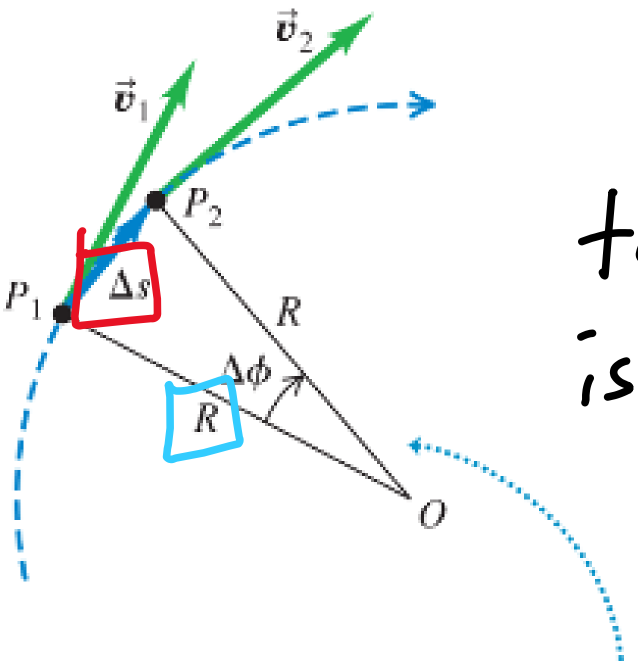

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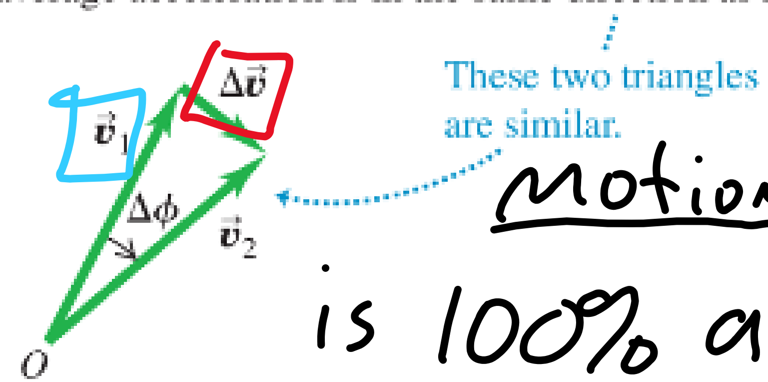
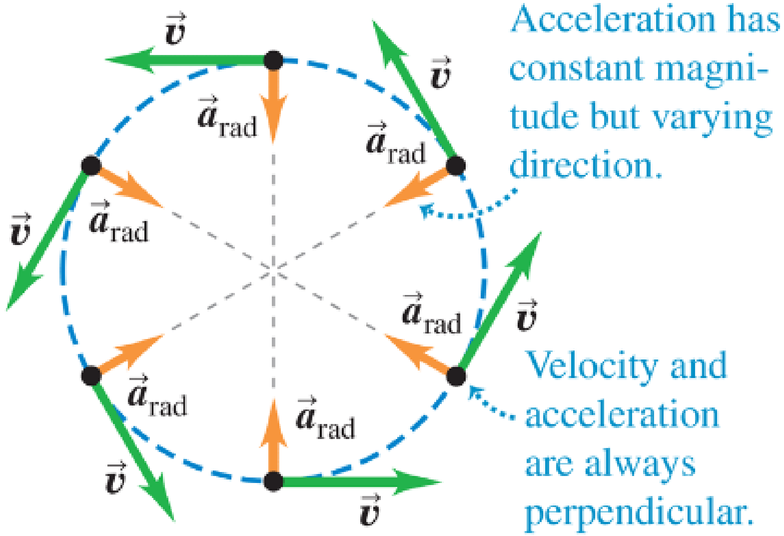
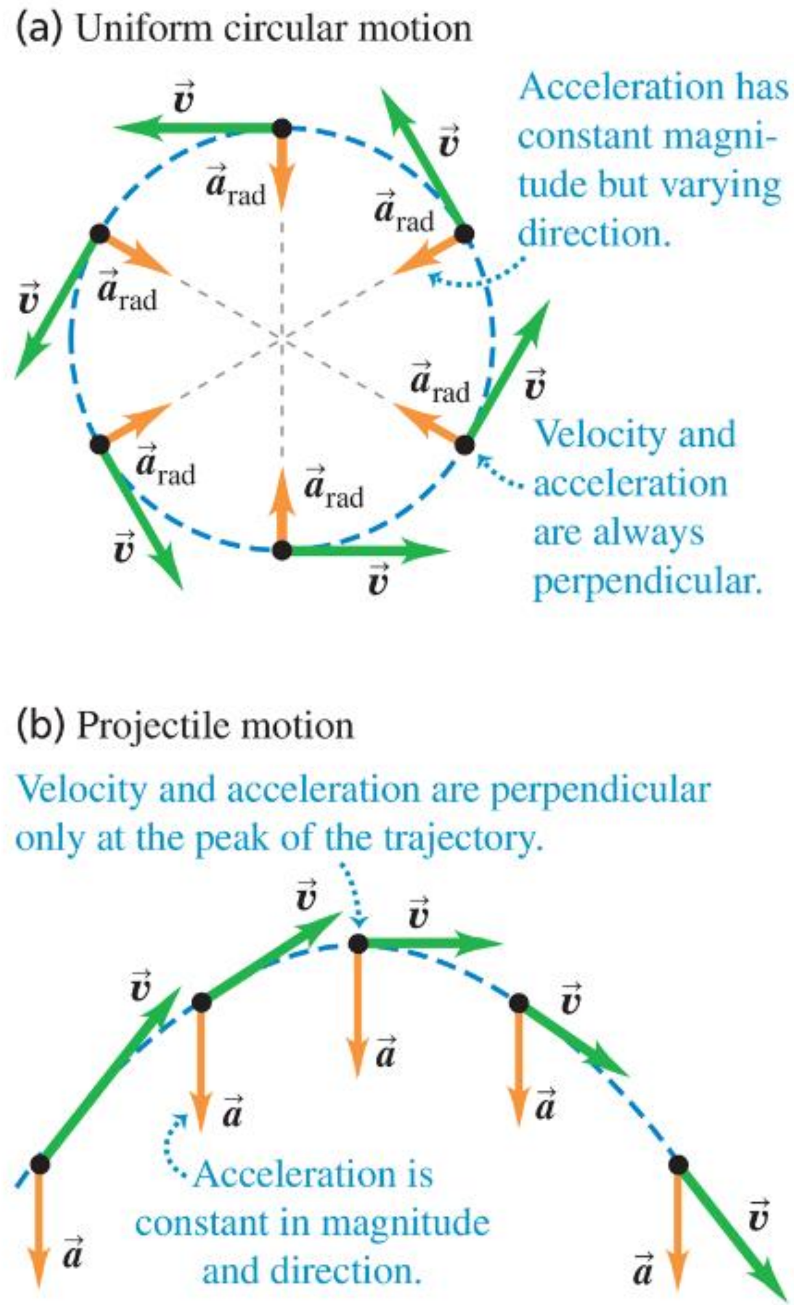


__Note__: we will write $a_{rad} = \frac{v^2}{R}$ to remind us that this is only for the radial [a_{rad} or $a_\perp$] part of the acceleration when __uniform circular motion__ the acceleration is 100% a_{rad} {or $a_\perp$}

(a) Uniform circular motion





(a) Uniform circular motion
Acceleration has constant magnitude but varying direction.
Velocity and acceleration are always perpendicular.
$\vec{v}$
$\vec{a}_{rad}$
(b) Projectile motion
Velocity and acceleration are perpendicular only at the peak of the trajectory.
Acceleration is constant in magnitude and direction.
$\vec{a}$

Uniform Circular Motion

From previous $v = \frac{\Delta s}{\Delta t}$

Uniform Circular Motion

From previous $V = \frac{\Delta s}{\Delta t}$ If Δs is one full revolution

Uniform Circular Motion

From previous $V = \frac{\Delta s}{\Delta t}$ If Δs is one full revolution then

$\Delta s = 2\pi R$

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Let $T \equiv$ time for one full revolution

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$$\Rightarrow \quad V = \frac{2\pi R}{T}$$

ASU

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$$\Rightarrow \boxed{V = \frac{2\pi R}{T}}$$ & since

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$$\Rightarrow \boxed{V = \frac{2\pi R}{T}}$$

& since $a_{rad} = \frac{V^2}{R}$ then $a_{rad} = \frac{4\pi^2 R}{T^2}$

ASU

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Let $T \equiv$ time for one full revolution $\equiv$ period of motion

$$\Rightarrow \quad V = \frac{2\pi R}{T}$$

& since

$$a_{rad} = \frac{V^2}{R}$$

then

$$a_{rad} = \frac{4\pi^2 R}{T^2}$$

ASU

An Aston Martin V12 Vantage sports car has a "lateral acceleration" of $0.97g = (0.97)(9.8\ \mathrm{m/s^2}) = 9.5\ \mathrm{m/s^2}$. This is the maximum centripetal acceleration the car can sustain without skidding out of a curved path. If the car is traveling at a constant $40\ \mathrm{m/s}$ (about $89\ \mathrm{mi/h}$, or $144\ \mathrm{km/h}$) on level ground, what is the radius R of the tightest unbanked curve it can negotiate?

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$a_{rad} = 0.97g = 9.5\ \mathrm{m/s^2}, \quad V = 40\ \mathrm{m/s}$

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$a_{rad} = 0.97g = 9.5\ \text{m/s}^2,\ V = 40\ \text{m/s}$

Find R_{min}:

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$a_{rad} = 0.97g = 9.5\ \mathrm{m/s^2}$, $v = 40\ \mathrm{m/s}$

Find R_{min}:

$$a_{rad} = \frac{v^2}{R}$$

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$a_{rad} = 0.97g = 9.5\ \mathrm{m/s^2},\ V = 40\ \mathrm{m/s}$

Find R_{min}: $\quad a_{rad} = \frac{V^2}{R} \Rightarrow$

$$R = \frac{V^2}{a_{rad}}$$

ASU

An Aston Martin V12 Vantage sports car has a "lateral acceleration" of $0.97g = (0.97)(9.8\,\mathrm{m/s^2}) = 9.5\,\mathrm{m/s^2}$. This is the maximum centripetal acceleration the car can sustain without skidding out of a curved path. If the car is traveling at a constant $40\,\mathrm{m/s}$ (about $89\,\mathrm{mi/h}$, or $144\,\mathrm{km/h}$) on level ground, what is the radius R of the tightest unbanked curve it can negotiate?

$a_{rad} = 0.97g = 9.5\,\mathrm{m/s^2}$, $V = 40\,\mathrm{m/s}$

Find R_{min}: $a_{rad} = \frac{V^2}{R} \Rightarrow$

$$R = \frac{V^2}{a_{rad}} = \frac{40\,\mathrm{m/s}}{9.5\,\mathrm{m/s^2}}$$

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$$a_{rad} = 0.97g = 9.5\ \mathrm{m/s^2},\ V = 40\ \mathrm{m/s}$$

Find R_{min}: $\quad a_{rad} = \frac{V^2}{R} \Rightarrow$

$$R = \frac{V^2}{a_{rad}} = \frac{40\ \mathrm{m/s}}{9.5\ \mathrm{m/s^2}} = 170\ \mathrm{m}$$

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An Aston Martin V12 Vantage sports car has a "lateral acceleration" of $0.97g = (0.97)(9.8\ \mathrm{m/s^2}) = 9.5\ \mathrm{m/s^2}$. This is the maximum centripetal acceleration the car can sustain without skidding out of a curved path. If the car is traveling at a constant $40\ \mathrm{m/s}$ (about $89\ \mathrm{mi/h}$, or $144\ \mathrm{km/h}$) on level ground, what is the radius R of the tightest unbanked curve it can negotiate?

$a_{rad} = 0.97g = 9.5\ \mathrm{m/s^2},\ V = 40\ \mathrm{m/s}$

Find R_{min}: $\quad a_{rad} = \dfrac{V^2}{R} \Rightarrow$

$$R = \frac{V^2}{a_{rad}} = \frac{40\ \mathrm{m/s}}{9.5\ \mathrm{m/s^2}} = 170\ \mathrm{m}$$

so $R_{min} = 170\ \mathrm{m}$

Passengers on a carnival ride move at constant speed in a horizontal circle of radius 5.0 m, making a complete circle in 4.0 s. What is their acceleration?

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Find a:

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$R = 5m, T = 4s$

Find a: Since uniform circular motion $a = a_{rad}$

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Find a:

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$R = 5 m$, $T = 4 s$

Find a: Since uniform circular motion $a = a_{rad} = \frac{v^2}{R}$ But $v = \frac{2\pi R}{T}$

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$R = 5\,m,\ T = 4\,s$

Find a: Since uniform circular motion $a = a_{rad} = \frac{v^2}{R}$ But $v = \frac{2\pi R}{T}$

So $a = \frac{4\pi^2 R}{T^2}$

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Find a: Since uniform circular motion $a = a_{rad} = \frac{V^2}{R}$ But $V = \frac{2\pi R}{T}$

so $a = \frac{4\pi^2 R}{T^2} = \frac{4 * 3.14^2 * 5m}{16 s^2}$

$\Rightarrow$ $a = 12 m/s^2$

Nonuniform circular motion

Nonuniform circular motion

Nonuniform circular motion

* Radial component is still $a_{rad} = \frac{v^2}{R}$

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ASU

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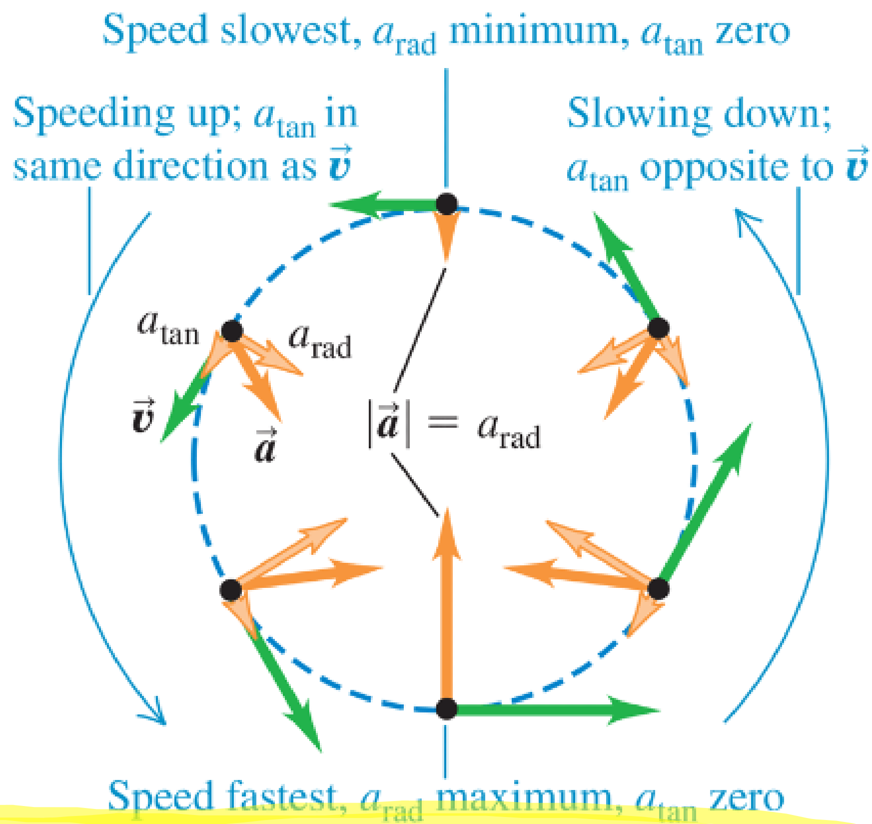

A particle moving in a vertical loop with a varying speed, like a roller coaster car.

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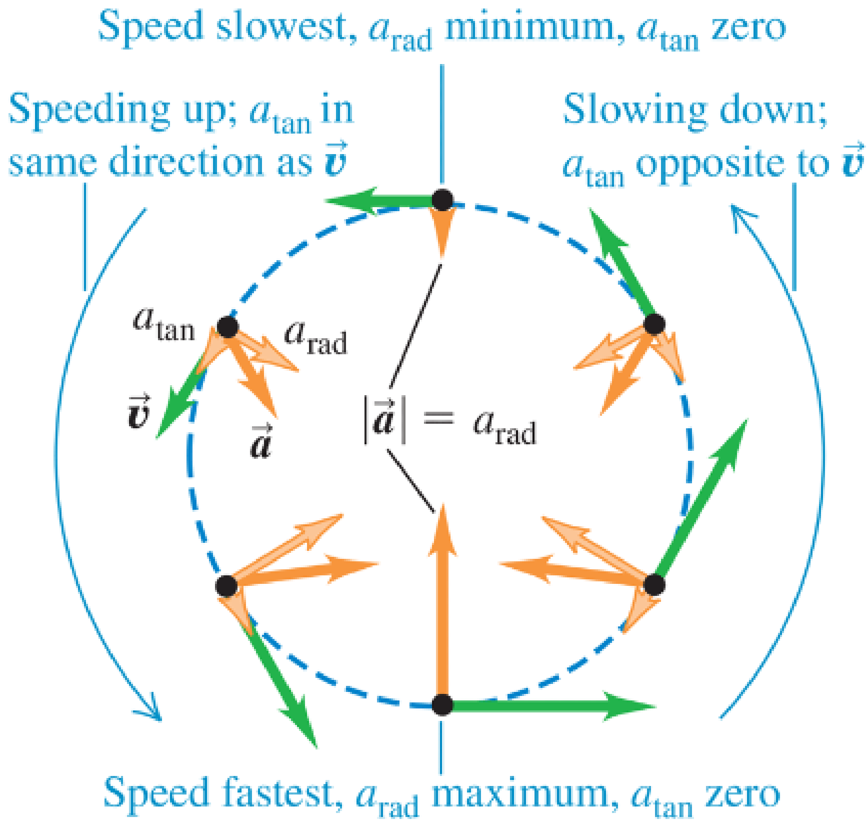

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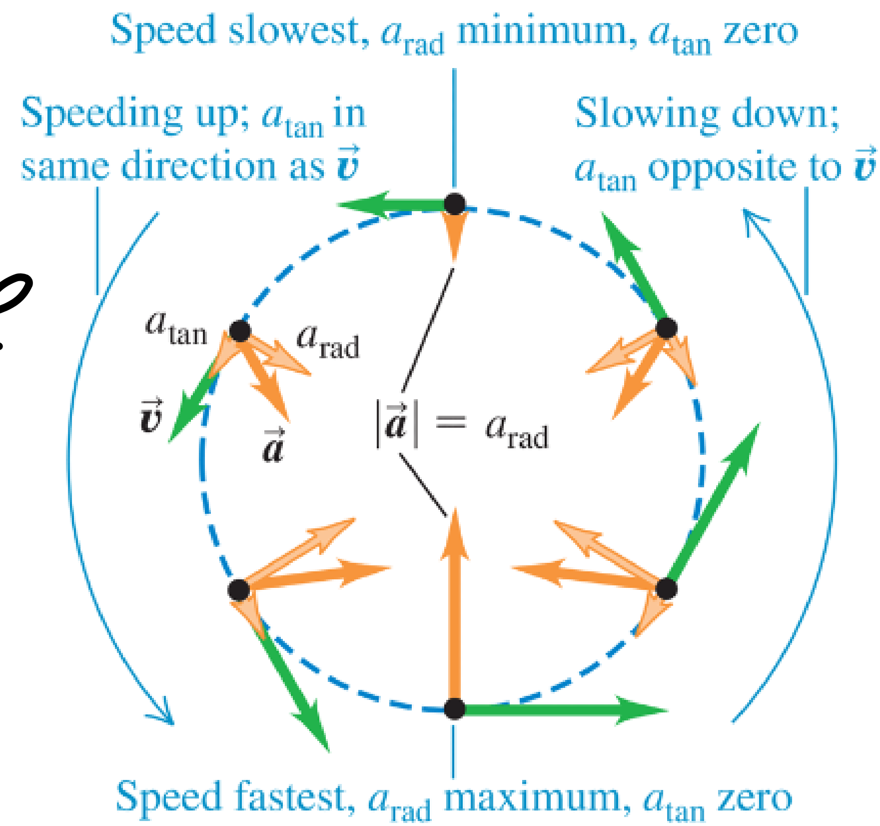

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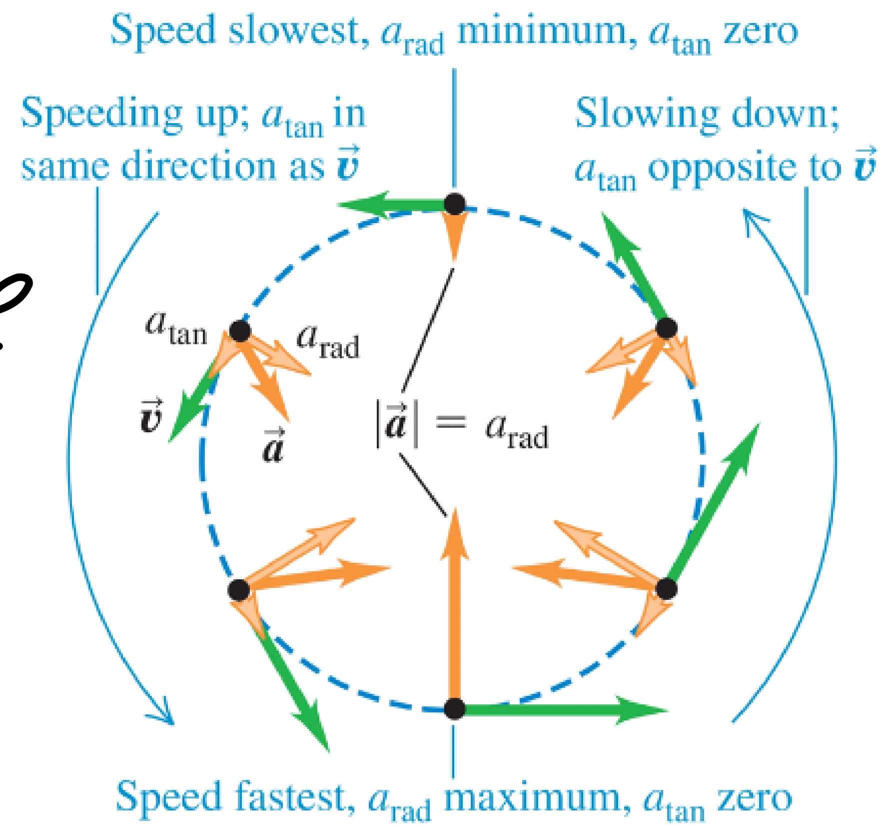

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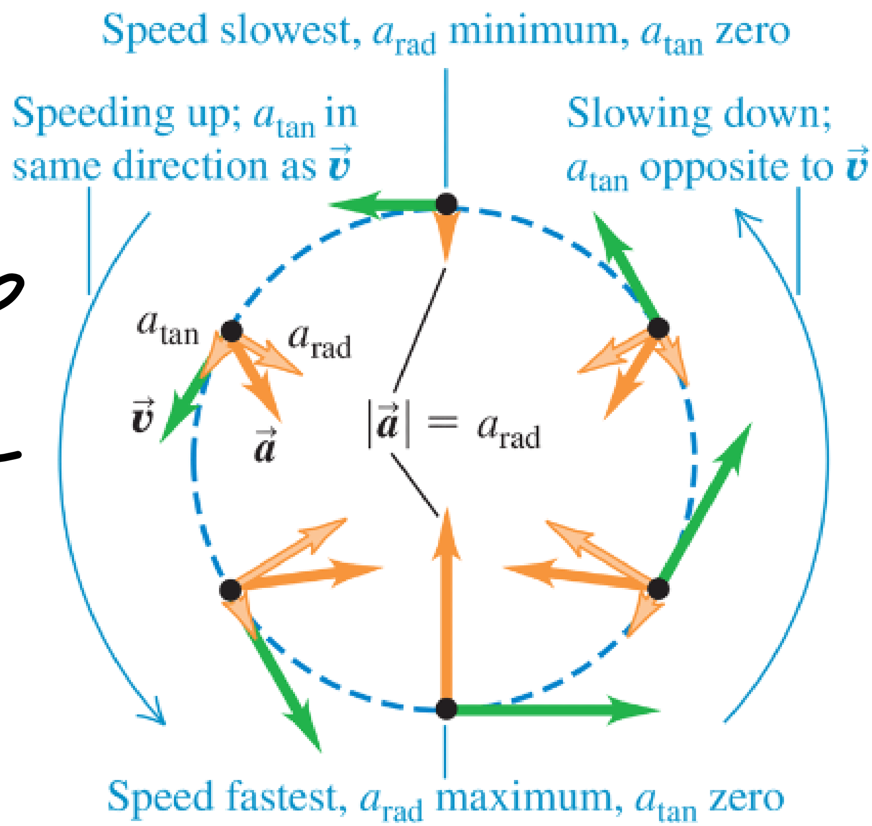

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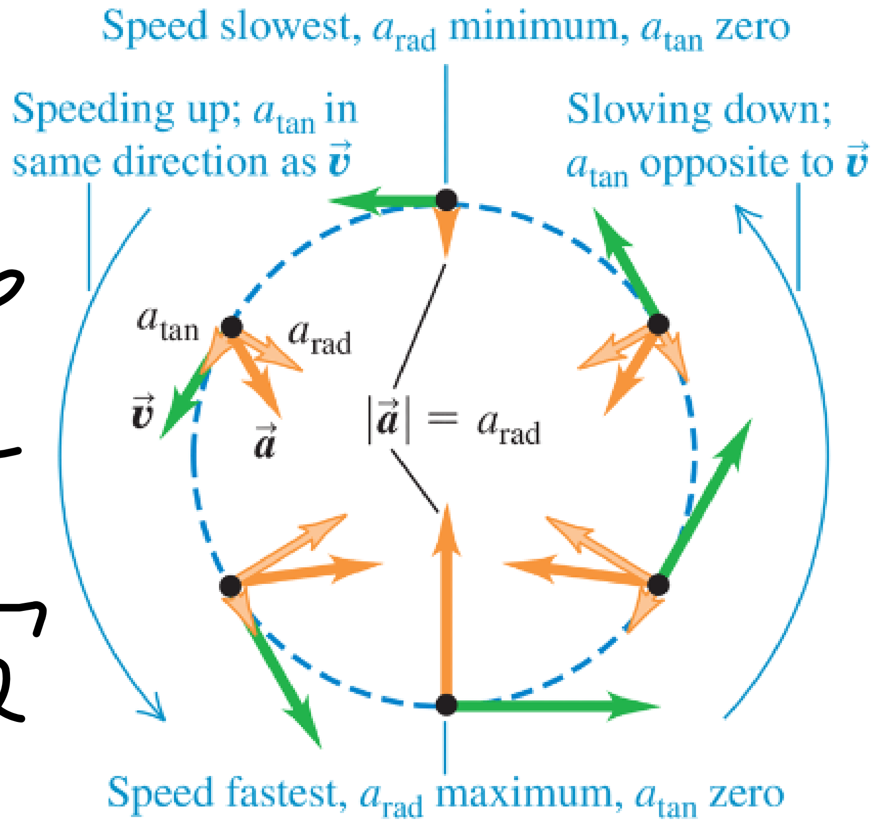

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