Today 15.1

L13

L13

Today 15.1

Translation & fixed axis rotation of rigid bodies

L13

Today 15.1

Thursday 15.2

Today 15.1
Thursday 15.2

General plane motion for rigid bodies

L13

Grade calculation at end of semester

Grade calculation at end of semester

Final score = (Exam ave)*

Grade calculation at end of semester

Final score = (Exam ave)*

*of 4 highest exams out of 5

Grade calculation at end of semester

Final score = (Exam ave) * 4

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave}) * 4 + (\text{HW ave})}{5}\right]\%$$

Grade calculation at end of semester

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If

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave}) * 4 + (\text{HW ave})}{5}\right]\%$$

If $HW_{AVE} = 100$

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave}) * 4 + (\text{HW ave})}{5}\right]\%$$

If $HW_{AVE} = 100$, then

$$\text{Exam ave} = \left[\frac{5 * (\text{Final score}) - 100}{4}\right]\%$$

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave}) * 4 + (\text{HW ave})}{5}\right]\%$$

If $HW_{AVE} = 100$, then

$$\text{Exam ave} = \left[\frac{5 * (\text{Final score}) - 100}{4}\right]\%$$

so **If** $HW_{AVE} = 100\%$

ASU

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave}) * 4 + (\text{HW ave})}{5}\right] \%$$

If $HW_{AVE} = 100$, then

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so **If** $HW_{AVE} = 100\%$

Final score	Exam ave

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave}) * 4 + (\text{HW ave})}{5}\right]\%$$

If $HW_{AVE} = 100$, then

$$\text{Exam ave} = \left[\frac{5 * (\text{Final score}) - 100}{4}\right]\%$$

So **If** $HW_{AVE} = 100\%$

Final score	Exam ave
A: 90%	87.5%

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave})*4 + (\text{HW ave})}{5}\right]\%$$

If $HW_{AVE} = 100$, then

$$\text{Exam ave} = \left[\frac{5*(\text{Final score}) - 100}{4}\right]\%$$

So If $HW_{AVE} = 100\%$

Final score	Exam ave
A: 90%	87.5%
B: 80%	75%

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave})*4 + (\text{HW ave})}{5}\right]\%$$

If $HW_{AVE} = 100$, then

$$\text{Exam ave} = \left[\frac{5*(\text{Final score}) - 100}{4}\right]\%$$

So **If** $HW_{AVE} = 100\%$

Final score	Exam ave
A: 90%	87.5%
B: 80%	75%
C: 70%	62.5%

ASU

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave}) * 4 + (\text{HW ave})}{5}\right]\%$$

If $HW_{AVE} = 100$, then

$$\text{Exam ave} = \left[\frac{5 * (\text{Final score}) - 100}{4}\right]\%$$

So If $HW_{AVE} = 100\%$

Final score	Exam ave
A: 90%	87.5%
B: 80%	75%
C: 70%	62.5%
D: 60%	50%

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave}) * 4 + (\text{HW ave})}{5}\right]\%$$

If $HW_{AVE} = 100$, then

$$\text{Exam ave} = \left[\frac{5 * (\text{Final score}) - 100}{4}\right]\%$$

so If $HW_{AVE} = 100\%$

Final score	Exam ave
A: 90%	87.5%
B: 80%	75%
C: 70%	62.5%
D: 60%	50%

¡Keep your homework scores high!

Grade calculation at end of semester

$$\text{Final score} = \left[\frac{(\text{Exam ave}) * 4 + (\text{HW ave})}{5}\right]\%$$

If $HW_{AVE} = 100$, then

$$\text{Exam ave} = \left[\frac{5 * (\text{Final score}) - 100}{4}\right]\%$$

so **If** $HW_{AVE} = 100\%$

Final score	Exam ave
A: 90%	87.5%
B: 80%	75%
C: 70%	62.5%
D: 60%	50%

¡Keep your homework scores high!

Rigid bodies

Rigid bodies

Definitions:

Translation if no rotation of body

Rigid bodies

Definitions:

Translation if **no** rotation of body

Rigid bodies

Definitions:

Translation if **no** rotation of body

Two types of translation

Rigid bodies

Definitions:

Translation if **no** rotation of body

Two types of translation

* Rectilinear translation

Rigid bodies

Definitions:

Translation if **no** rotation of body

Two types of translation

* Rectilinear translation

And

Rigid bodies

Definitions:

Translation if <u>NO</u> rotation of body

Two types of translation

* Rectilinear translation

  And

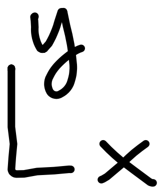
* Curvilinear translation

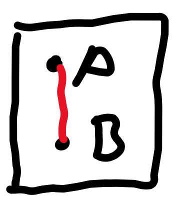
Rectilinear translation

Rectilinear translation

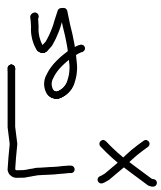
Rectilinear translation

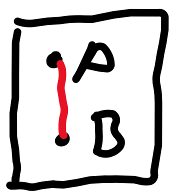
Rectilinear translation





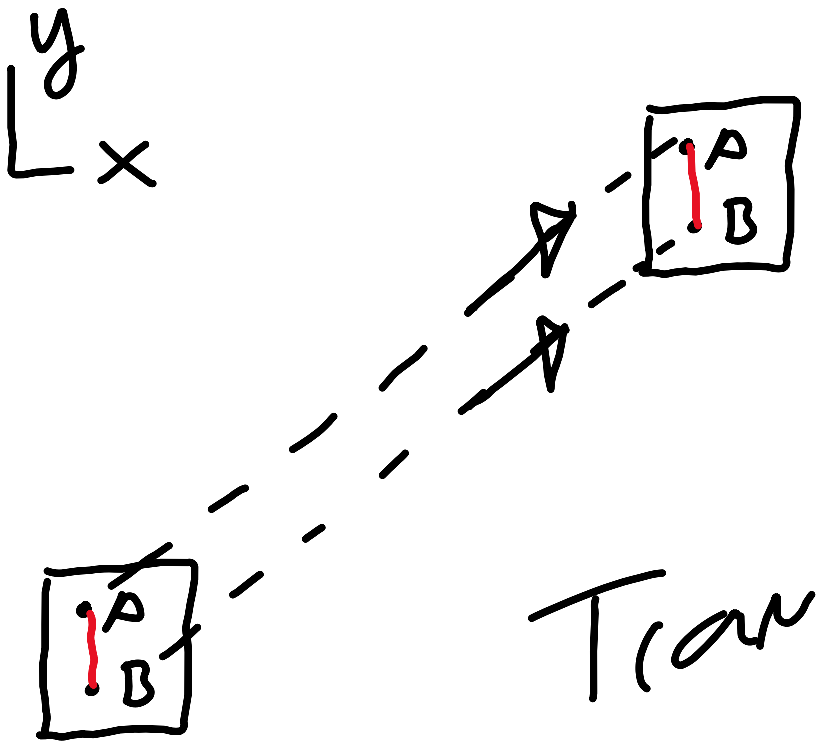
Rectilinear translation





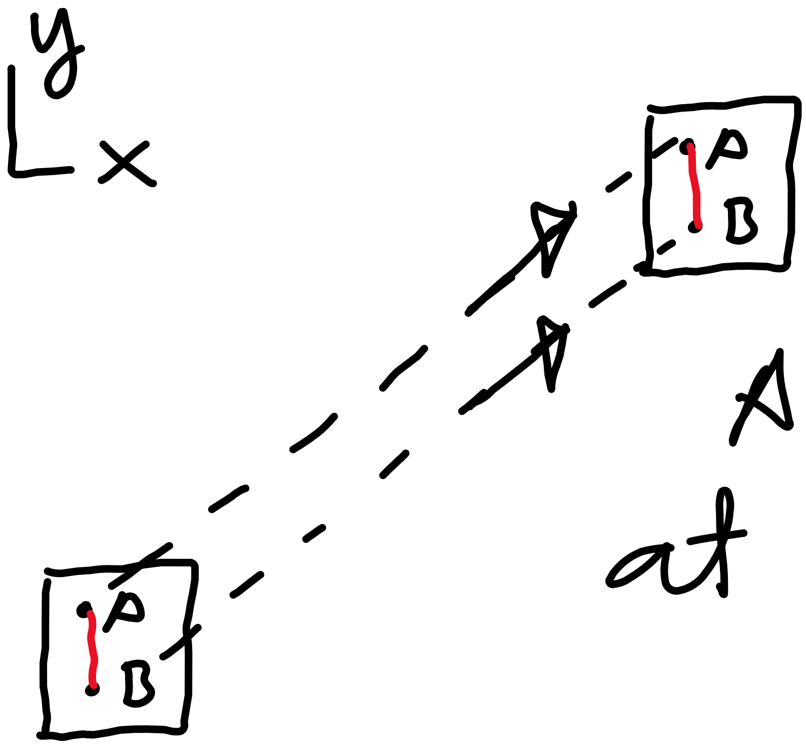
Note: red line connecting points A & B

Rectilinear translation



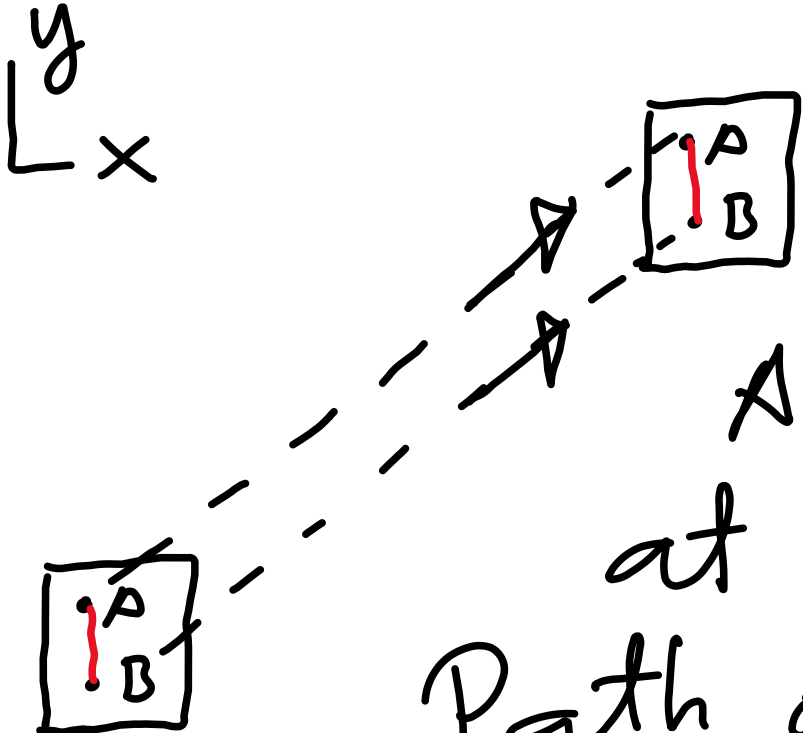
Translate as shown

Rectilinear translation



line connecting A & B always at same angle.

Rectilinear translation

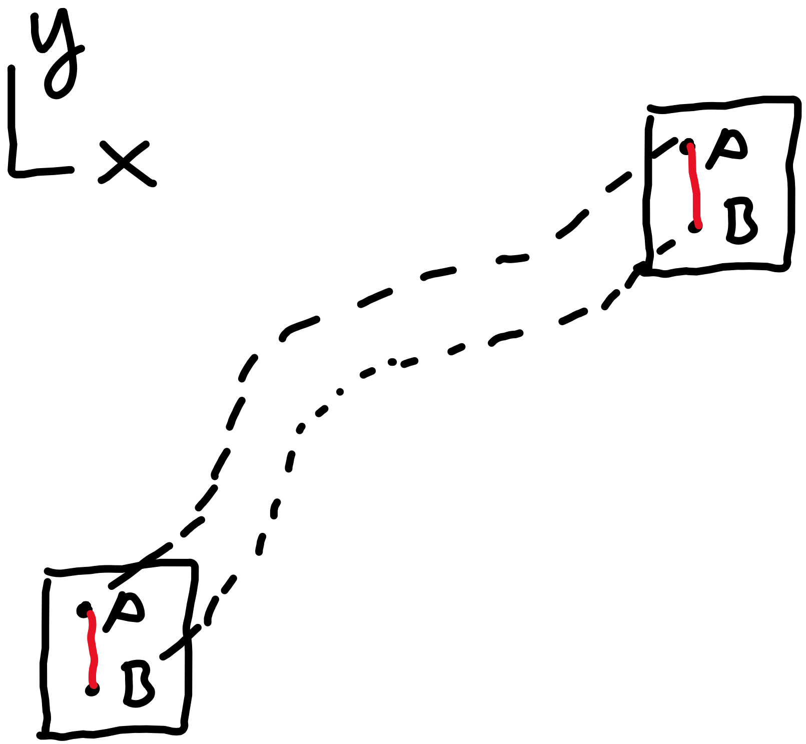


line connecting A & B always at same angle.

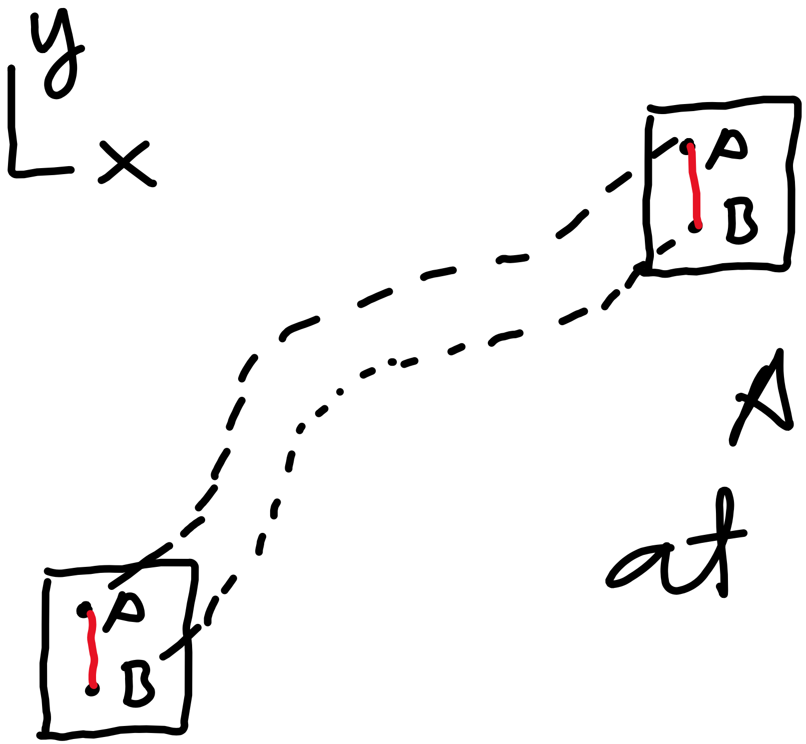
Path of object is a straight line

Curvilinear translation

Curvilinear translation

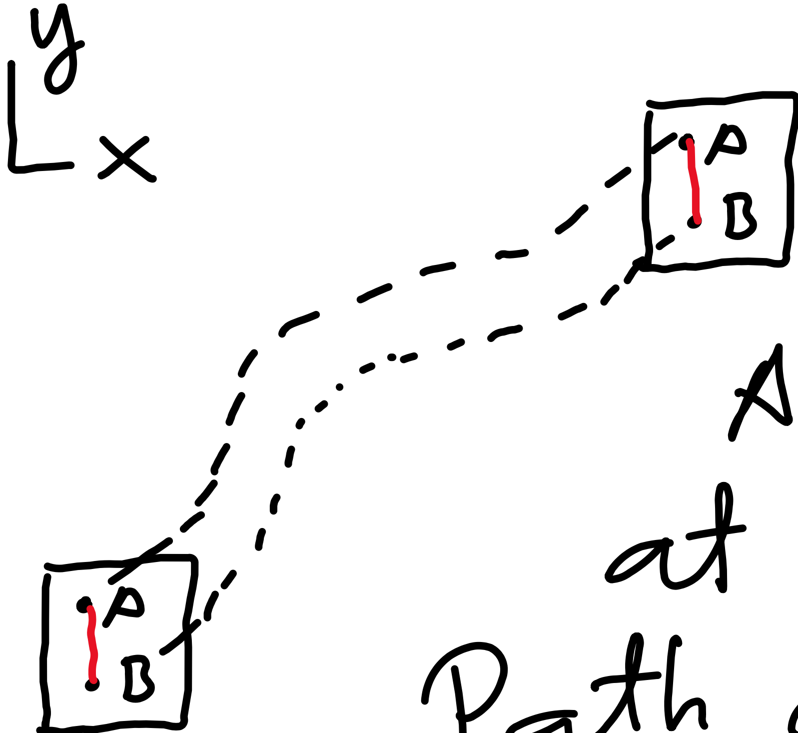


Curvilinear translation



line connecting A & B always at same angle.

Curvilinear translation

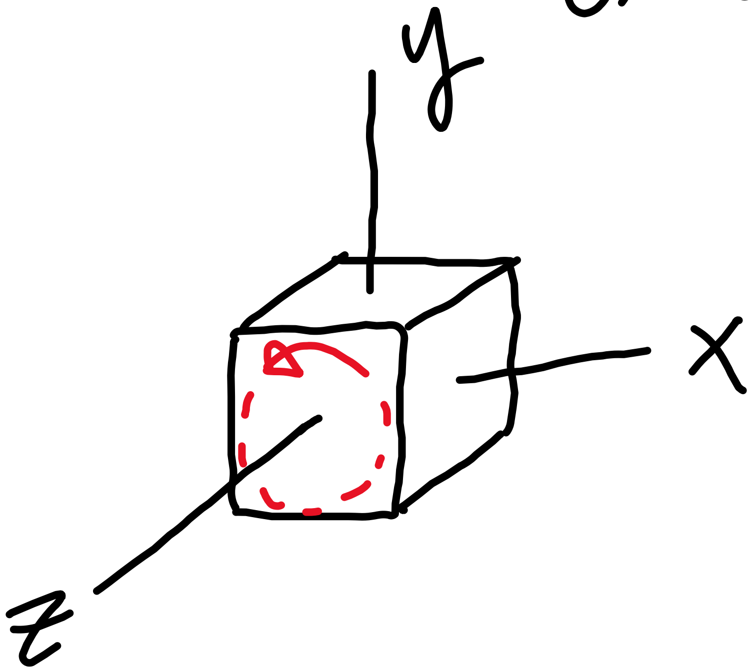


line connecting A & B always at same angle.

Path of object is a curved line

Rotation about fixed axis

Motion along circles centered on axis of rotation.



Rotation about fixed axis

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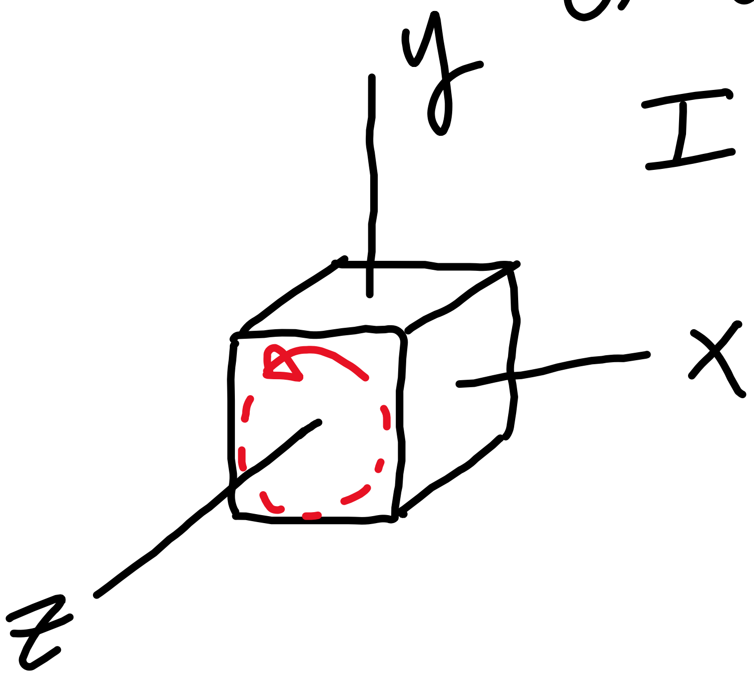
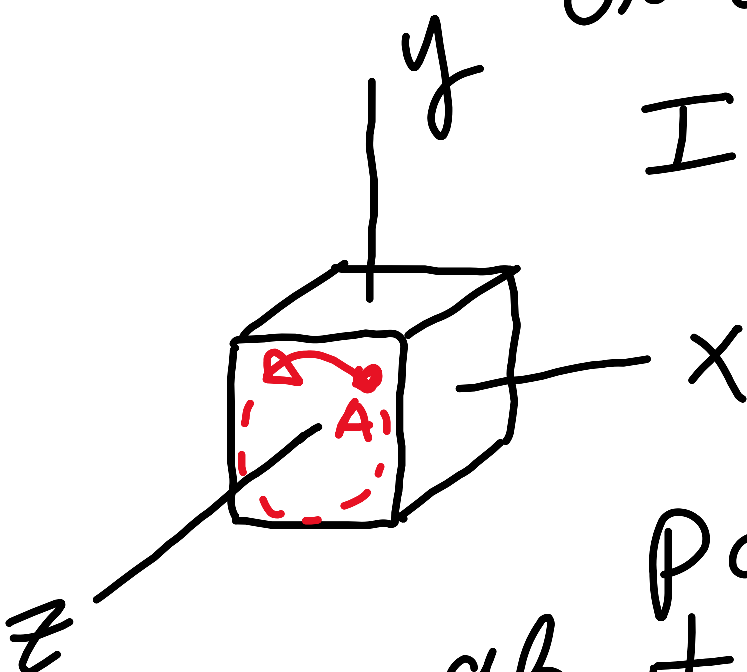


In this, a cube is rotated about the z-axis.

Rotation about fixed axis

Motion along circles centered on axis of rotation.



In this, a cube is rotated about the z-axis.

point A rotates about this axis as shown

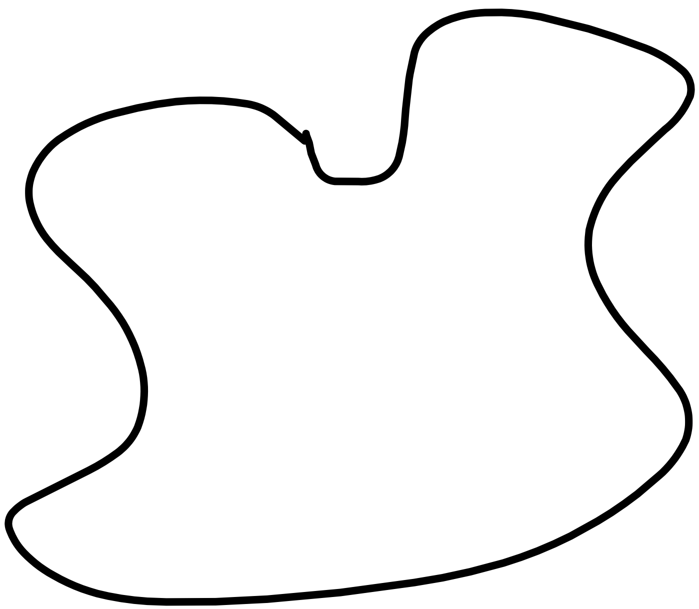
For translation of rigid body

For translation of rigid body

On a rigid body,

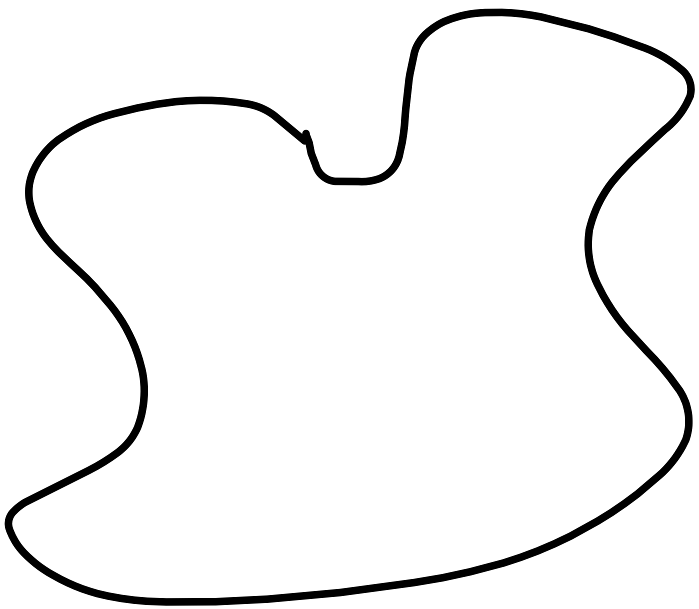
For translation of rigid body

On a rigid body,



For translation of rigid body

On a rigid body, if we choose **any** two points A & B



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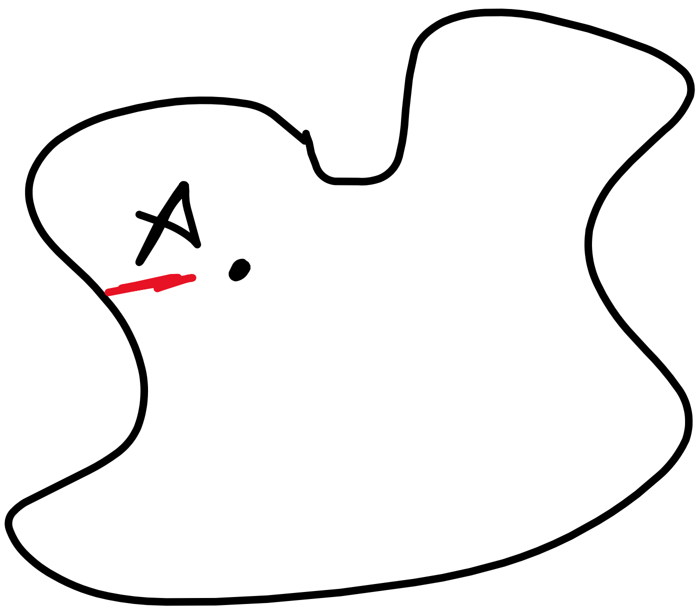

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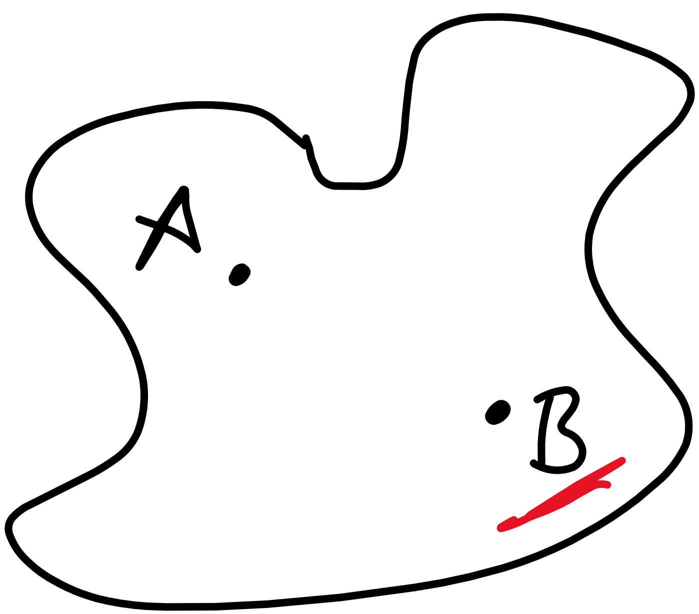
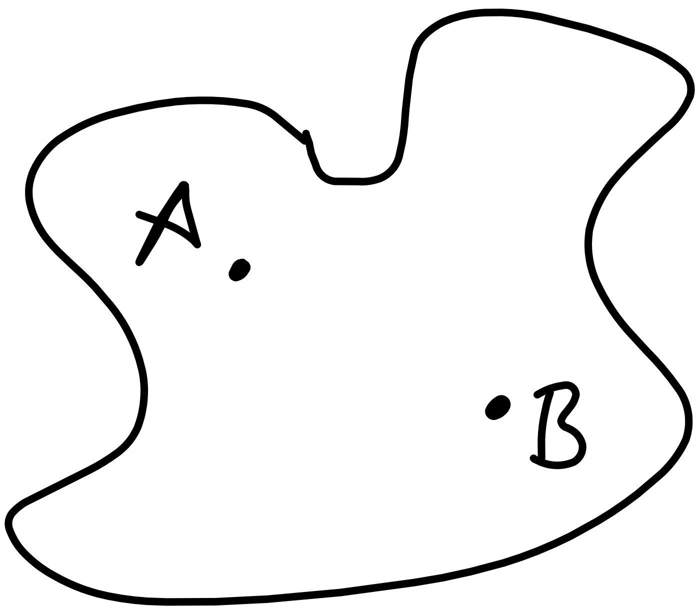


For translation of rigid body

On a rigid body, if we choose any two points A & B, then we can relate the position of B to that of point A as $\vec{r}_B = \vec{r}_A + \vec{r}_{B/A}$



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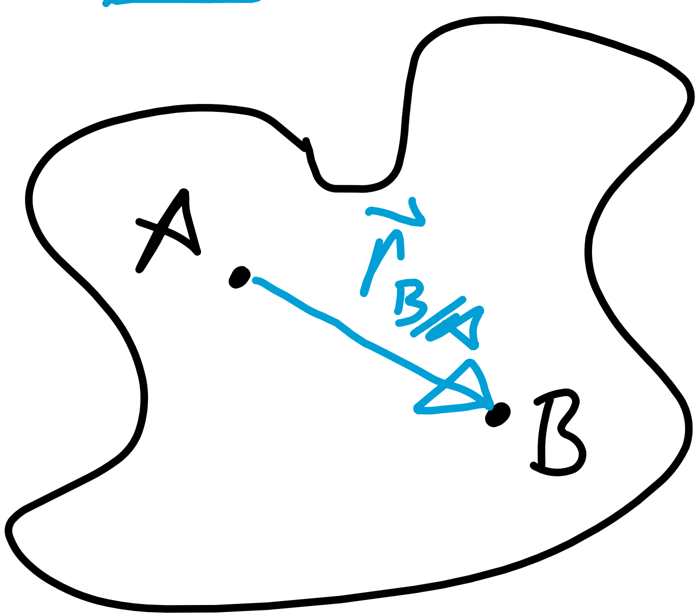

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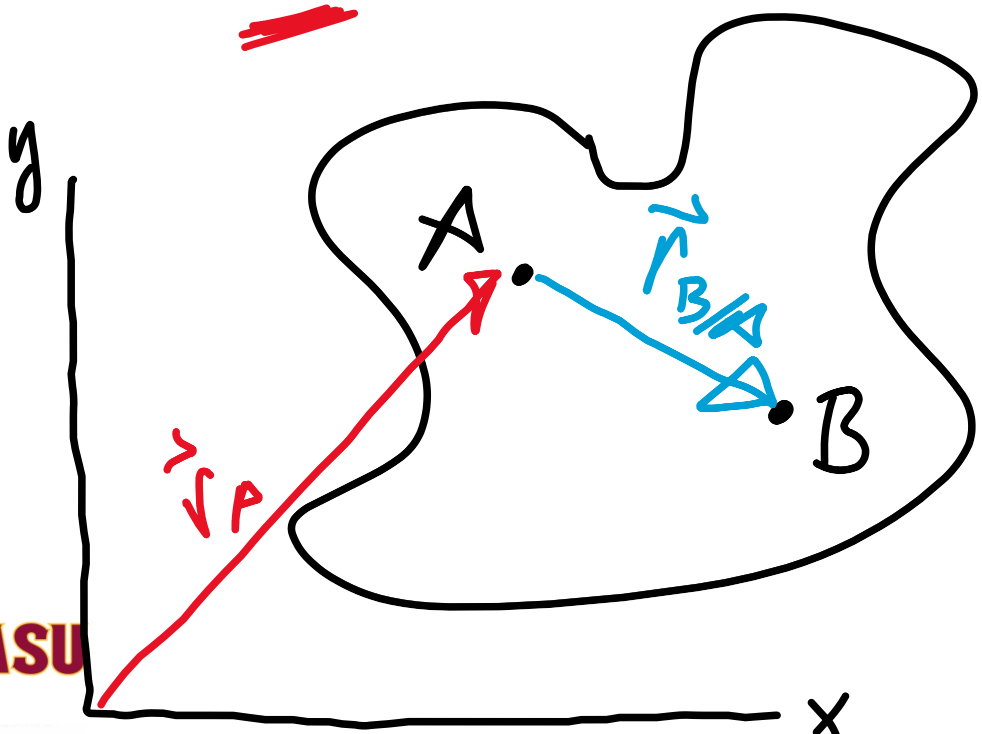

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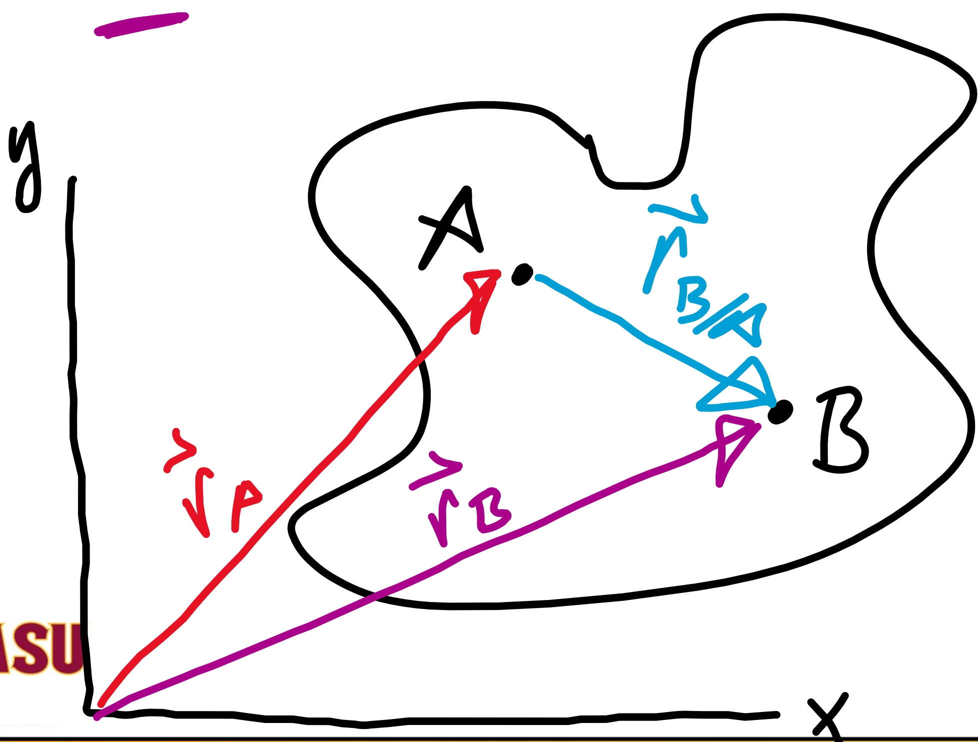
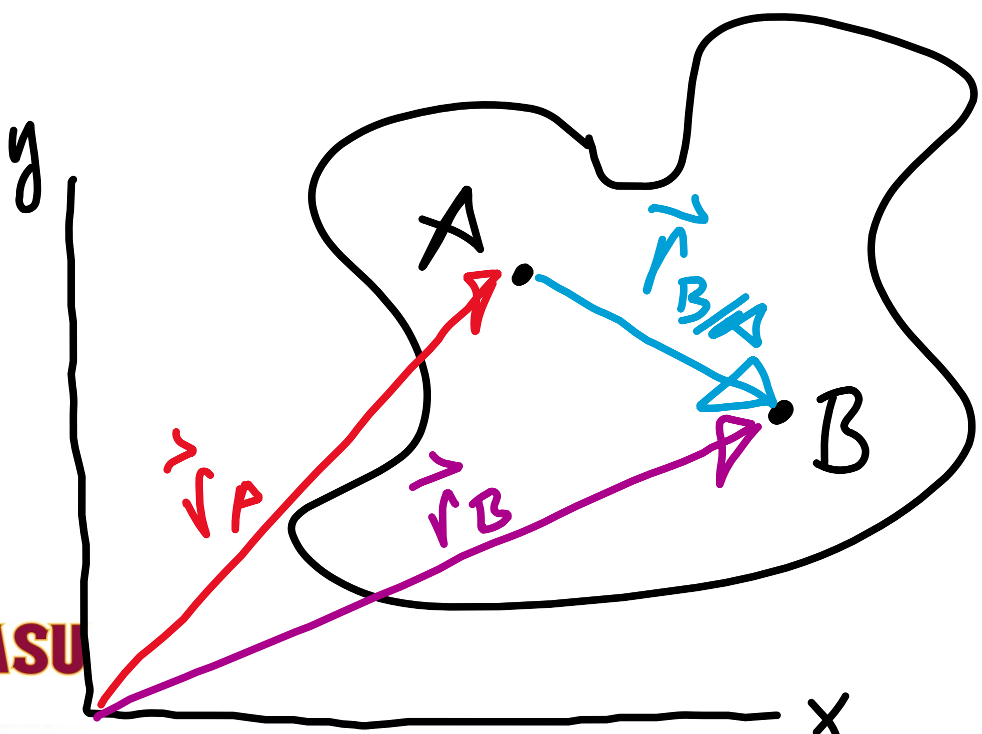


For translation of rigid body

On a rigid body, if we choose <u>any</u> two points A & B, then we can relate the position of B to that of point A as $\vec{r}_B = \vec{r}_A + \vec{r}_{B/A}$. Since A & B are fixed on rigid body

$$|\vec{r}_{B/A}| = \text{const.}$$



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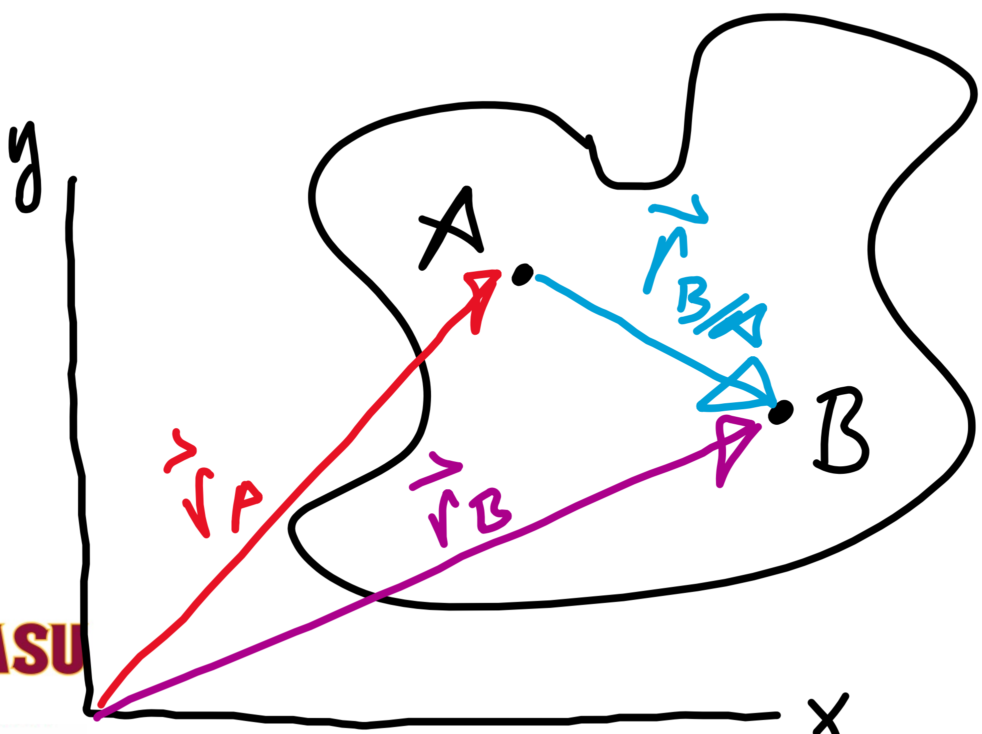


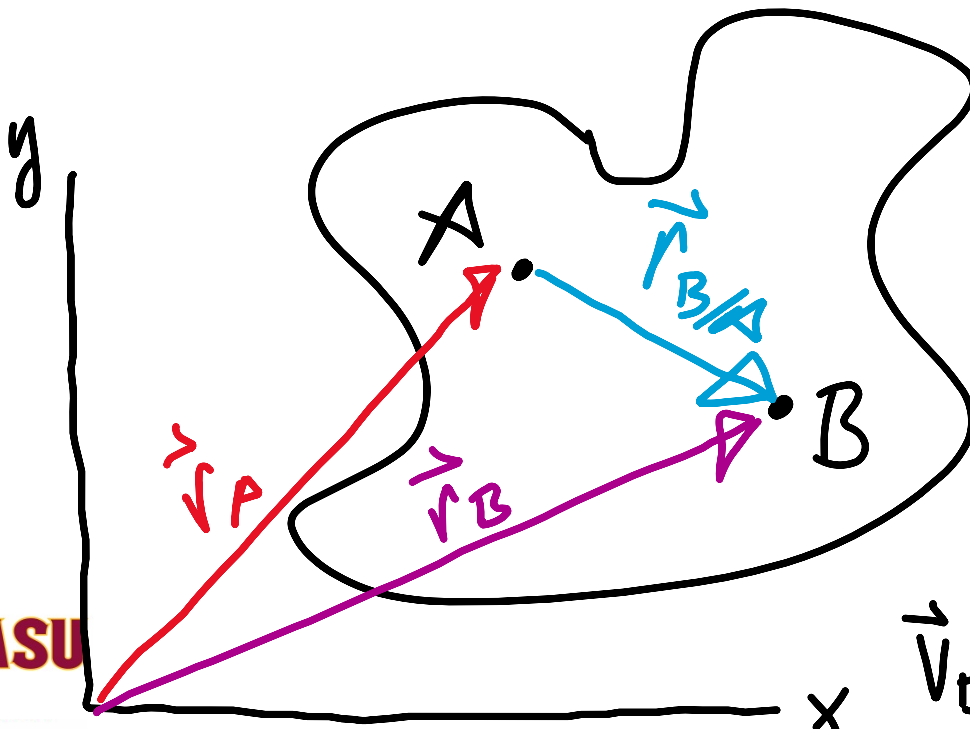
$|\vec{r}_{B/A}| = \text{const.}$ &

Since no rotation

$$\frac{d\vec{r}_{BA}}{dt} = 0$$

For translation of rigid body

On a rigid body, if we choose <u>any</u> two points A & B, then we can relate the position of B to that of point A as $\vec{r}_B = \vec{r}_A + \vec{r}_{B/A}$. Since A & B are fixed on rigid body



$|\vec{r}_{B/A}| = \text{const.}$ &

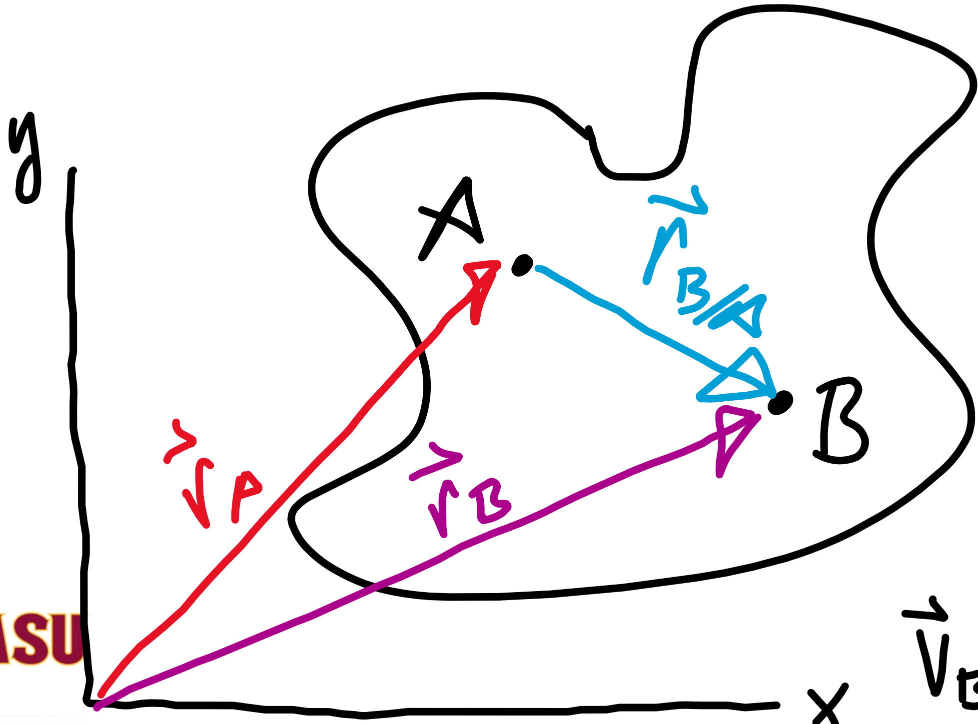
Since no rotation

$\frac{d\vec{r}_{BA}}{dt} = 0$ So

$\vec{V}_B = \vec{V}_A$

For translation of rigid body

On a rigid body, if we choose <u>any</u> two points A & B, then we can relate the position of B to that of point A as $\vec{r}_B = \vec{r}_A + \vec{r}_{B/A}$. Since A & B are fixed on rigid body



$|\vec{r}_{B/A}| = $ const. &

Since no rotation

$\frac{d\vec{r}_{BA}}{dt} = 0$ So

$\vec{V}_B = \vec{V}_A$ & $\vec{a}_B = \vec{a}_A$

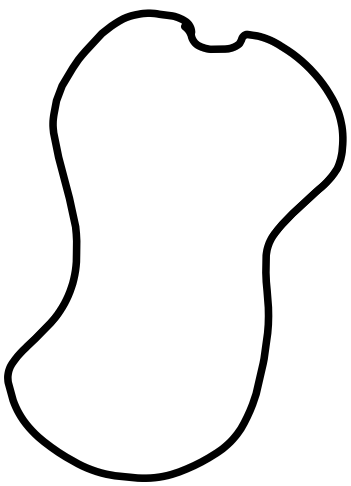
For rotation about a fixed axis

For rotation about a fixed axis

* On a rigid body

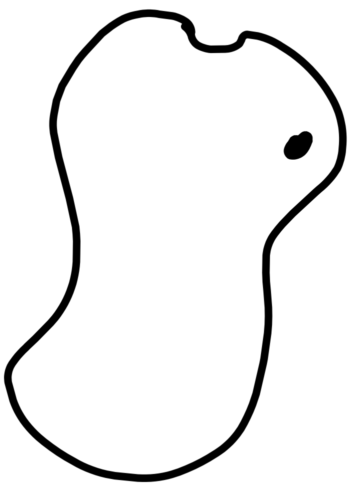
For rotation about a fixed axis

* On a rigid body



For rotation about a fixed axis

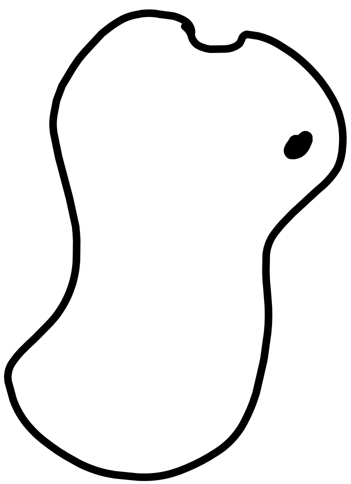
* On a rigid body take a point



For rotation about a fixed axis

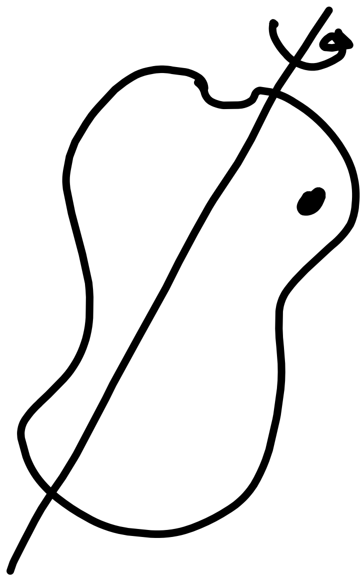
* On a rigid body take a point

For rotation about a fixed axis



* On a rigid body take a point
* Along the axis of rotation

For rotation about a fixed axis



* On a rigid body take a point
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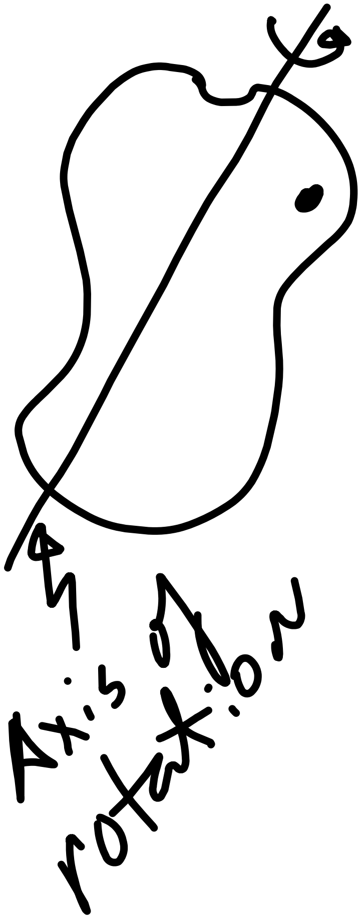
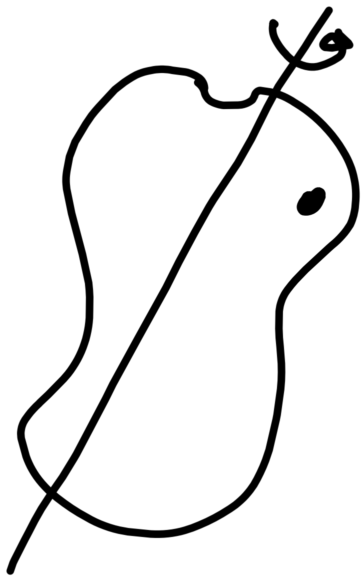
For rotation about a fixed axis



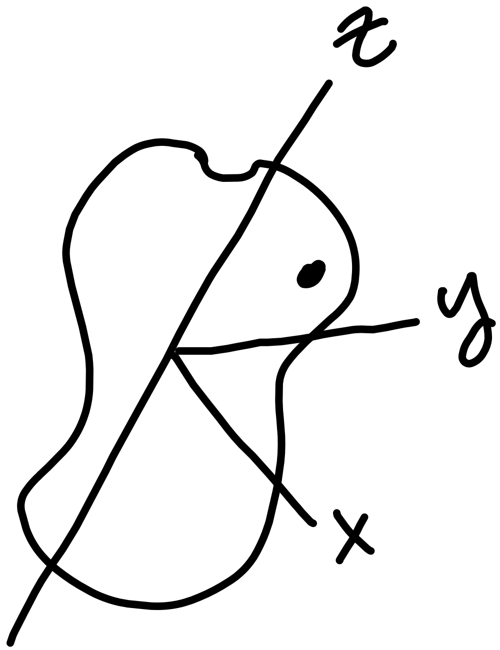
* On a rigid body take a point
* Along the axis of rotation

For rotation about a fixed axis



* On a rigid body take a point
* Along the axis of rotation Define the z-axis

For rotation about a fixed axis



* On a rigid body take a point
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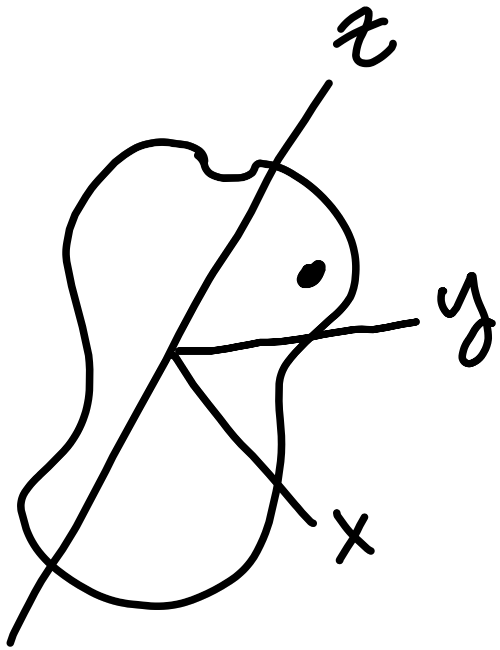
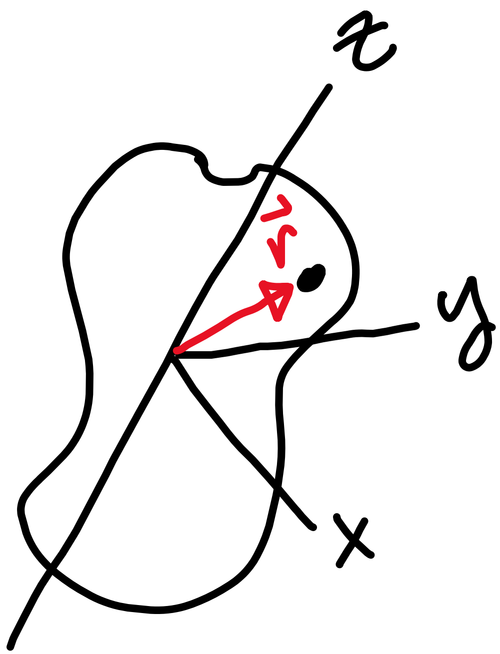
For rotation about a fixed axis



* On a rigid body take a point
* Along the axis of rotation Define the z-axis
* angle $\vec{r}$ makes with z-axis is φ

For rotation about a fixed axis



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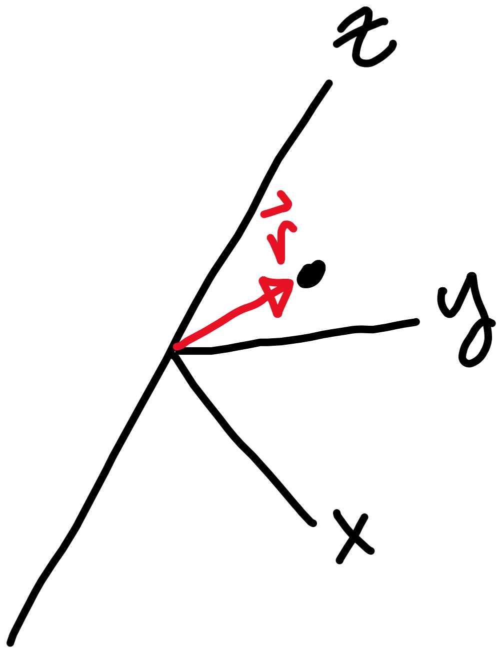
For rotation about a fixed axis



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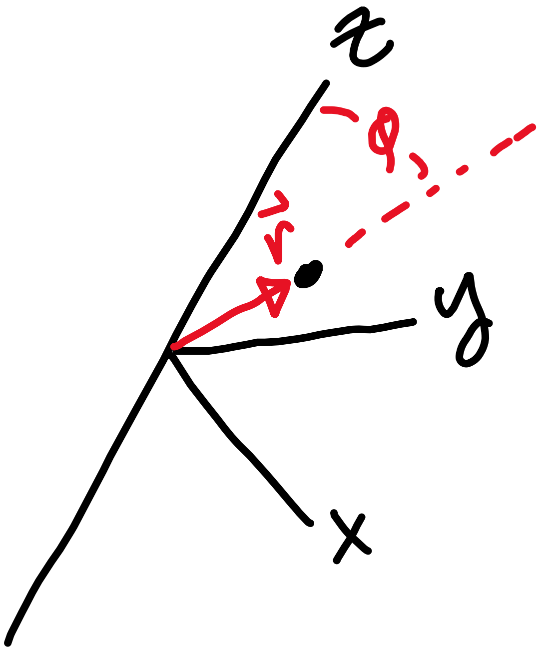
For rotation about a fixed axis



* On a rigid body take a point
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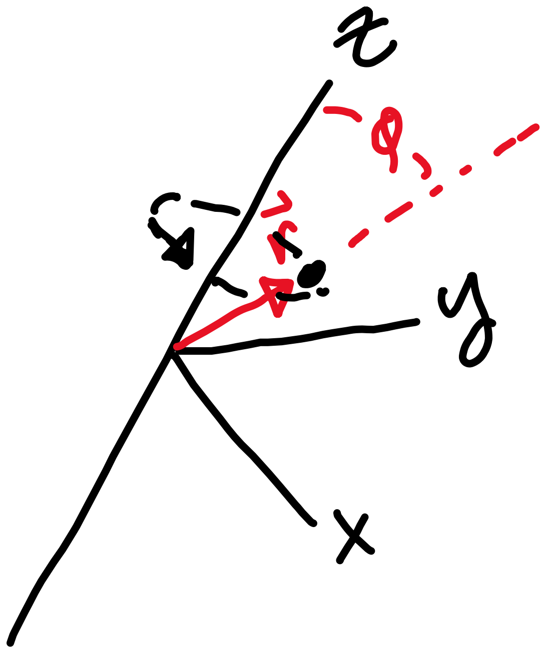
For rotation about a fixed axis



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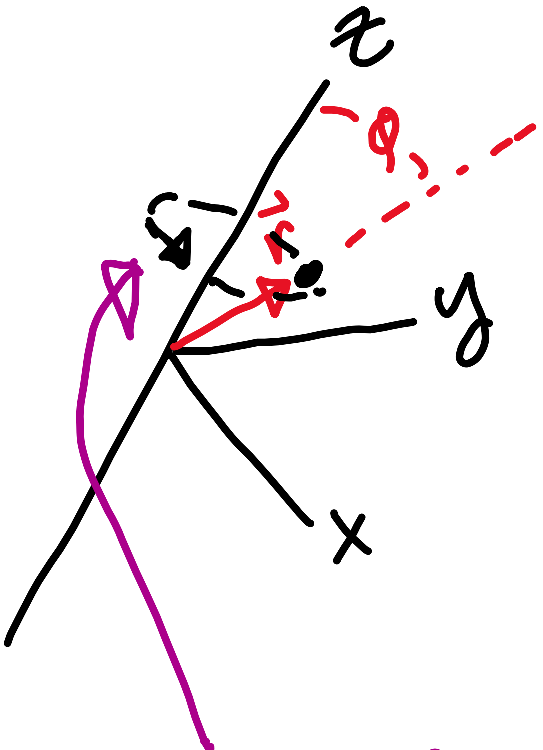
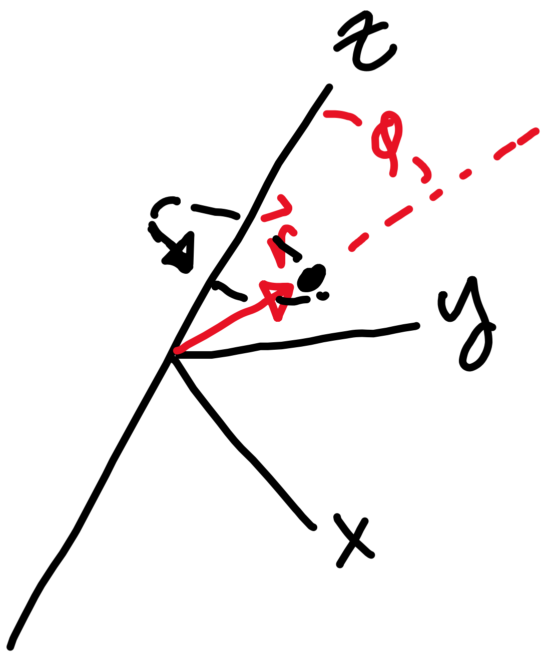
For rotation about a fixed axis



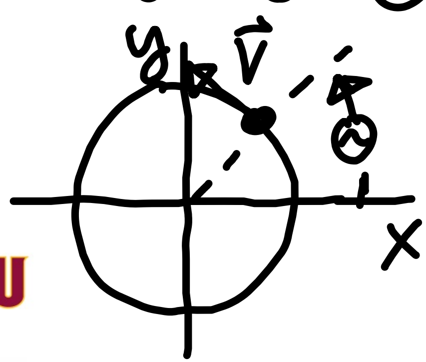
* On a rigid body take a point
* Along the axis of rotation
Define the z-axis
* angle $\vec{r}$ makes with z-axis is φ

Circular path swept by point of interest about axis of rotation

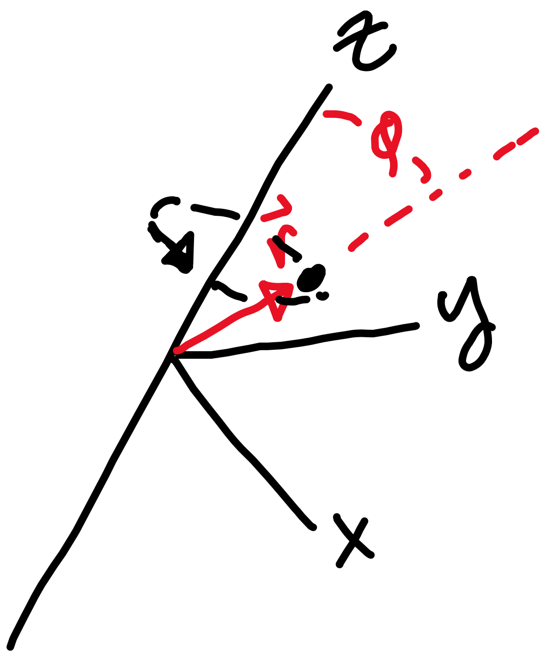
For rotation about a fixed axis



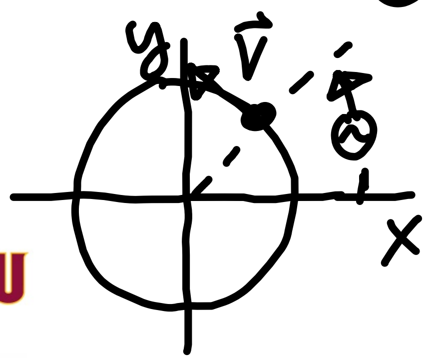
* On a rigid body take a point
* Along the axis of rotation Define the z-axis
* angle $\vec{r}$ makes with z-axis is φ
* Angle on xy-plane between $\vec{r}$ & x-axis is θ



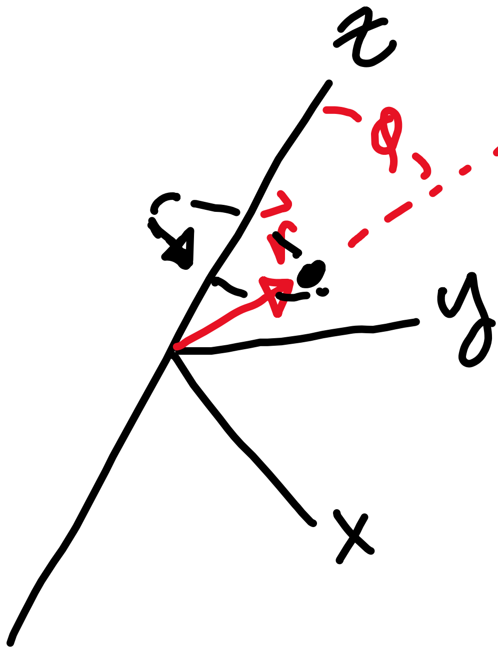
For rotation about a fixed axis



* On a rigid body take a point
* Along the axis of rotation Define the z-axis
* angle $\vec{r}$ makes with z-axis is φ
* Angle on xy-plane between $\vec{r}$ & x-axis is Θ
* radius of curvature is ρ



For rotation about a fixed axis



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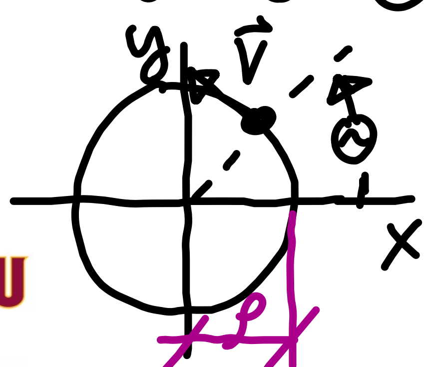
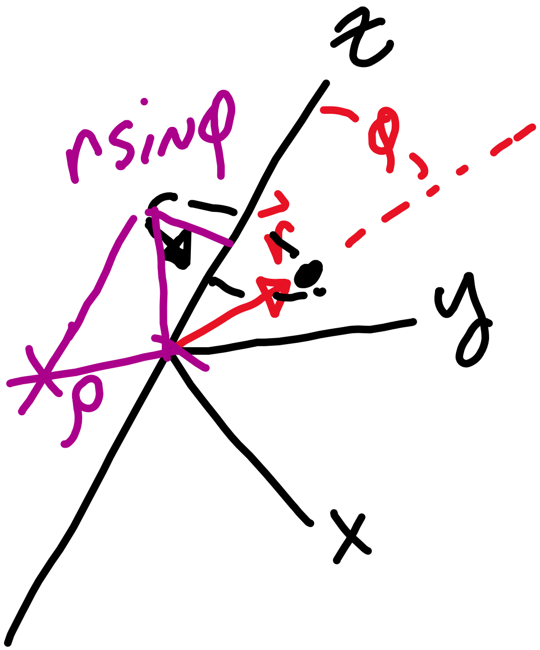


For rotation about a fixed axis



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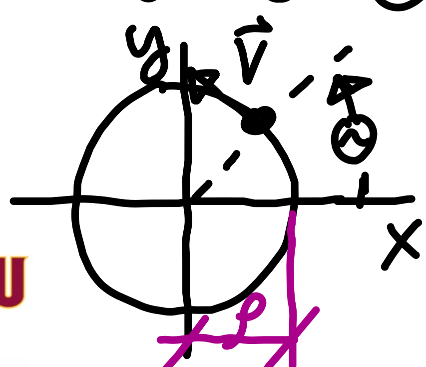
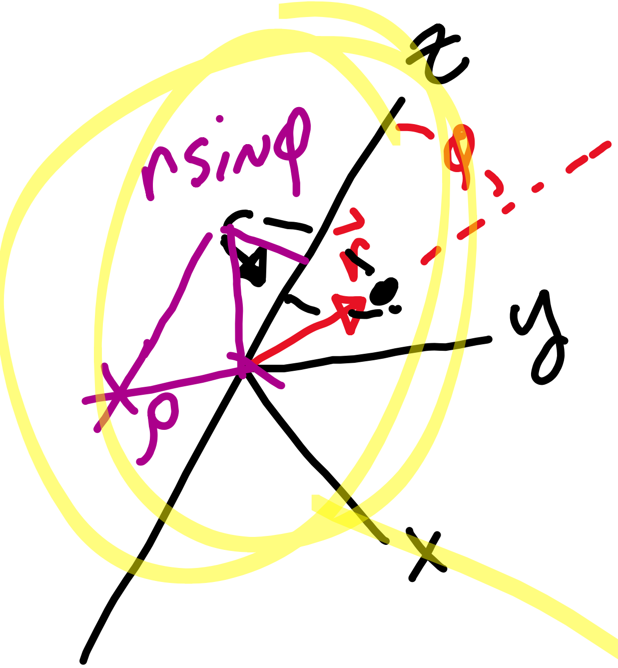
* Along the axis of rotation Define the z-axis
* angle $\vec{r}$ makes with z-axis is φ
* Angle on xy-plane between $\vec{r}$ & x-axis is θ



* radius of curvature is ρ & $\rho = r\sin\varphi$

For rotation about a fixed axis



* On a rigid body take a point
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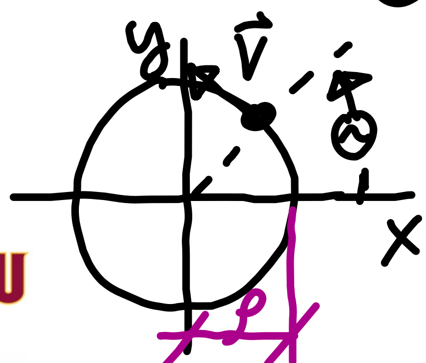
* angle $\vec{r}$ makes with z-axis is φ
* Angle on xy-plane between $\vec{r}$ & x-axis is Θ



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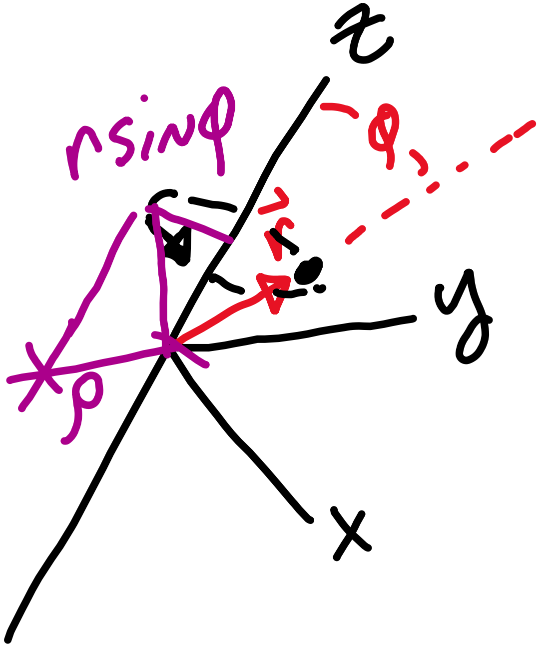

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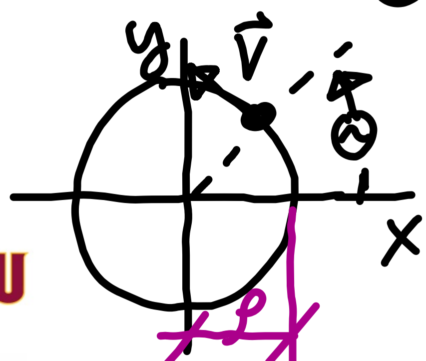

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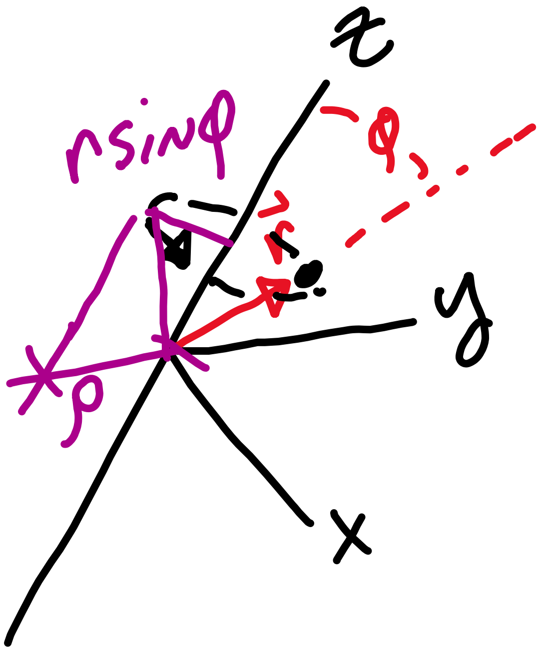
For rotation about a fixed axis



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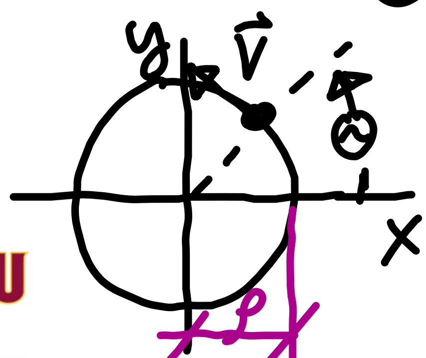
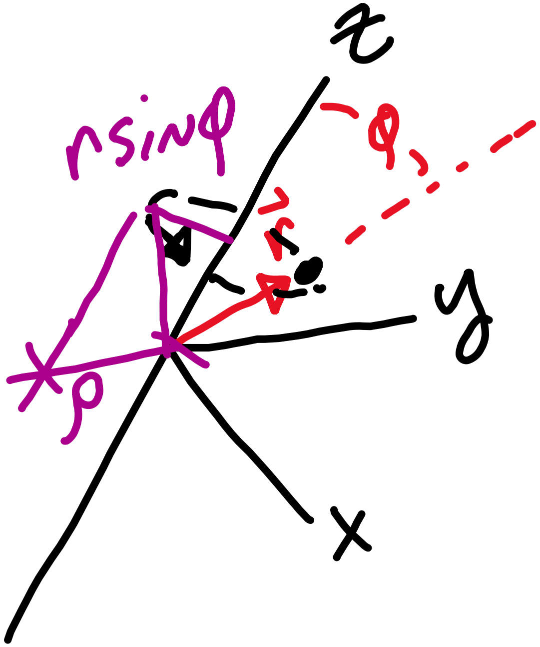


- radius of curvature is ρ & $\rho = r\sin\varphi$
- Take $\vec{\omega} \equiv \dot{\theta}\hat{k}$ Now $v = \rho\dot{\theta}$

For rotation about a fixed axis



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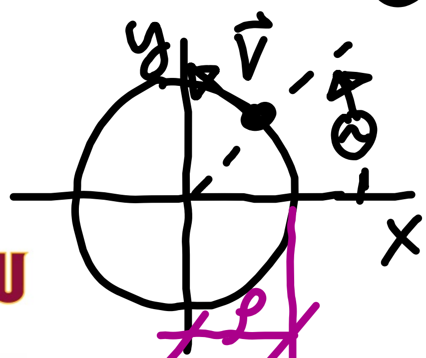

* radius of curvature is ρ & $\rho = r\sin\varphi$
* Take $\omega \equiv \dot{\Theta}\hat{k}$ Now $v = \rho\dot{\Theta}$

$\Rightarrow v = \omega r \sin\varphi$

we saw that, for rotation fixed about the z-axis, $\vec{v} = \vec{\omega} \times \vec{r}$

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We will do the analysis of $\vec{v} = \vec{\omega} \times \vec{r}$ again but with different notation

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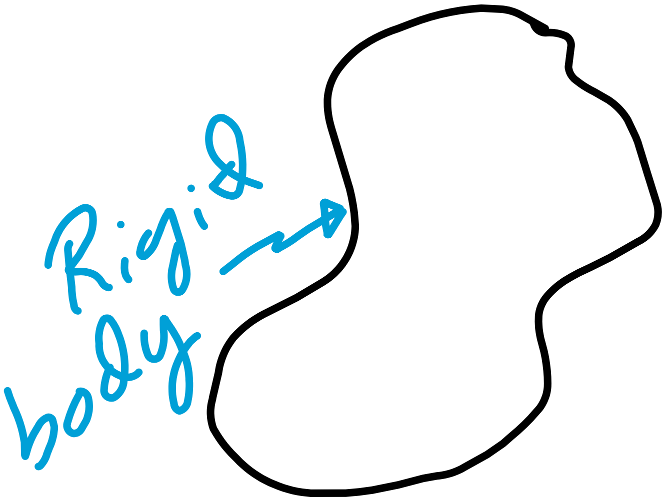
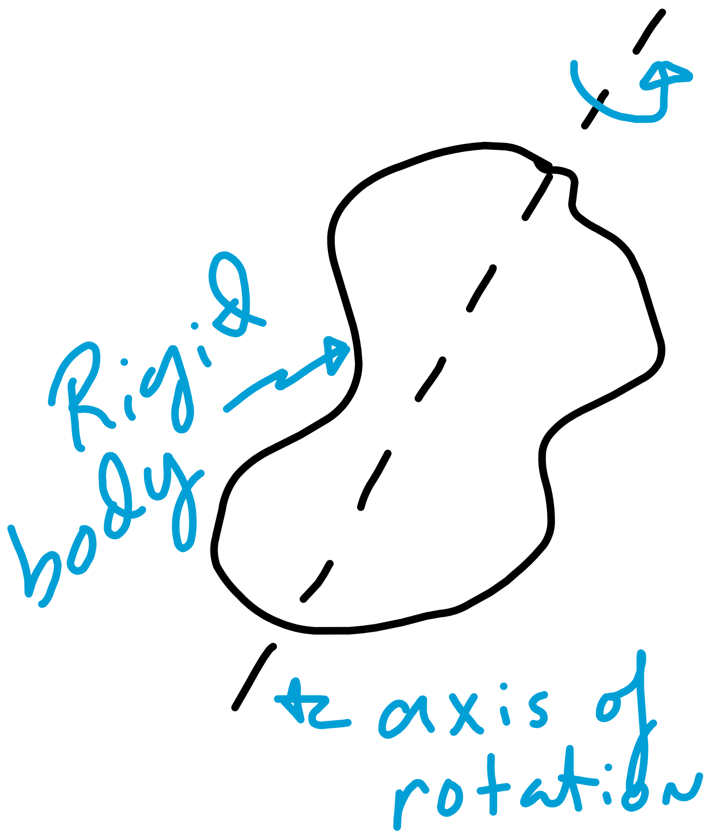
<u>Notation</u>:

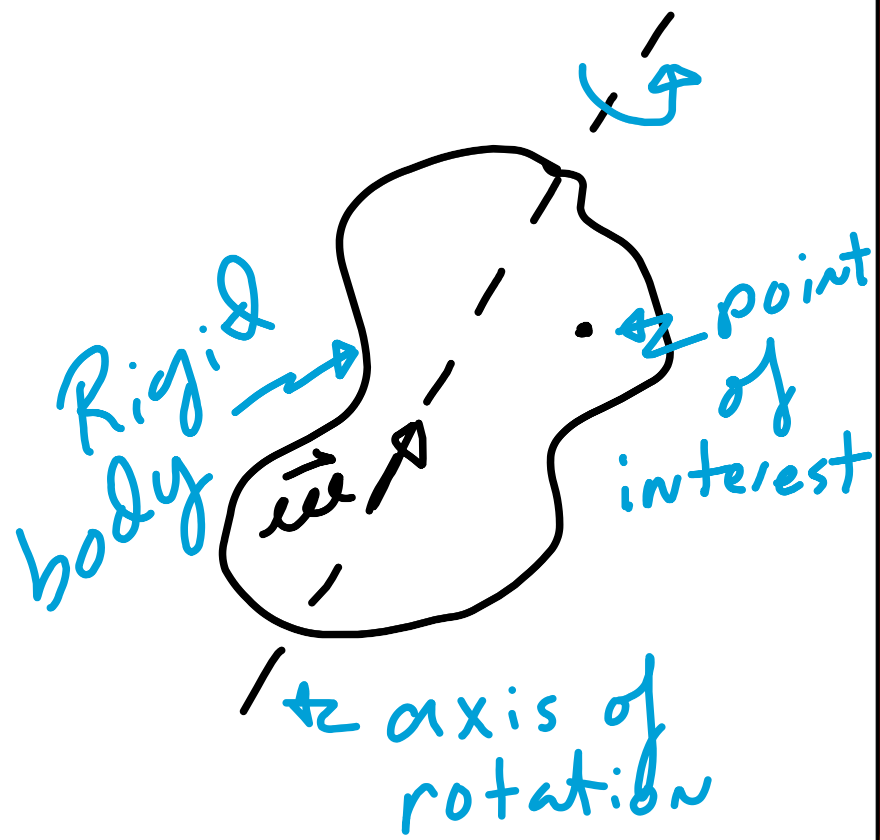
Let $\vec{a}$ be some vector. Define $\hat{a}$ as the unit vector $\hat{a} \equiv \dfrac{\vec{a}}{|\vec{a}|}$. So, with this notation $\hat{i} = \hat{x}$, $\hat{j} = \hat{y}$ & $\hat{k} = \hat{z}$.


Rigid
body

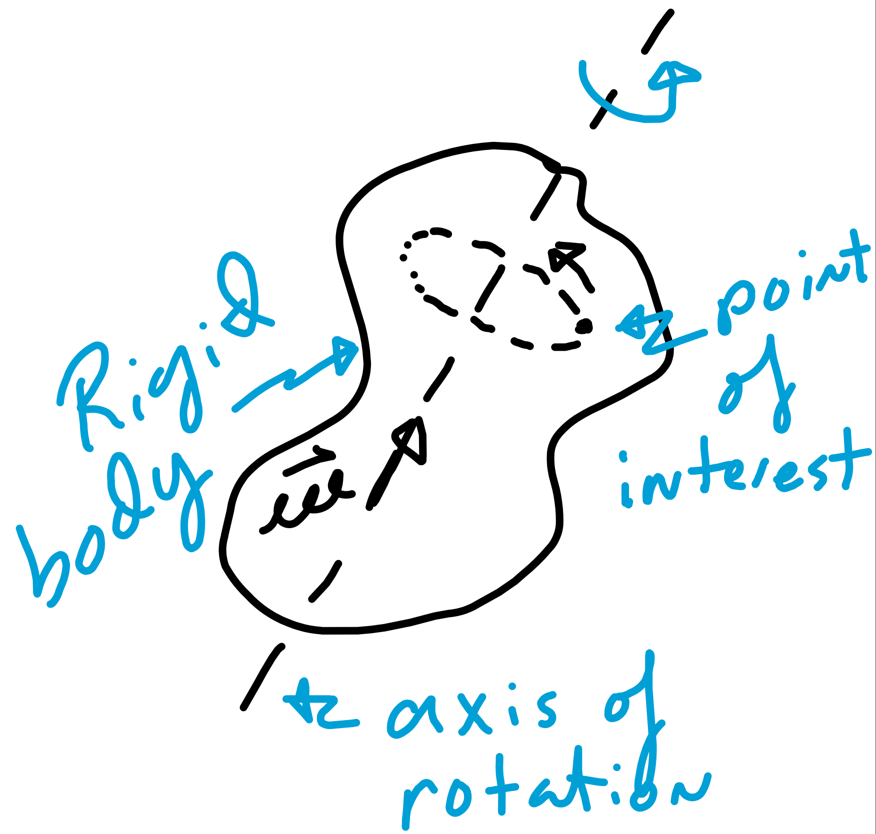

Rigid body
axis of rotation

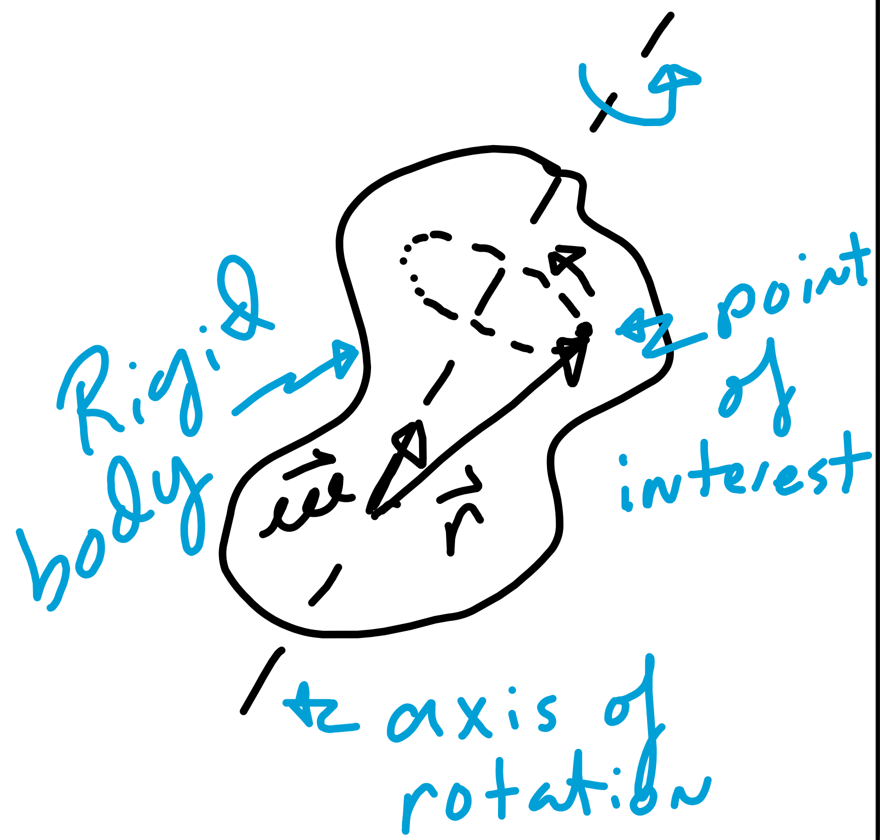

Rigid body
axis of rotation

Rigid body
$\vec{\omega}$
axis of rotation

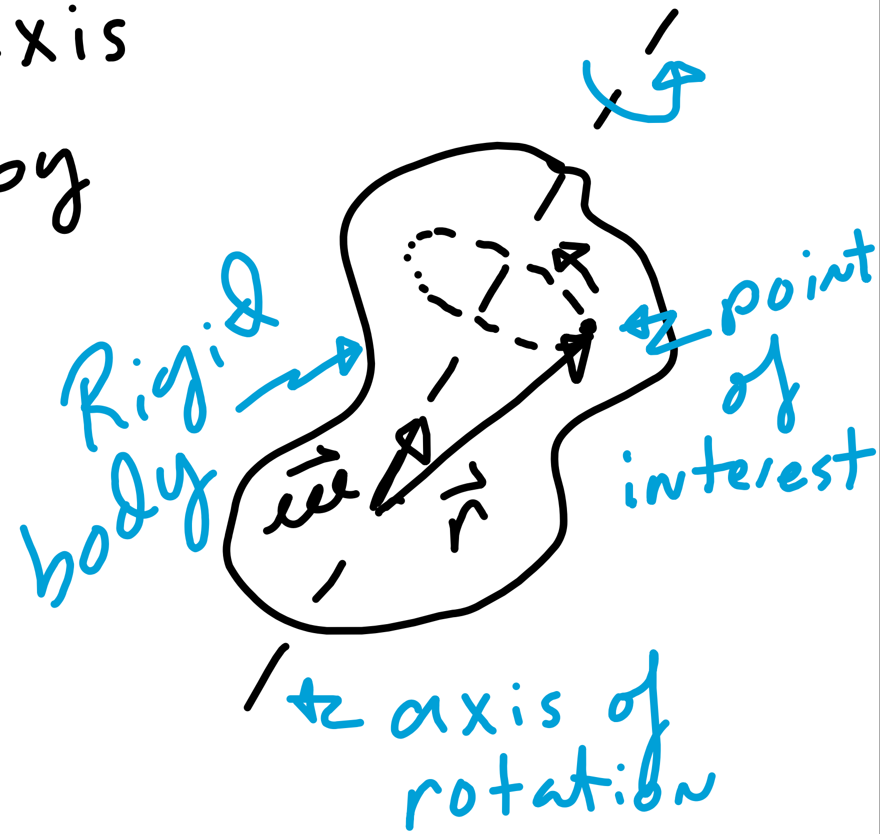


Rigid body
point of interest
$\vec{\omega}$
axis of rotation

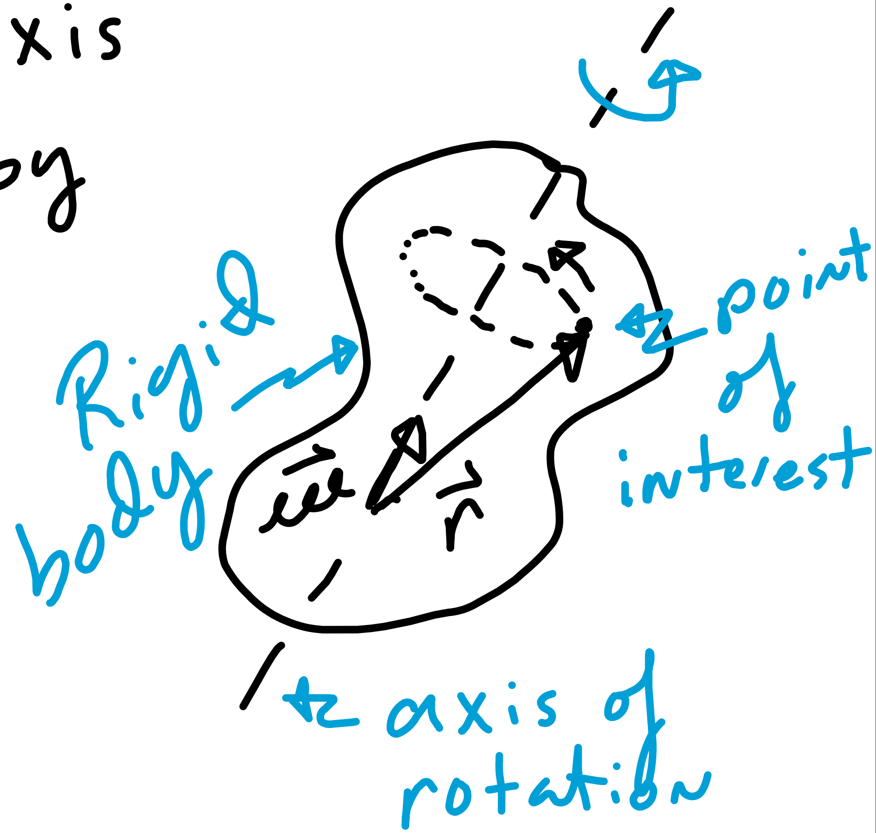

Rigid body
point of interest
axis of rotation
$\vec{\omega}$


Rigid body
point of interest
axis of rotation
$\vec{\omega}$
$\vec{r}$

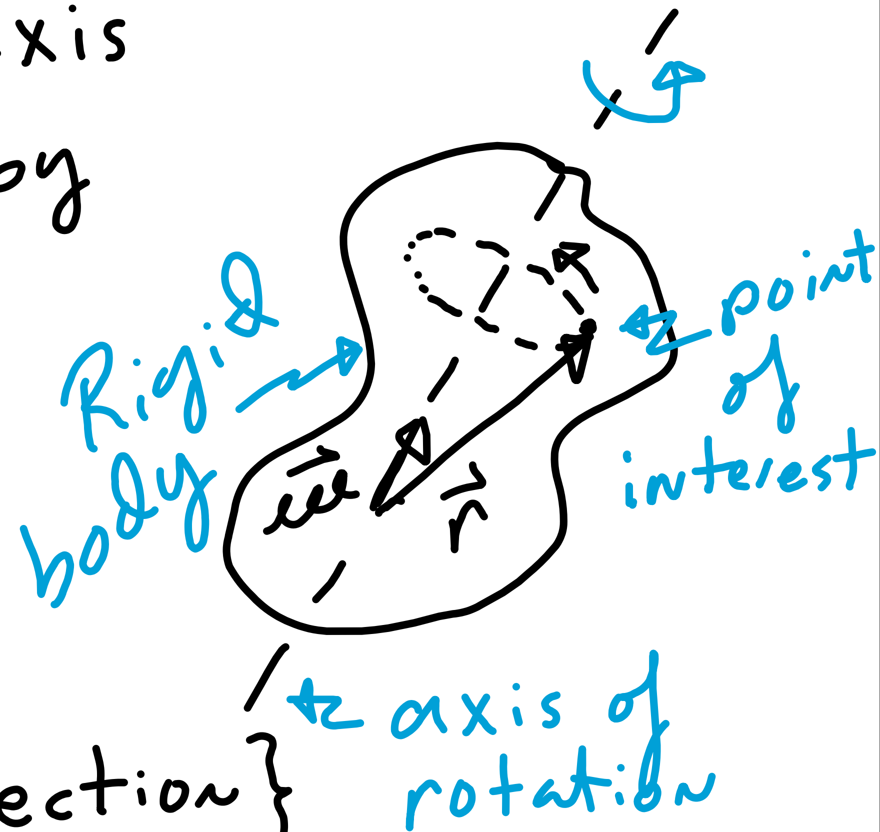
$\vec{\omega}$ is along axis of rotation defined by the right hand rule



$\vec{\omega}$ is along axis of rotation defined by the right hand rule {grab axis of rotation such that fingers wrap in direction of rotation}

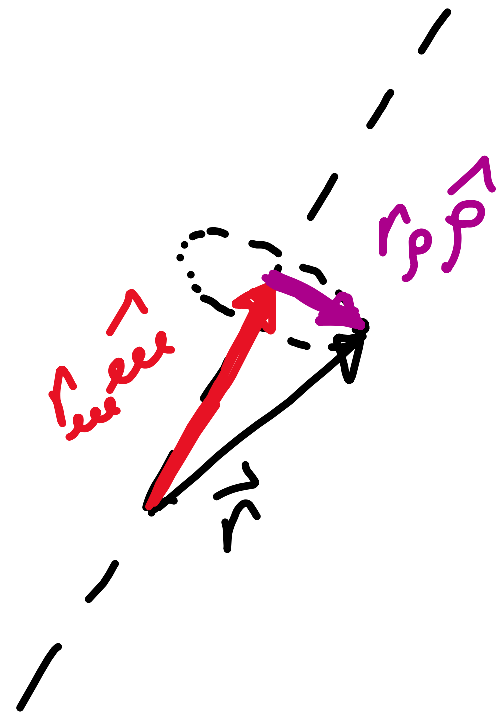


$\vec{\omega}$ is along axis of rotation defined by the right hand rule {grab axis of rotation such that fingers wrap in direction of rotation & thumb points in $\vec{\omega}$ direction}

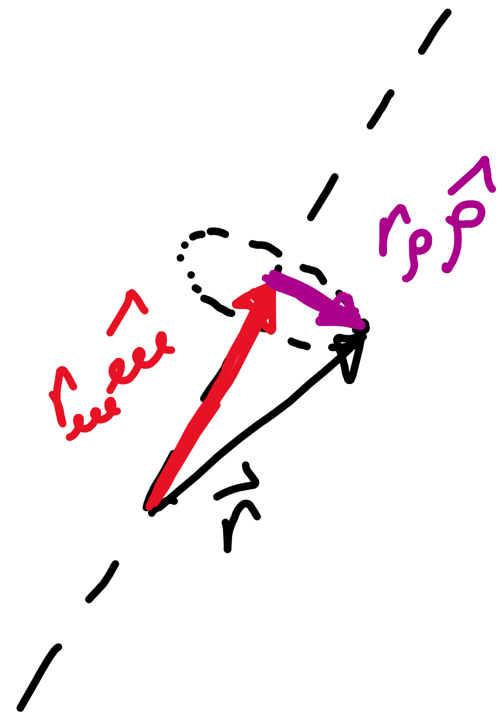


We can break up $\vec{r}$ into orthogonal directions of $\hat{p}$ & $\hat{\mu}$:

We can break up $\vec{r}$ into orthogonal directions of $\hat{\rho}$ & $\hat{\mu}$:



We can break up $\vec{r}$ into orthogonal directions of $\hat{\rho}$ & $\hat{\ell\ell}$: $\vec{r} = r_{\ell\ell\ell}\,\hat{\ell\ell\ell} + r_\rho\,\hat{\rho}$



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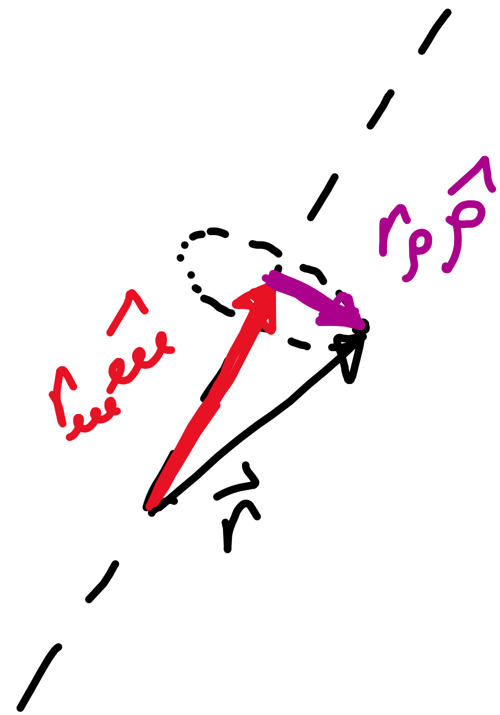
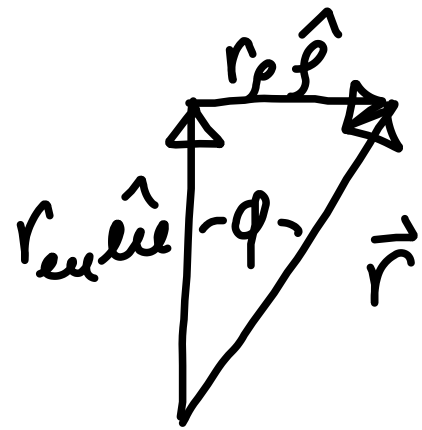
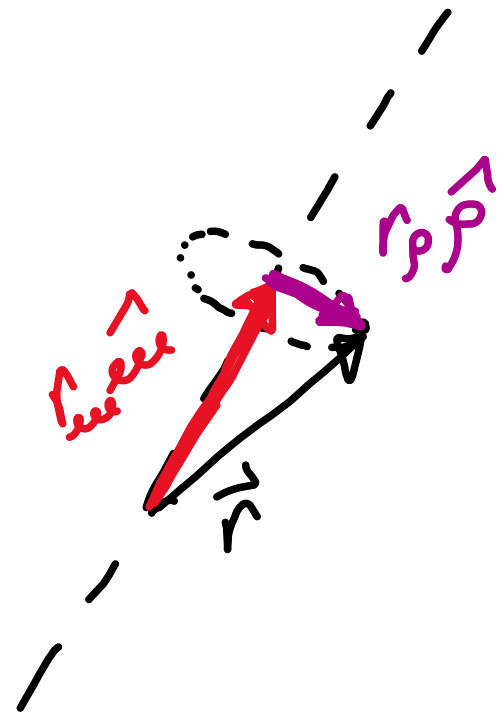


"side" view:



We can break up $\vec{r}$ into orthogonal directions of $\hat{\rho}$ & $\hat{\text{ш}}$: $\vec{r} = r_{\text{ш}}\hat{\text{ш}} + r_{\rho}\hat{\rho}$

Now $\vec{r} = r\cos\varphi\,\hat{\text{ш}} + r\sin\varphi\,\hat{\rho}$



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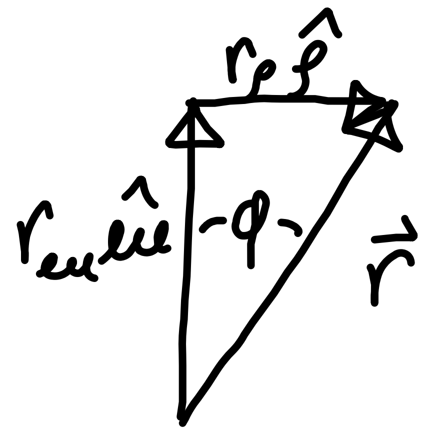
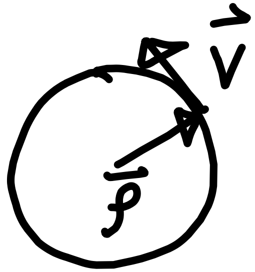
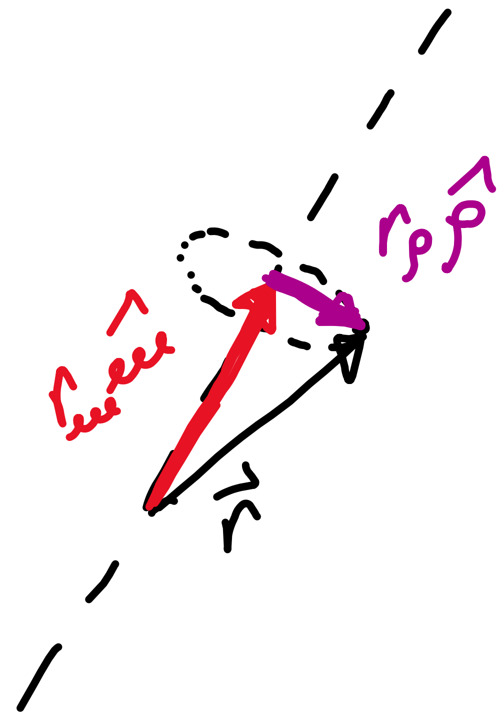


We can break up $\vec{r}$ into orthogonal directions of $\hat{\rho}$ & $\hat{u}$: $\vec{r} = r_u \hat{u} + r_\rho \hat{\rho}$

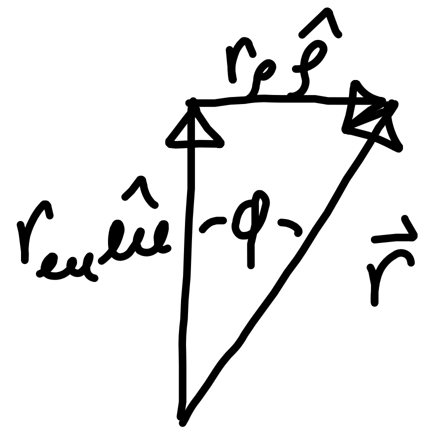
Now $\vec{r} = r\cos\varphi\,\hat{u} + r\sin\varphi\,\hat{\rho}$

"TOP" VIEW:



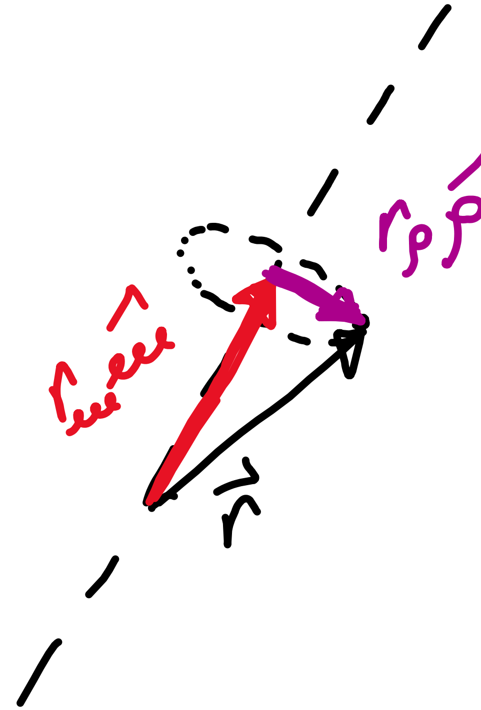


"side" view:

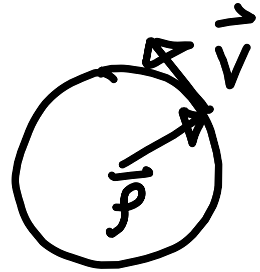


We can break up $\vec{r}$ into orthogonal directions of $\hat{\rho}$ & $\hat{\omega}$: $\vec{r} = r_{\omega}\hat{\omega} + r_{\rho}\hat{\rho}$

Now $\vec{r} = r\cos\varphi\,\hat{\omega} + r\sin\varphi\,\hat{\rho}$



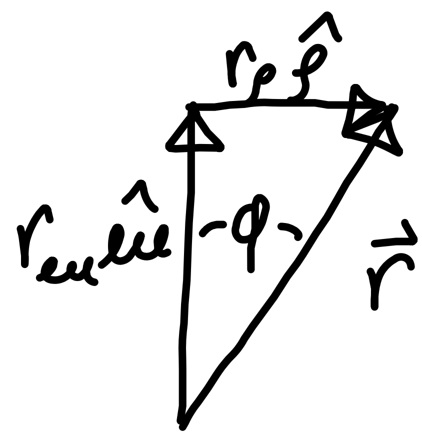
"Top" view:



we know that

$V = \rho\dot{\theta} = \rho\omega$

"Side" view:



We can break up $\vec{r}$ into orthogonal directions of $\hat{\rho}$ & $\hat{\omega}$: $\vec{r} = r_{\omega}\hat{\omega} + r_{\rho}\hat{\rho}$

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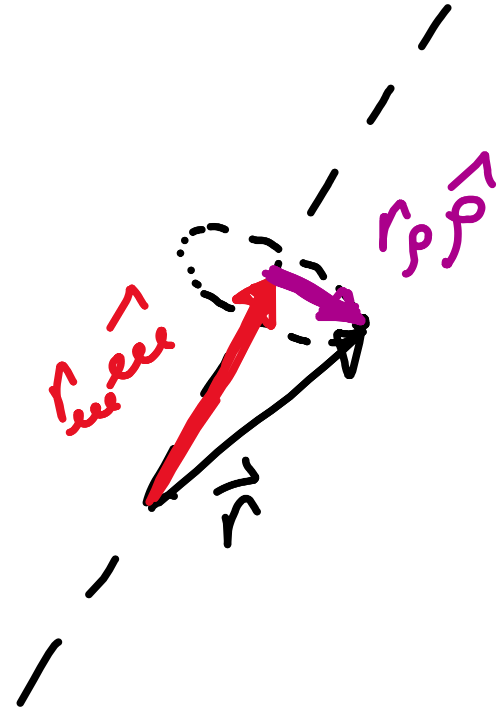
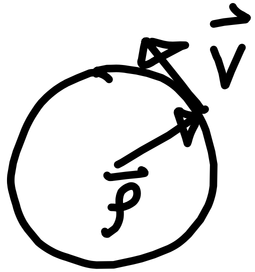


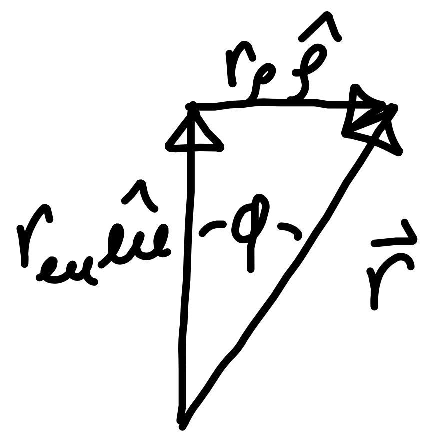
"TOP" VIEW:



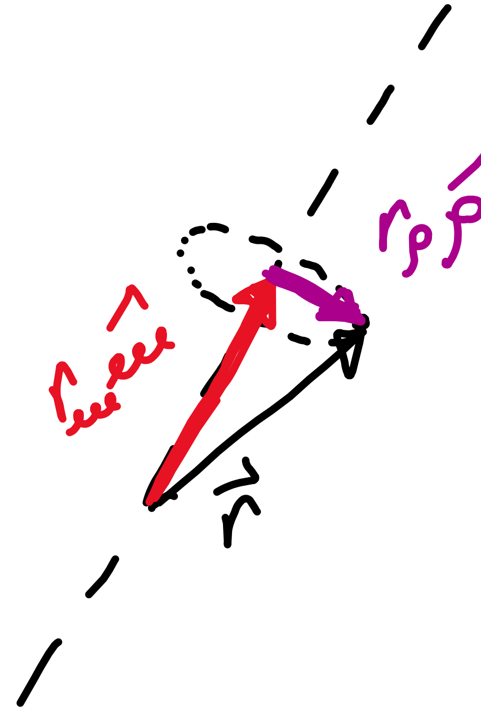
we know that

$V = \rho\dot{\theta} = \rho\omega$, but $\rho = r\sin\varphi$

"side" view:

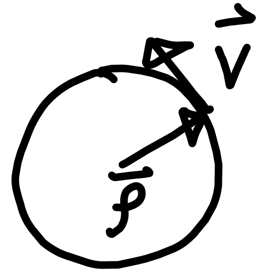


We can break up $\vec{r}$ into orthogonal directions of $\hat{\rho}$ & $\hat{\omega}$: $\vec{r} = r_\omega \hat{\omega} + r_\rho \hat{\rho}$



Now $\vec{r} = r\cos\varphi\,\hat{\omega} + r\sin\varphi\,\hat{\rho}$

"Top" view:

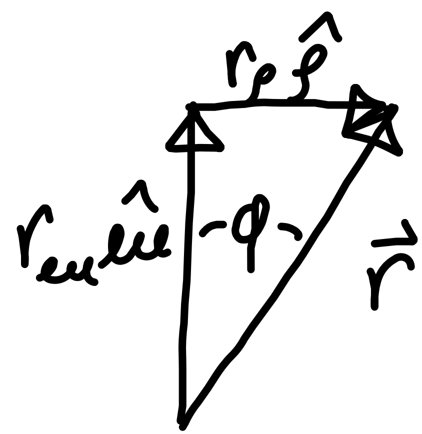


we know that

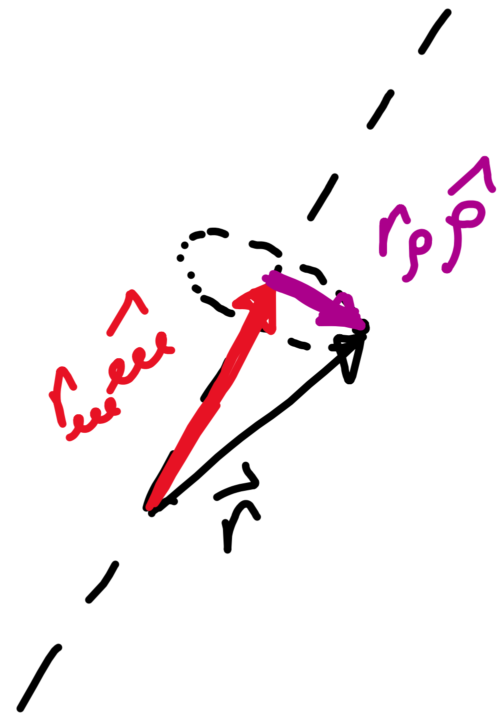
$v = \rho\dot{\theta} = \rho\omega$, but $\rho = r\sin\varphi$

$\Rightarrow v = (r\sin\varphi)\omega$

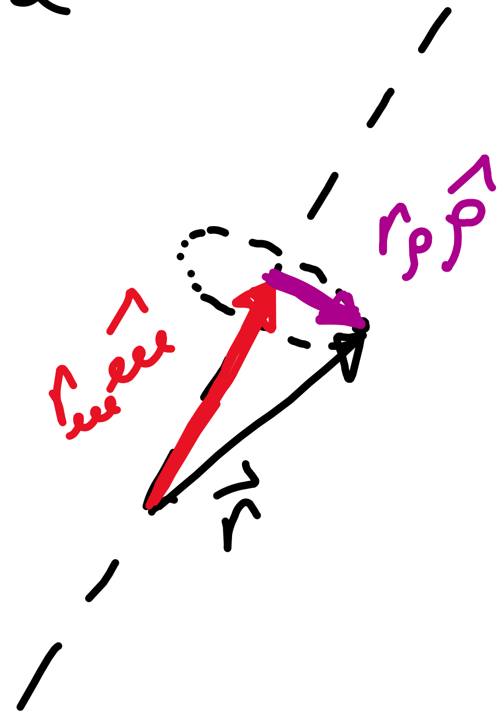
"Side" view:



We have $v = (r \sin\varphi)$eee

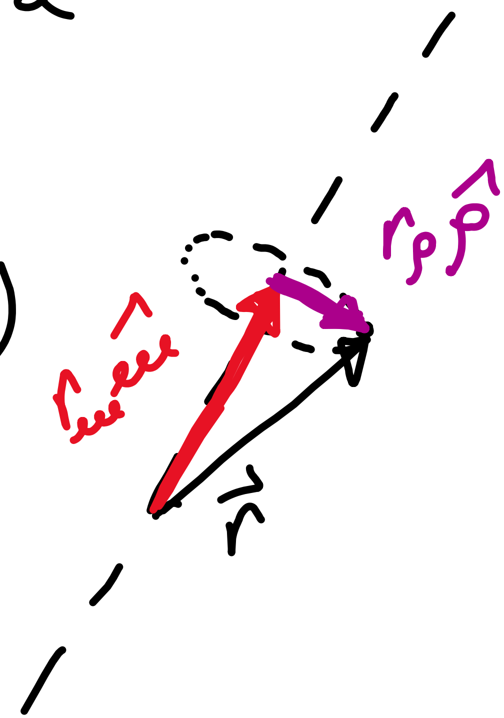


We have $v=(r\sin\varphi)\omega$ and only need to obtain the direction:

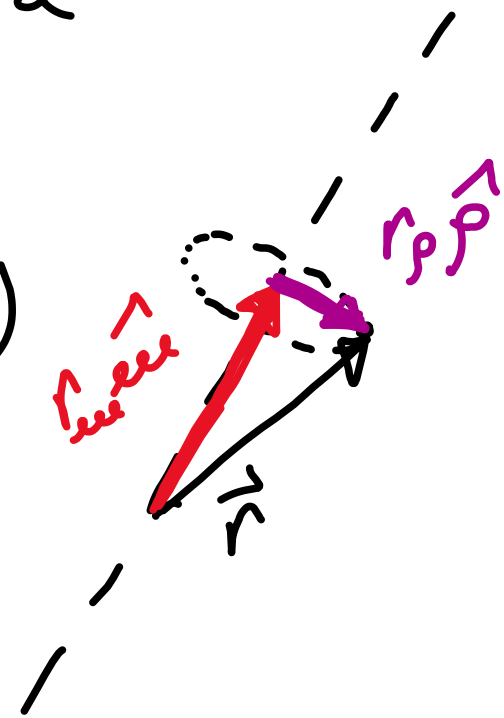


We have $v = (r\sin\varphi)\omega$ and only need to obtain the direction:

Note: $\vec{\omega} \times \vec{r} = \omega\hat{\omega} \times (r_\omega \hat{\omega} + r_\rho \hat{\rho})$



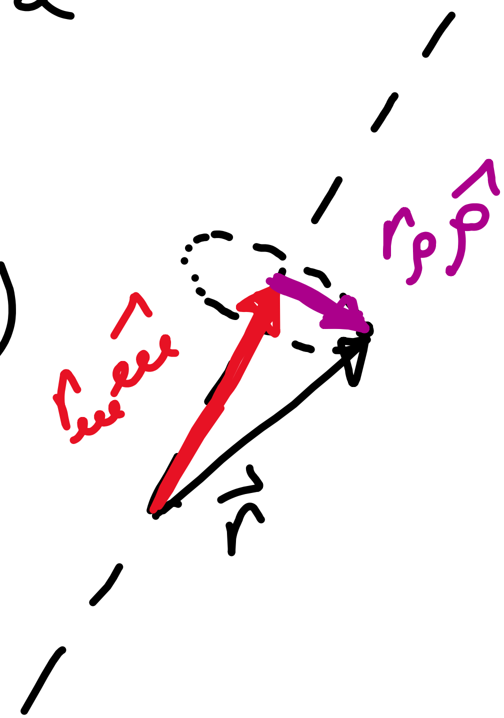
We have $v = (r\sin\varphi)\omega$ and only need to obtain the direction:



<u>Note</u>: $\vec{\omega} \times \vec{r} = \omega\hat{\omega} \times (r_\omega \hat{\omega} + r_\rho \hat{\rho})$

But $\rho = r_\rho = r\sin\varphi$

We have $v = (r \sin\varphi) e$ and only need to obtain the direction:



<u>Note</u>: $\vec{e} \times \vec{r} = e\hat{e} \times (r_e \hat{e} + r_\rho \hat{\rho})$

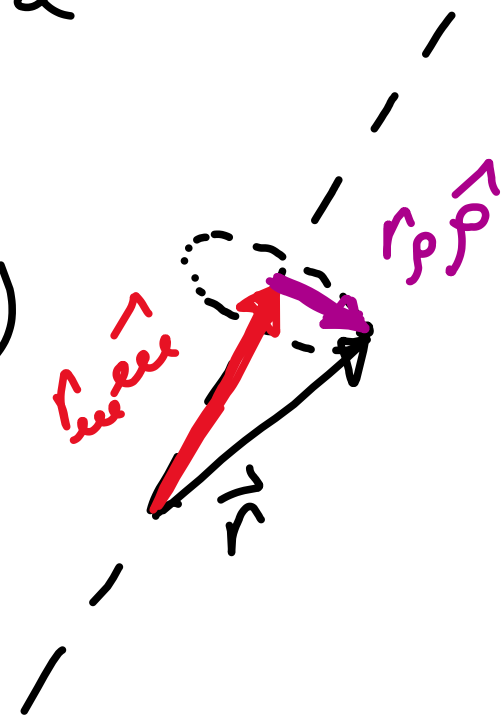
But $\hat{e} \times \hat{e} = \theta$

We have $v = (r\sin\varphi)\omega$ and only need to obtain the direction:

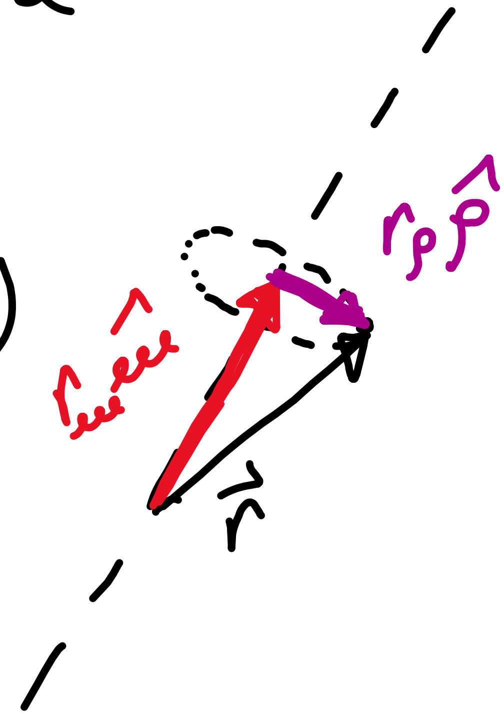
<u>Note</u>: $\vec{\omega}\times\vec{r} = \omega\hat{\omega}\times(r_\omega\hat{\omega} + r_\rho\hat{\rho})$

But $\hat{\omega}\times\hat{\omega} = \vec{0}$ so

$\vec{\omega}\times\vec{r} = \omega r_\rho \hat{\omega}\times\hat{\rho}$



We have $v = (r \sin\varphi)\,\omega$ and only need to obtain the direction:



<u>Note</u>: $\vec{\omega} \times \vec{r} = \omega\,\hat{\omega} \times (r_\omega \hat{\omega} + r_\rho \hat{\rho})$

But $\hat{\omega} \times \hat{\omega} = 0$ so

$\vec{\omega} \times \vec{r} = \omega\, r_\rho\, \hat{\omega} \times \hat{\rho}$ But

$|\hat{\omega} \times \hat{\rho}| = 1$

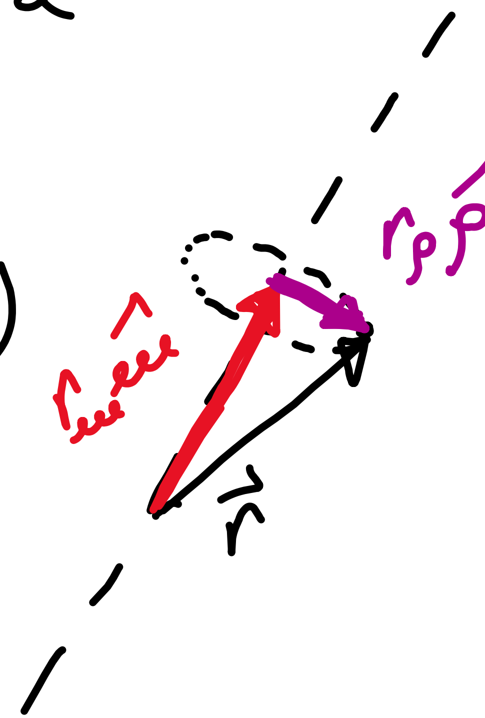
We have $v = (r\sin\varphi)\,\omega$ and only need to obtain the direction:

<u>Note</u>: $\vec{\omega} \times \vec{r} = \omega\,\hat{\omega} \times (r_\omega \hat{\omega} + r_\rho \hat{\rho})$

But $\hat{\omega} \times \hat{\omega} = \vec{0}$ so

$\vec{\omega} \times \vec{r} = \omega\, r_\rho\, \hat{\omega} \times \hat{\rho}$ But

$|\hat{\omega} \times \hat{\rho}| = 1$ [$\hat{\omega}$ orthogonal to $\hat{\rho}$]



We have $v = (r \sin\varphi)\,\omega$ and only need to obtain the direction:

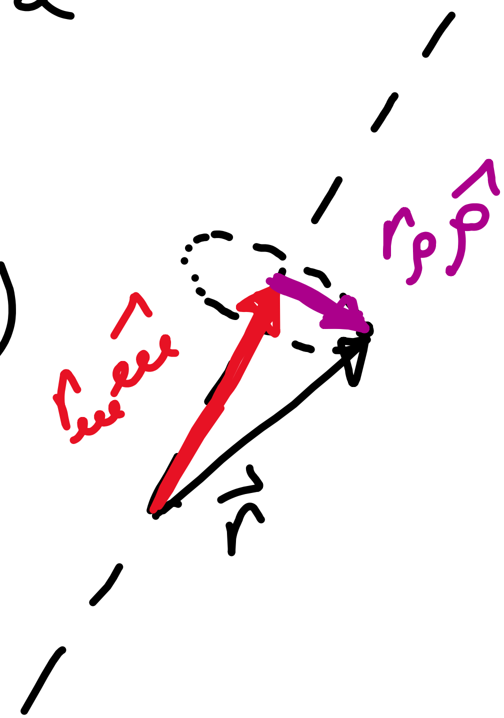
Note: $\vec{\omega} \times \vec{r} = \omega\,\hat{\omega} \times (r_\omega \hat{\omega} + r_\rho \hat{\rho})$

But $\hat{\omega} \times \hat{\omega} = \vec{0}$ so

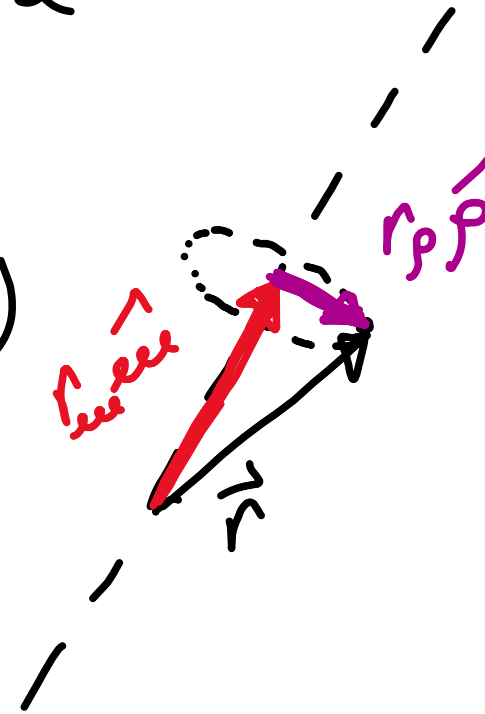
$\vec{\omega} \times \vec{r} = \omega\, r_\rho\, \hat{\omega} \times \hat{\rho}$ But

$|\hat{\omega} \times \hat{\rho}| = 1$ [$\hat{\omega}$ orthogonal to $\hat{\rho}$]

Even better, $\hat{\omega} \times \hat{\rho} = \hat{v}$



We have $v = (r \sin\varphi)\,\omega$ and only need to obtain the direction:



Note: $\vec{\omega} \times \vec{r} = \omega \hat{\omega} \times (r_\omega \hat{\omega} + r_\rho \hat{\rho})$

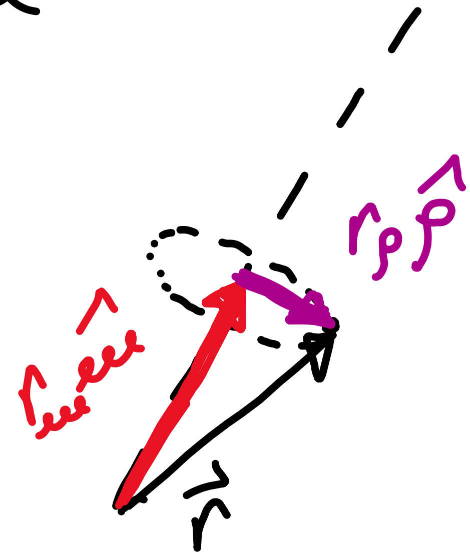
But $\hat{\omega} \times \hat{\omega} = 0$ so

$\vec{\omega} \times \vec{r} = \omega r_\rho \hat{\omega} \times \hat{\rho}$ But

$|\hat{\omega} \times \hat{\rho}| = 1$ [$\hat{\omega}$ orthogonal to $\hat{\rho}$]

Even better, $\hat{\omega} \times \hat{\rho} = \hat{v}$ [$\vec{v}$ orthogonal to $\hat{\omega}$ & $\hat{\rho}$ & points the correct way]

We have $v = (r\sin\varphi)\omega$ and only need to obtain the direction:



<u>Note</u>: $\vec{\omega}\times\vec{r} = \omega\hat{\omega}\times(r_\omega\hat{\omega} + r_\rho\hat{\rho})$

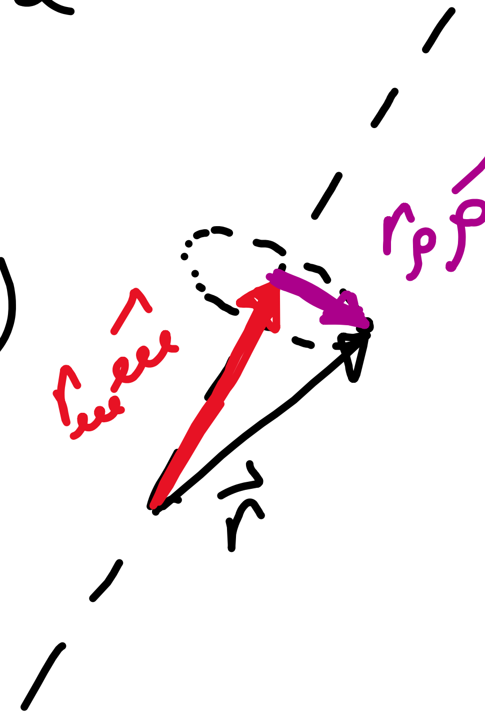
But $\hat{\omega}\times\hat{\omega} = \vec{0}$ so

$\vec{\omega}\times\vec{r} = \omega r_\rho\,\hat{\omega}\times\hat{\rho}$ But

$|\hat{\omega}\times\hat{\rho}| = 1$ [$\hat{\omega}$ orthogonal to $\hat{\rho}$]

Even better, $\hat{\omega}\times\hat{\rho} = \hat{v}$ [$\vec{v}$ orthogonal to $\hat{\omega}$ & $\hat{\rho}$ & points the correct way] so $\vec{\omega}\times\vec{r} = v\hat{v}$

We have $v = (r\sin\varphi)\omega$ and only need to obtain the direction:



<u>Note</u>: $\vec{\omega}\times\vec{r} = \omega\hat{\omega}\times(r_\omega\hat{\omega} + r_\rho\hat{\rho})$

But $\hat{\omega}\times\hat{\omega} = 0$ so

$\vec{\omega}\times\vec{r} = \omega r_\rho\,\hat{\omega}\times\hat{\rho}$ But

$|\hat{\omega}\times\hat{\rho}| = 1$ [$\hat{\omega}$ orthogonal to $\hat{\rho}$]

Even better, $\hat{\omega}\times\hat{\rho} = \hat{v}$ [$\vec{v}$ orthogonal to ω & $\hat{\rho}$ & points the correct way] so $\vec{\omega}\times\vec{r} = v\hat{v}$

$\Rightarrow \quad \vec{v} = \vec{\omega}\times\vec{r}$

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$?

x

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$? Just need to work out the derivitive:

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$? Just need to work out the derivitive:

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}\left[\vec{\omega} \times \vec{r}\right]$$

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$? Just need to work out the derivitive:

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}\left[\vec{\omega} \times \vec{r}\right] = \dot{\vec{\omega}} \times \vec{r} + \vec{\omega} \times \dot{\vec{r}}$$

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$? Just need to work out the derivitive:

$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}\left[\vec{\omega} \times \vec{r}\right] = \dot{\vec{\omega}} \times \vec{r} + \vec{\omega} \times \dot{\vec{r}}$, but

$\dot{\vec{r}} = \vec{v}$

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$? Just need to work out the derivitive:

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}\left[\vec{\omega} \times \vec{r}\right] = \dot{\vec{\omega}} \times \vec{r} + \vec{\omega} \times \dot{\vec{r}}$$

, but $\dot{\vec{r}} = \vec{v}$ & we will define $\vec{\alpha} \equiv \frac{d\vec{\omega}}{dt}$

ASU

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$? Just need to work out the derivitive:

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}\left[\vec{\omega} \times \vec{r}\right] = \dot{\vec{\omega}} \times \vec{r} + \vec{\omega} \times \dot{\vec{r}}, \text{ but}$$

$\dot{\vec{r}} = \vec{v}$ & we will define $\vec{\alpha} \equiv \frac{d\vec{\omega}}{dt}$ so

$$\vec{a} = \vec{\alpha} \times \vec{r} + \vec{\omega} \times \vec{v}$$

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$? Just need to work out the derivitive:

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}\left[\vec{\omega} \times \vec{r}\right] = \dot{\vec{\omega}} \times \vec{r} + \vec{\omega} \times \dot{\vec{r}},$$ but

$\dot{\vec{r}} = \vec{v}$ & we will define $\vec{\alpha} \equiv \frac{d\vec{\omega}}{dt}$ so

$\vec{a} = \vec{\alpha} \times \vec{r} + \vec{\omega} \times \vec{v}$ & since $\vec{v} = \vec{\omega} \times \vec{r}$

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$? Just need to work out the derivitive:

$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}\left[\vec{\omega} \times \vec{r}\right] = \dot{\vec{\omega}} \times \vec{r} + \vec{\omega} \times \dot{\vec{r}}$, but

$\dot{\vec{r}} = \vec{v}$ & we will define $\vec{\alpha} \equiv \frac{d\vec{\omega}}{dt}$ so

$\vec{a} = \vec{\alpha} \times \vec{r} + \vec{\omega} \times \vec{v}$ & since $\vec{v} = \vec{\omega} \times \vec{r}$

then $\vec{a} = \vec{\alpha} \times \vec{r} + \vec{\omega} \times (\vec{\omega} \times \vec{r})$

We have seen that $\vec{v} = \vec{\omega} \times \vec{r}$

What about $\vec{a} = \frac{d\vec{v}}{dt}$? Just need to work out the derivitive:

$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}[\vec{\omega} \times \vec{r}] = \dot{\vec{\omega}} \times \vec{r} + \vec{\omega} \times \dot{\vec{r}}$, but

$\dot{\vec{r}} = \vec{v}$ & we will define $\vec{\alpha} \equiv \frac{d\vec{\omega}}{dt}$ so

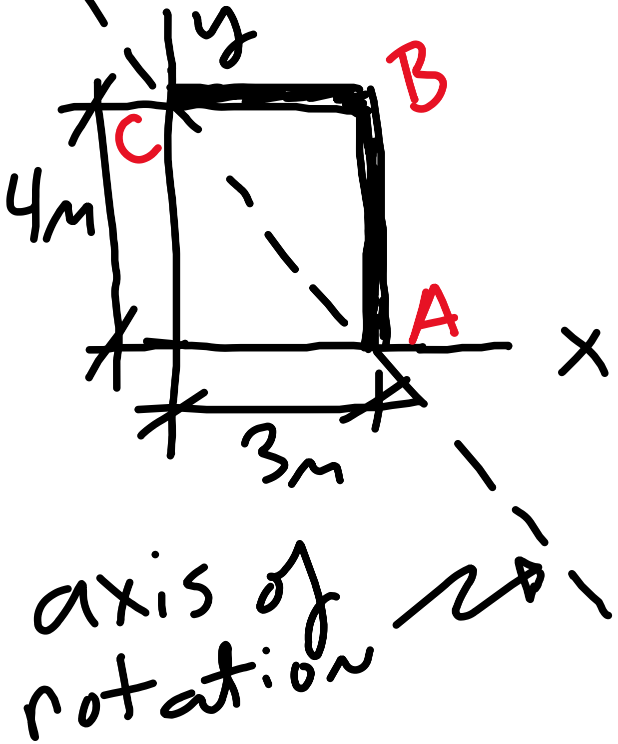
$\vec{a} = \vec{\alpha} \times \vec{r} + \vec{\omega} \times \vec{v}$ & since $\vec{v} = \vec{\omega} \times \vec{r}$

then $\boxed{\vec{a} = \vec{\alpha} \times \vec{r} + \vec{\omega} \times (\vec{\omega} \times \vec{r})}$

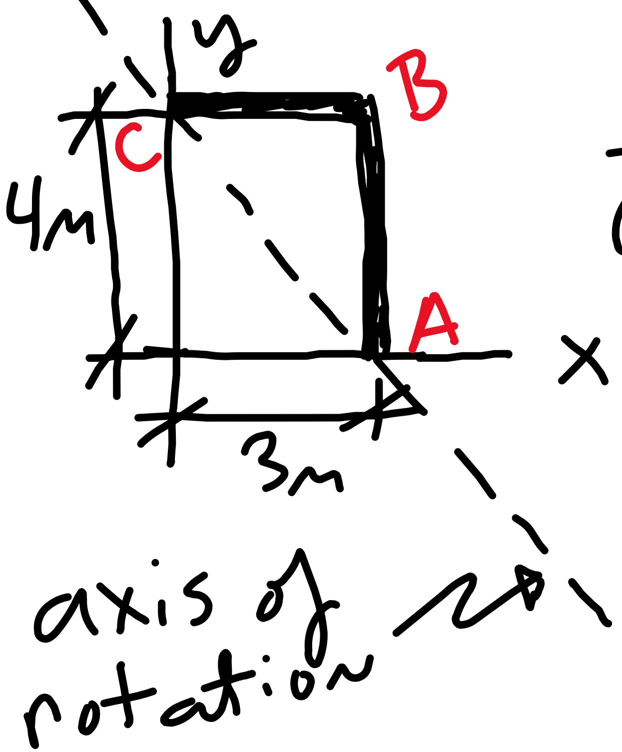
ASU

Example similar to problem 15.10

Example similar to problem 15.10

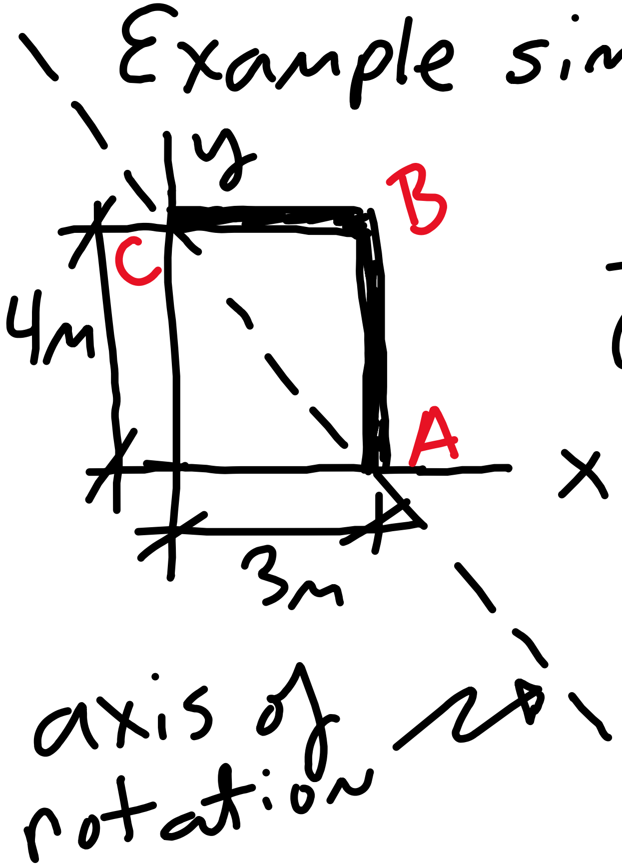


Example similar to problem 15.10



Rotation clockwise as viewed from point A.

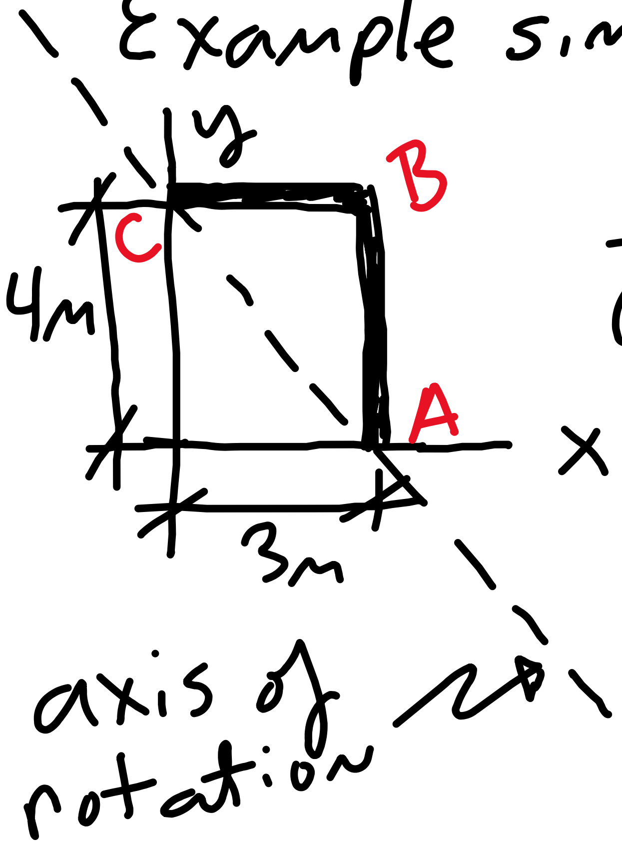
Example similar to problem 15.10



Rotation clockwise as viewed from point A. Find $\vec{v}_B$:

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

Example similar to problem 15.10

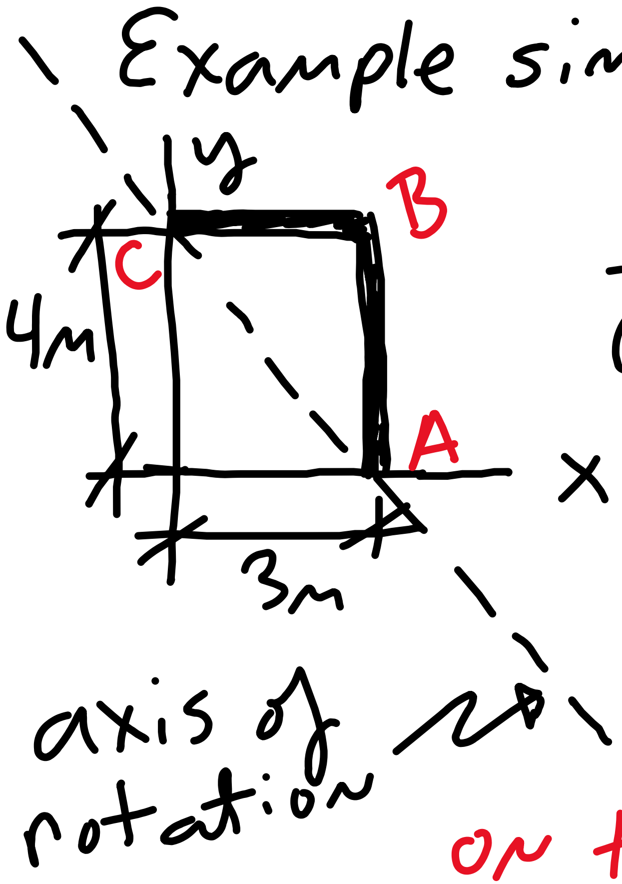


Rotation clockwise as viewed from point A. <u>Find $\vec{v}_B$</u>:

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

Need to determine $\vec{r}$ & $\vec{\omega}$.

Example similar to problem 15.10



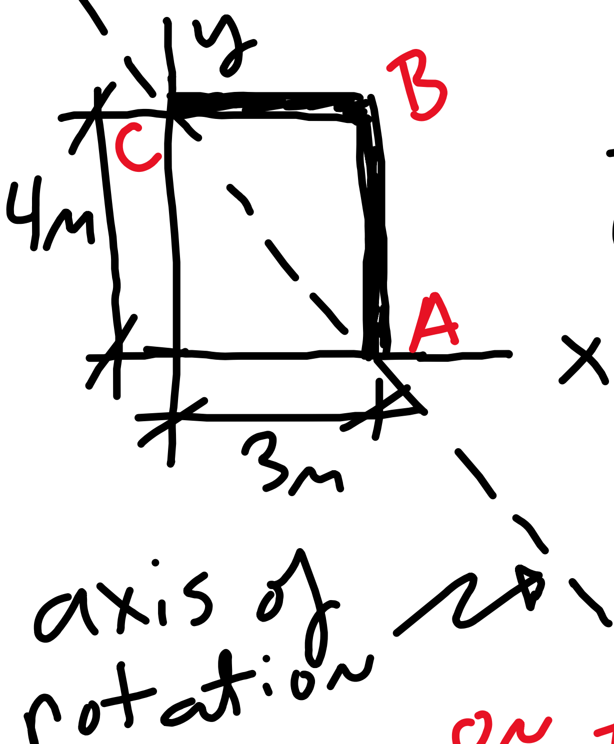
Rotation clockwise as viewed from point A. Find $\vec{v}_B$:

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

Need to determine $\vec{r}$ & $\vec{\omega}$.

$\vec{r}$ must start somewhere on the axis of rotation

Example similar to problem 15.10



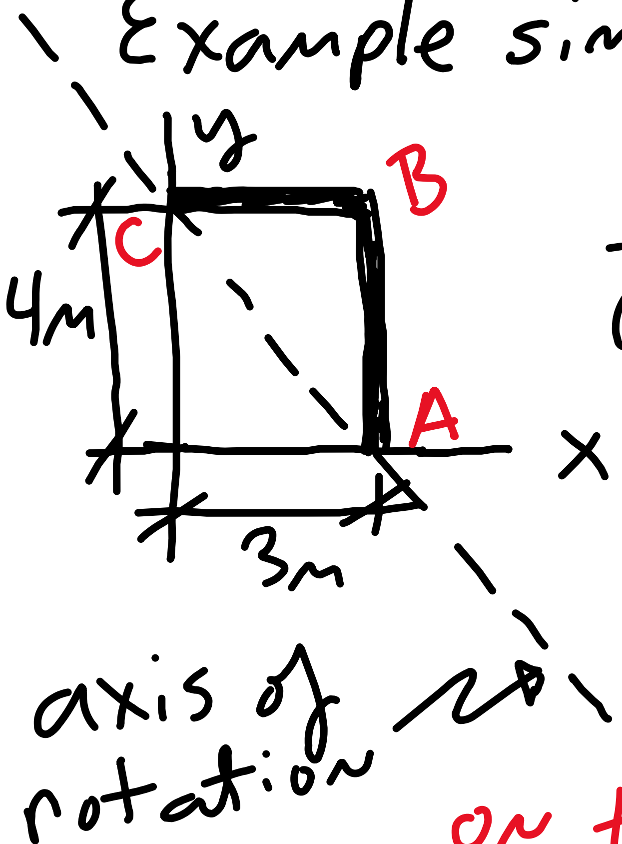
Rotation clockwise as viewed from point A. <u>Find $\vec{v}_B$</u>:

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

Need to determine $\vec{r}$ & $\vec{\omega}$.

$\vec{r}$ <u>must</u> start somewhere on the axis of rotation & end at point B.

Example similar to problem 15.10



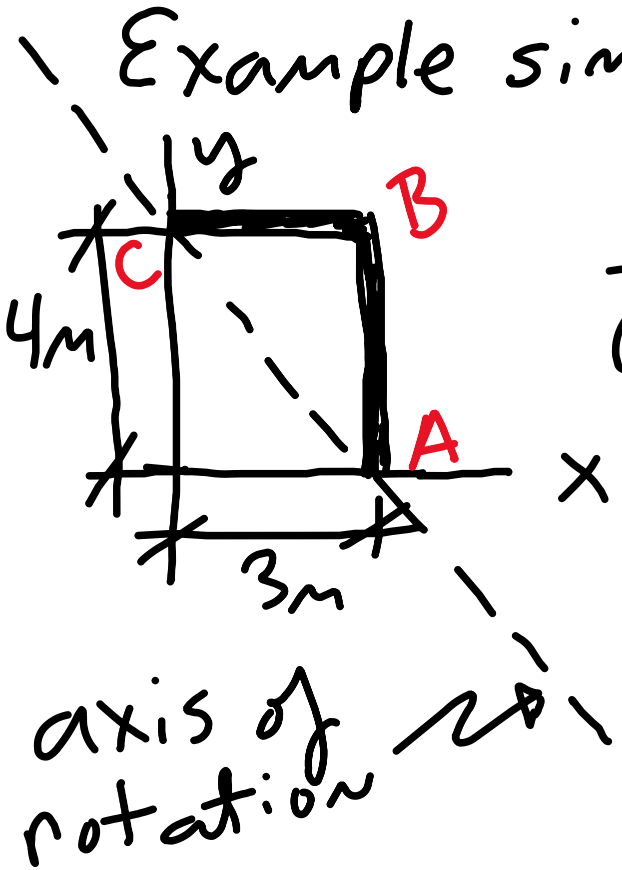
Rotation clockwise as viewed from point A. <u>Find $\vec{v}_B$</u>:

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

Need to determine $\vec{r}$ & $\vec{\omega}$.

$\vec{r}$ <u>must</u> start somewhere on the axis of rotation & end at point B. $\vec{\omega}$ must point along direction from point A to C.

Example similar to problem 15.10

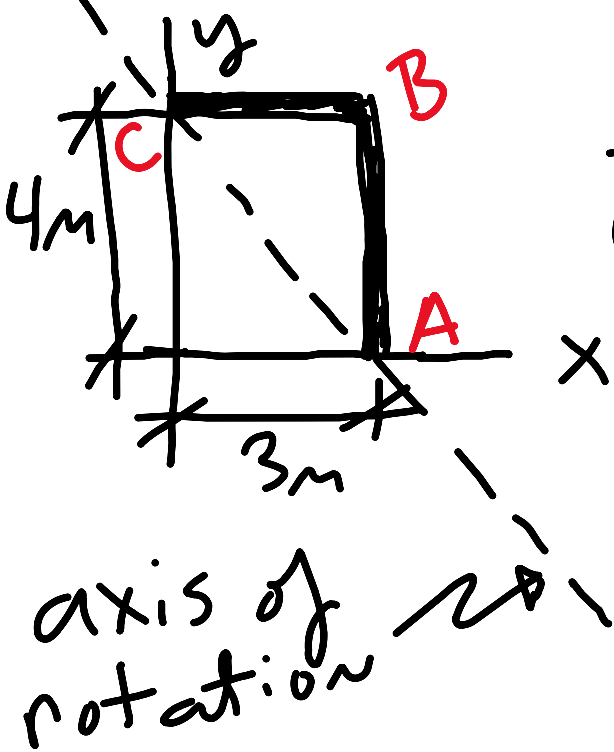


Rotation clockwise as viewed from point A. **Find $\vec{v}_B$:**

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

ω-direction:

Example similar to problem 15.10

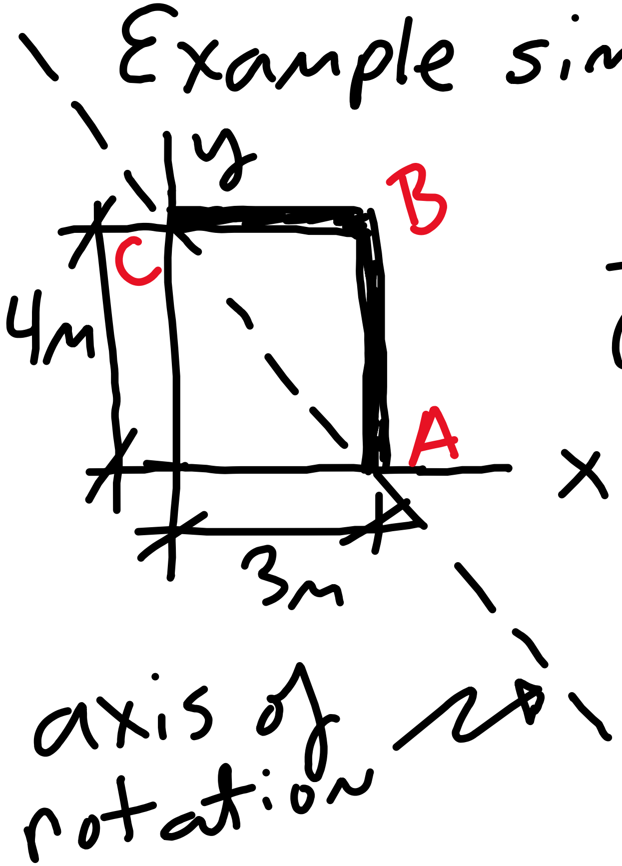


Rotation clockwise as viewed from point A. **Find $\vec{v}_B$:**

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

ω-direction: $\hat{\omega} = \frac{\vec{r}_{c/A}}{|\vec{r}_{c/A}|}$

Example similar to problem 15.10



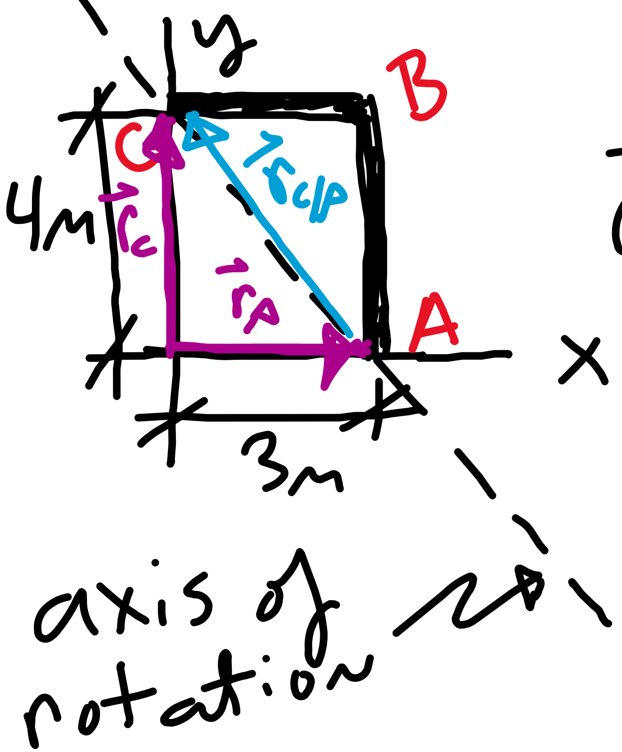
Rotation clockwise as viewed from point A. <u>Find $\vec{v}_B$:</u>

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

ω-direction: $\hat{\omega} = \frac{\vec{r}_{C/A}}{|\vec{r}_{C/A}|}$, with

$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A$

Example similar to problem 15.10



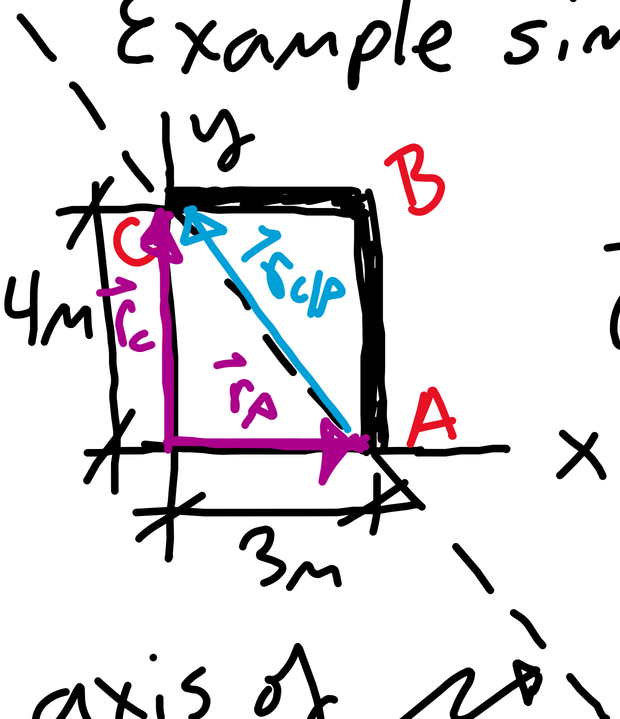
Rotation clockwise as viewed from point A. **Find $\vec{v}_B$:**

$$\vec{v}_B = \vec{\omega} \times \vec{r}, \text{ with } \omega = 1\,\frac{rad}{s}$$

ω-direction: $\hat{\omega} = \dfrac{\vec{r}_{C/A}}{|\vec{r}_{C/A}|}$, with

$$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A = 4m\,\hat{y} - 3m\,\hat{x}$$

Example similar to problem 15.10



axis of rotation

Rotation clockwise as viewed from point A. Find $\vec{v}_B$:

$$\vec{v}_B = \vec{\omega} \times \vec{r}, \text{ with } \omega = 1\,\frac{rad}{s}$$

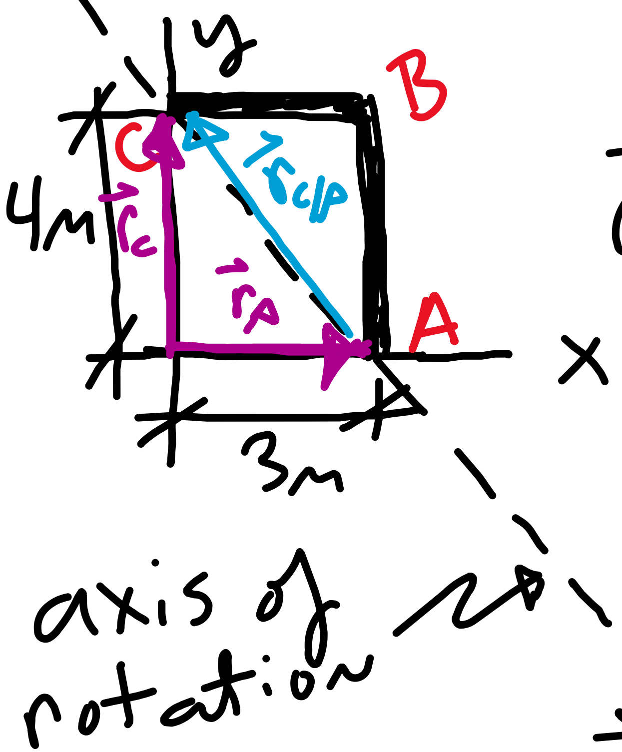
ω-direction: $\hat{\omega} = \dfrac{\vec{r}_{C/A}}{|\vec{r}_{C/A}|}$, with

$$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A = 4m\,\hat{y} - 3m\,\hat{x}$$

$$\Rightarrow |\vec{r}_{C/A}| = 5m$$

ASU

Example similar to problem 15.10



Rotation clockwise as viewed from point A. **Find $\vec{v}_B$:**

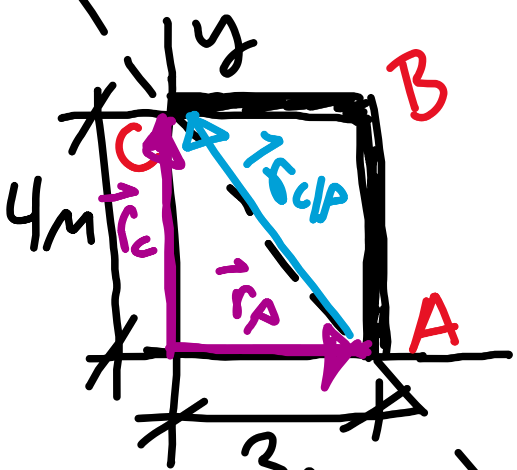
$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1\,\frac{rad}{s}$

ω-direction: $\hat{\omega} = \frac{\vec{r}_{C/A}}{|\vec{r}_{C/A}|}$, with

$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A = 4m\,\hat{y} - 3m\,\hat{x}$

$\Rightarrow |\vec{r}_{C/A}| = 5m$ Now $\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$

Example similar to problem 15.10



Rotation clockwise as viewed from point A. **Find $\vec{v}_B$:**

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1\,\frac{rad}{s}$

ω-direction: $\hat{\omega} = \frac{\vec{r}_{C/A}}{|\vec{r}_{C/A}|}$, with

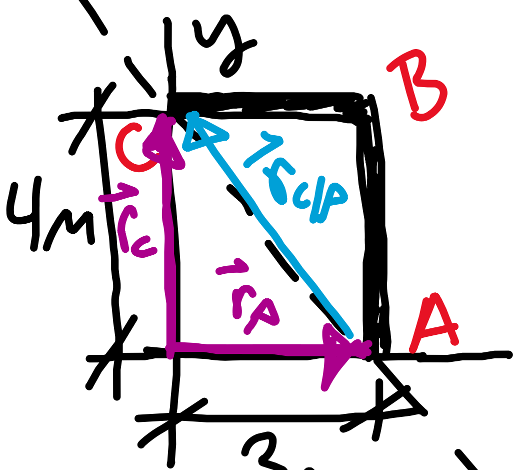
axis of rotation

$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A = 4m\,\hat{y} - 3m\,\hat{x}$

$\Rightarrow |\vec{r}_{C/A}| = 5m$ Now $\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$

$\vec{r}$ vector:

Example similar to problem 15.10



axis of rotation

Rotation clockwise as viewed from point A. **Find $\vec{v}_B$:**

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1\,\frac{rad}{s}$

ω-direction: $\hat{\omega} = \frac{\vec{r}_{C/A}}{|\vec{r}_{C/A}|}$, with

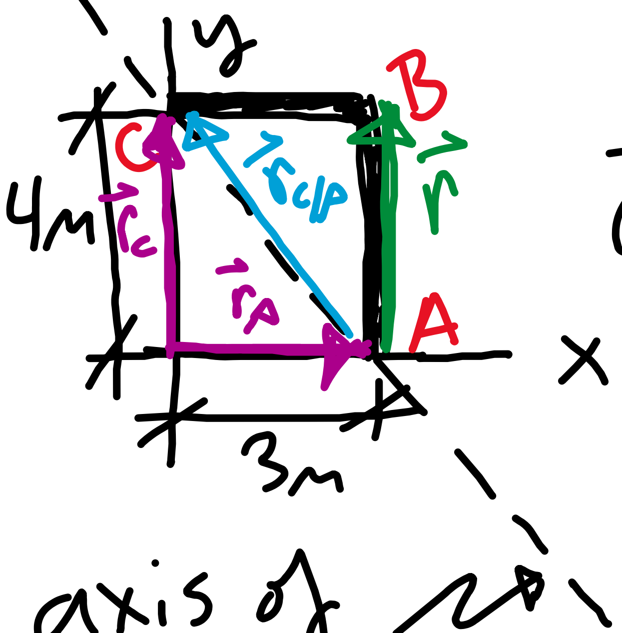
$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A = 4m\,\hat{y} - 3m\,\hat{x}$

$\Rightarrow |\vec{r}_{C/A}| = 5m$ Now $\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$

$\vec{r}$ vector: might as well start at point A

ASU

Example similar to problem 15.10



Rotation clockwise as viewed from point A. **Find $\vec{v}_B$:**

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

ω-direction: $\hat{\omega} = \dfrac{\vec{r}_{C/A}}{|\vec{r}_{C/A}|}$, with

axis of rotation

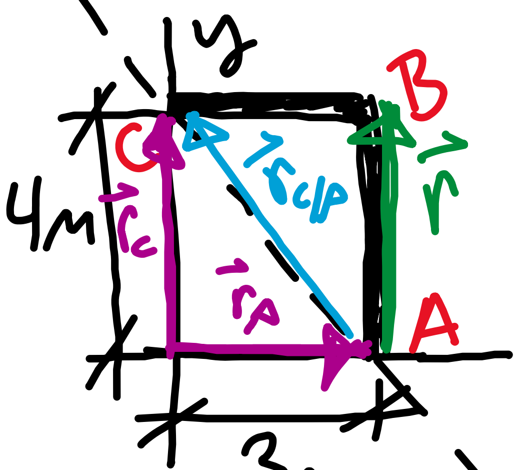
$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A = 4m\,\hat{y} - 3m\,\hat{x}$

$\Rightarrow |\vec{r}_{C/A}| = 5m$ Now $\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$

$\vec{r}$ vector: might as well start at point A

$\vec{r} = \vec{r}_{B/A}$

Example similar to problem 15.10



Rotation clockwise as viewed from point A. Find $\vec{v}_B$:

$\times$ $\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1\,\frac{rad}{s}$

ω-direction: $\hat{\omega} = \frac{\vec{r}_{C/A}}{|\vec{r}_{C/A}|}$, with

axis of rotation

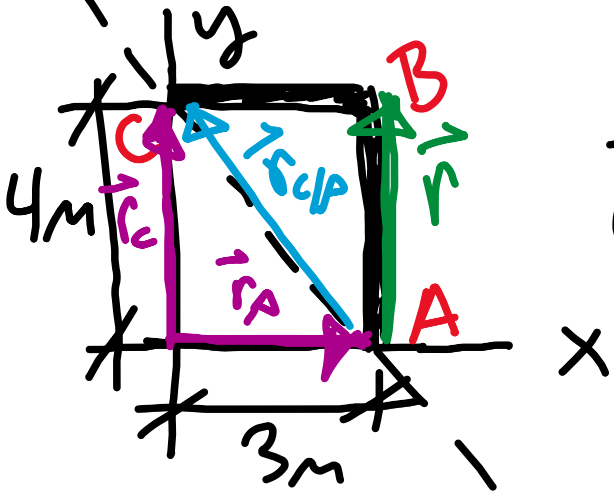
$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A = 4m\,\hat{y} - 3m\,\hat{x}$

$\Rightarrow |\vec{r}_{C/A}| = 5m$ Now $\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$

$\vec{r}$ vector: might as well start at point A

$\vec{r} = \vec{r}_{B/A} = \vec{r}_B - \vec{r}_A$

Example similar to problem 15.10



Rotation clockwise as viewed from point A. **Find $\vec{V}_B$:**

$$\vec{V}_B = \vec{\omega} \times \vec{r}, \text{ with } \omega = 1\,\frac{\text{rad}}{\text{s}}$$

ω-Direction: $\hat{\omega} = \dfrac{\vec{r}_{c/A}}{|\vec{r}_{c/A}|}$, with

axis of rotation

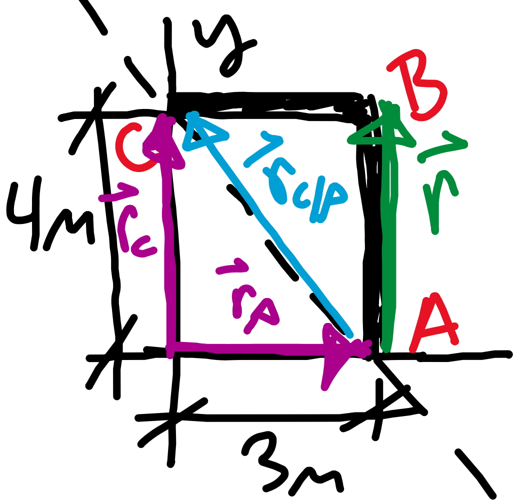
$$\vec{r}_{c/A} = \vec{r}_c - \vec{r}_A = 4m\,\hat{y} - 3m\,\hat{x}$$

$\Rightarrow |\vec{r}_{c/A}| = 5m$ Now $\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$

$\vec{r}$ vector: might as well start at point A

$$\vec{r} = \vec{r}_{B/A} = \vec{r}_B - \vec{r}_A = (3m\,\hat{x} + 4m\,\hat{y}) - 3m\,\hat{x}$$

Example similar to problem 15.10



Rotation clockwise as viewed from point A. **Find $\vec{V}_B$:**

$\vec{V}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1\,\frac{rad}{s}$

ω-direction: $\hat{\omega} = \frac{\vec{r}_{C/A}}{|\vec{r}_{C/A}|}$, with

axis of rotation

$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A = 4m\,\hat{y} - 3m\,\hat{x}$

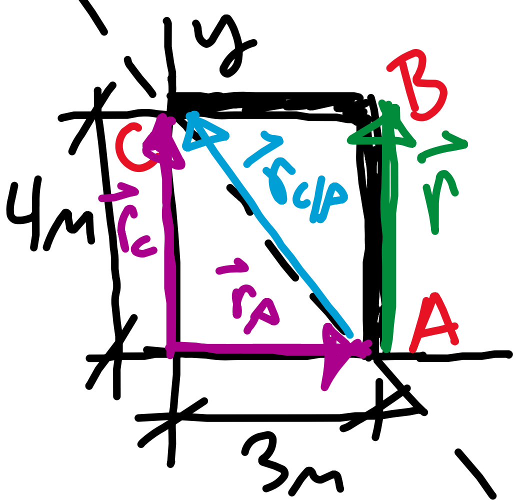
$\Rightarrow |\vec{r}_{C/A}| = 5m$ Now $\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$

$\vec{r}$ vector: might as well start at point A

$\vec{r} = \vec{r}_{B/A} = \vec{r}_B - \vec{r}_A = (3m\,\hat{x} + 4m\,\hat{y}) - 3m\,\hat{x} = 4m\,\hat{y}$

ASU

Example similar to problem 15.10



axis of rotation

Rotation clockwise as viewed from point A. <u>Find $\vec{v}_B$</u>:

$\vec{v}_B = \vec{\omega} \times \vec{r}$, with $\omega = 1 \frac{rad}{s}$

ω-direction: $\hat{\omega} = \frac{\vec{r}_{c/A}}{|\vec{r}_{c/A}|}$, with

$\vec{r}_{c/A} = \vec{r}_c - \vec{r}_A = 4m\hat{y} - 3m\hat{x}$

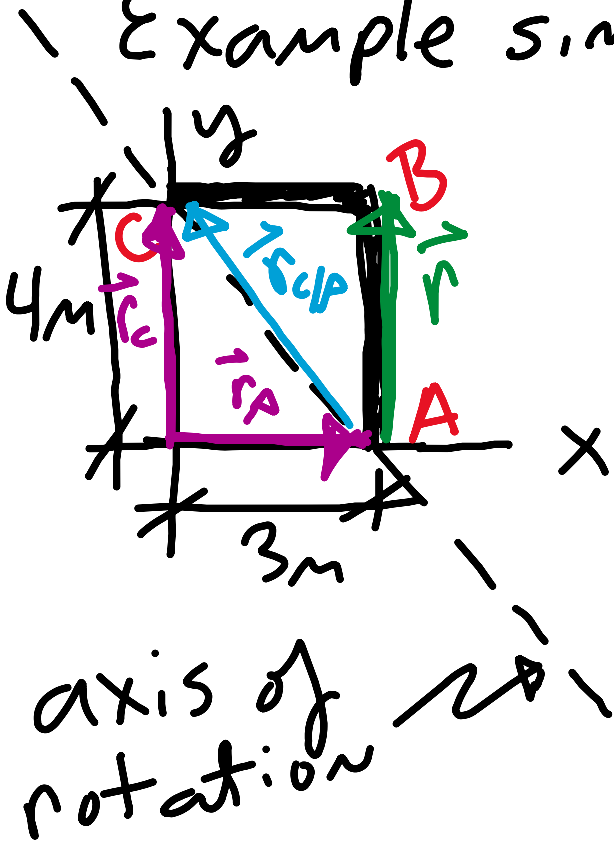
$\Rightarrow |\vec{r}_{c/A}| = 5m$ Now $\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$

$\vec{r}$ vector: might as well start at point A

$\vec{r} = \vec{r}_{B/A} = \vec{r}_B - \vec{r}_A = (3m\hat{x} + 4m\hat{y}) - 3m\hat{x} = 4m\hat{y}$

Could have just read off of diagram

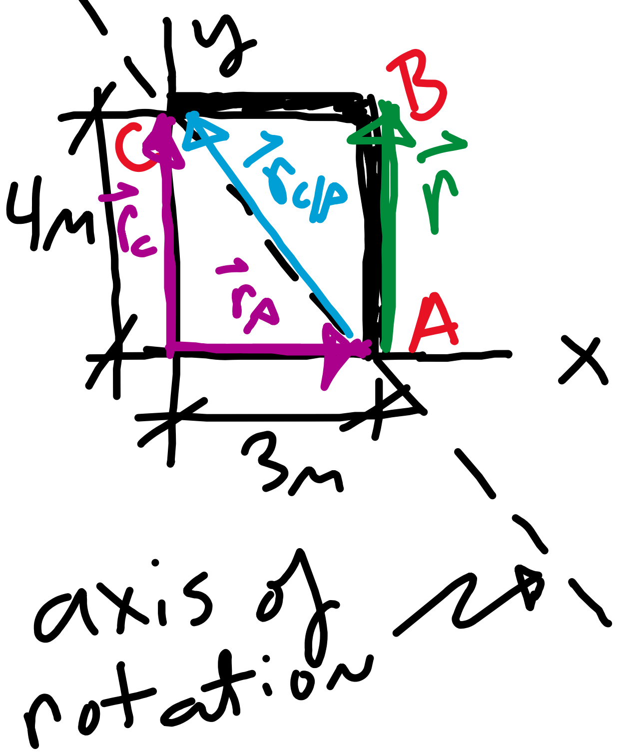
Example similar to problem 15.10



Now we have

$$\hat{e} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$$

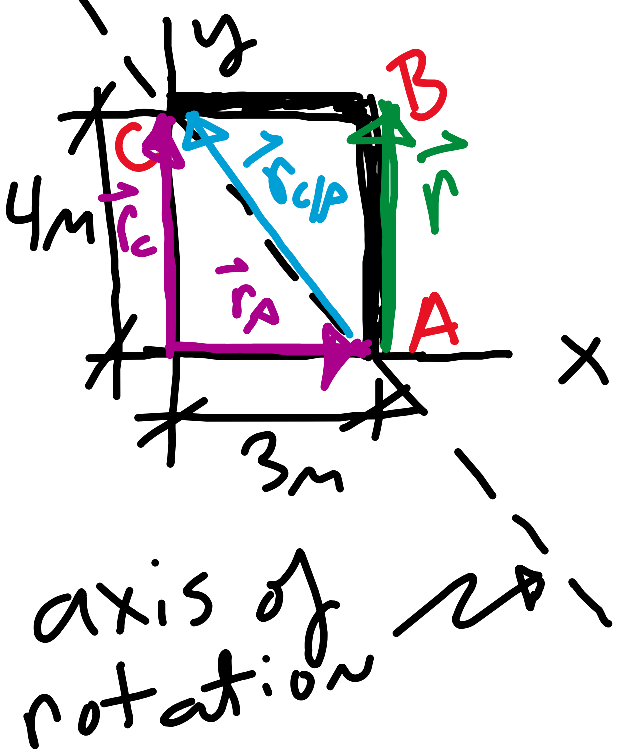
Example similar to problem 15.10



Now we have

$\hat{e}_l = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$ & $\vec{r} = 4m\,\hat{y}$

Example similar to problem 15.10



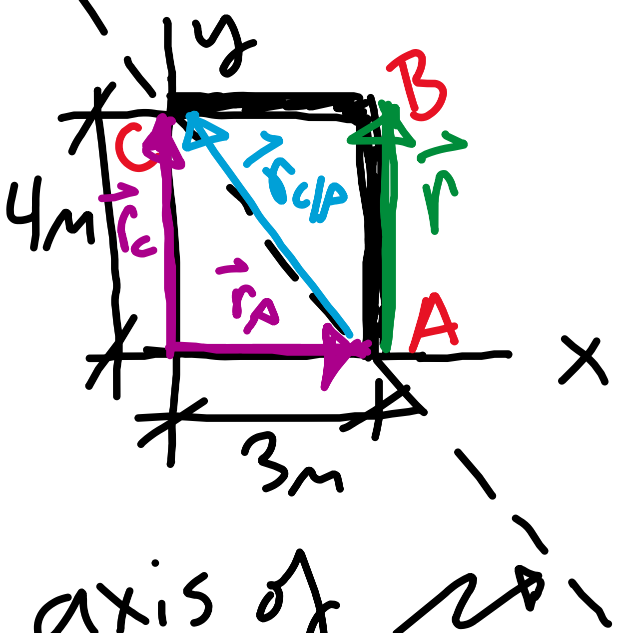
Now we have

$\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$ & $\vec{r} = 4m\hat{y}$

So

$\vec{V}_B = \vec{\omega} \times \vec{r} = \left[\left(\frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}\right)\omega\right] \times 4m\hat{y}$

Example similar to problem 15.10



axis of rotation

Now we have

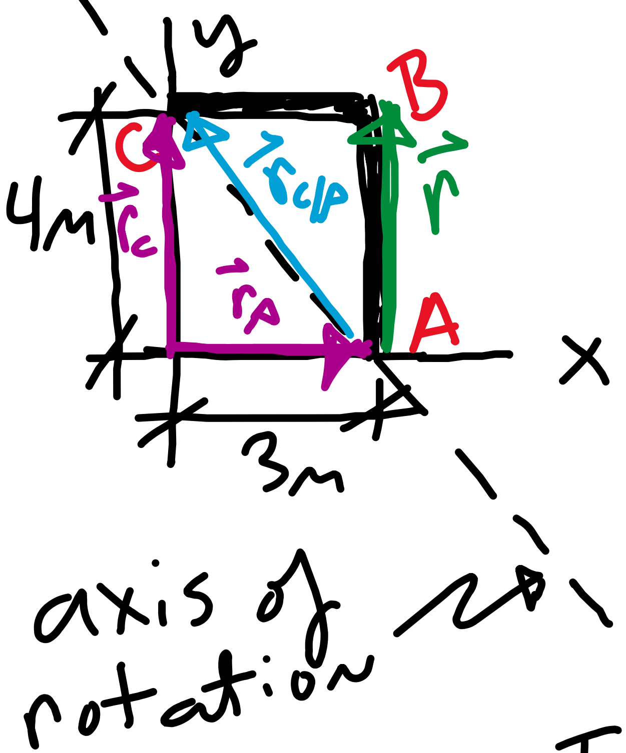
$\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}$ & $\vec{r} = 4m\hat{y}$

So

$\vec{V}_B = \vec{\omega} \times \vec{r} = \left[\left(\frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}\right)\omega\right] \times 4m\hat{y}$

$$\vec{V}_B = -\left(\frac{12}{5}\right)\frac{m}{s}\hat{z}$$

Example similar to problem 15.10



Now we have

$$\hat{\omega} = \frac{4}{5}\hat{y} - \frac{3}{5}\hat{x} \quad \& \quad \vec{r} = 4m\hat{y}$$

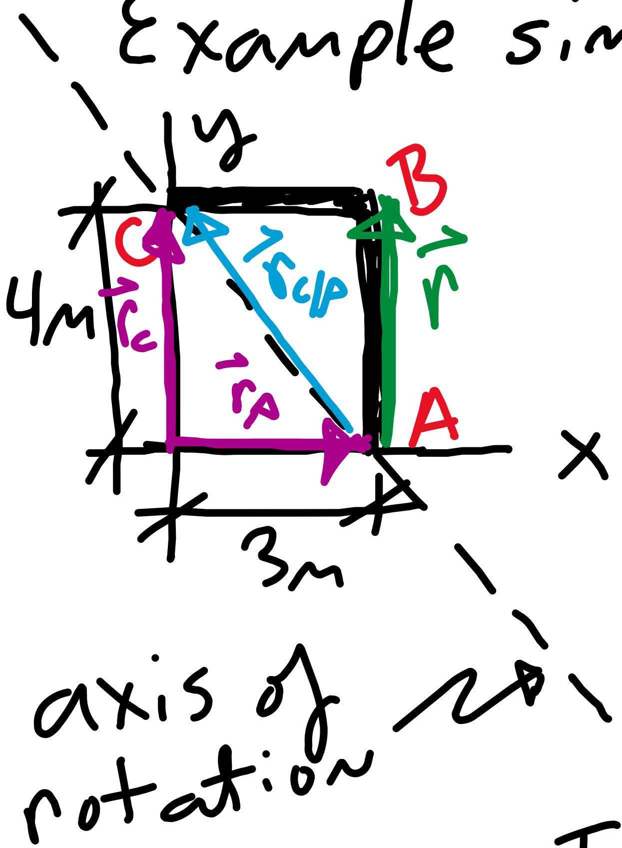
So

$$\vec{V}_B = \vec{\omega} \times \vec{r} = \left[\left(\frac{4}{5}\hat{y} - \frac{3}{5}\hat{x}\right)\omega\right] \times 4m\hat{y}$$

$$\vec{V}_B = -\left(\frac{12}{5}\right)\frac{m}{s}\hat{z}$$

To find $\vec{a}_B$

Example similar to problem 15.10



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To find $\vec{a}_B = \vec{\alpha} \times \vec{r} + \vec{\omega} \times (\vec{\omega} \times \vec{r})$

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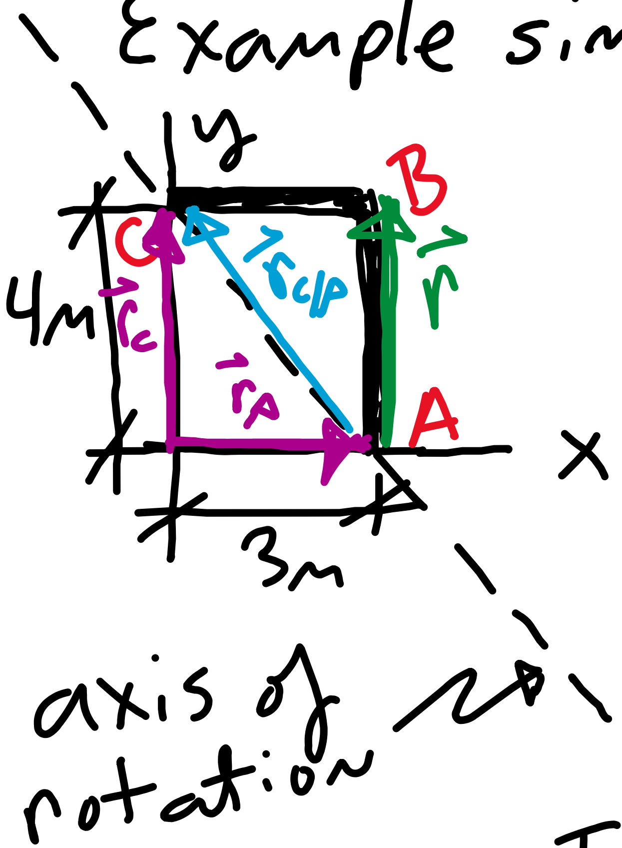

Now we have

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Just notice that $\vec{\alpha} = 0$

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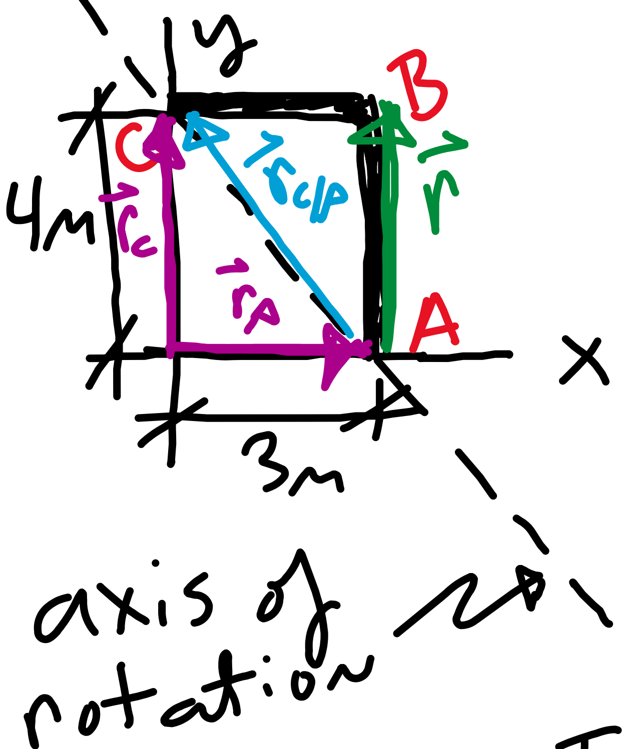

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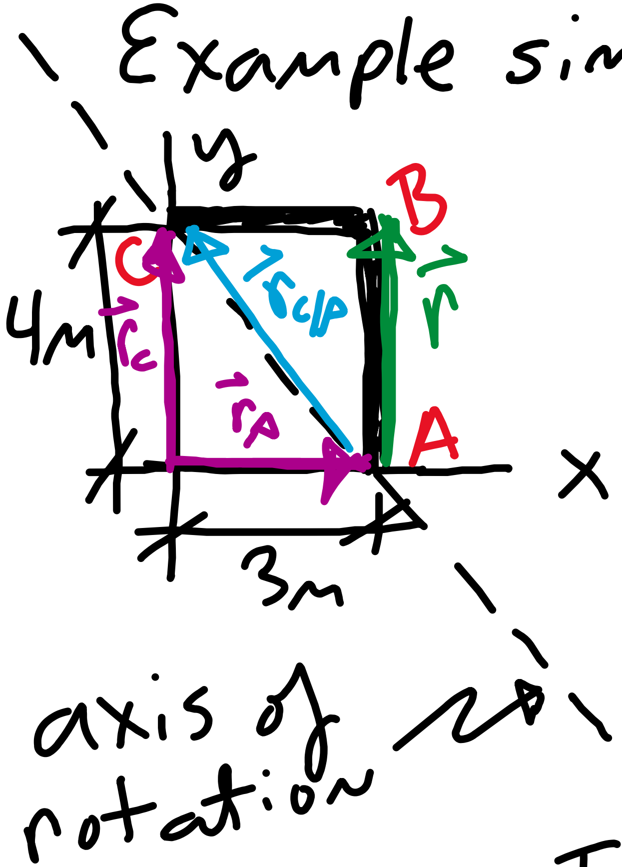

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$\Rightarrow \quad \vec{a}_B = \vec{\omega} \times \vec{V}_B$

Angular Kinematics

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Just as $v = \frac{dx}{dt}$ & $a = \frac{dv}{dt}$

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ASU

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just replace $x \to \theta$

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just replace $x \to \theta$, $v \to \omega$,

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so $\frac{\text{rev}}{2\pi} = 1$

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so $\frac{\text{rev}}{2\pi} = 1$ & $\frac{\text{rev}}{360°} = 1$

ASU

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just replace $x \to \theta$, $v \to \omega$, $a \to \alpha$

Note: $1\text{ rev} = 360° = 2\pi\text{ rad}$

so $\frac{\text{rev}}{2\pi} = 1$ & $\frac{\text{rev}}{360°} = 1$

& $\frac{2\pi\text{ rad}}{360°} = 1$