Today 14.2

$\boxed{L11}$

Today $\underbrace{14.2}$

$\boxed{L11}$

work &

energy

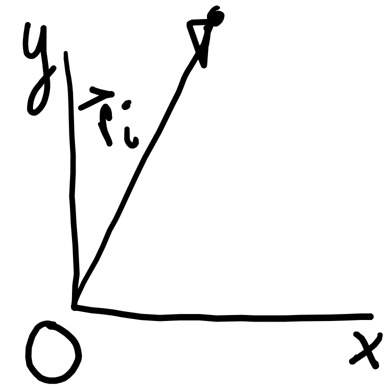
Today 14.2

Tuesday Review

$\boxed{L11}$

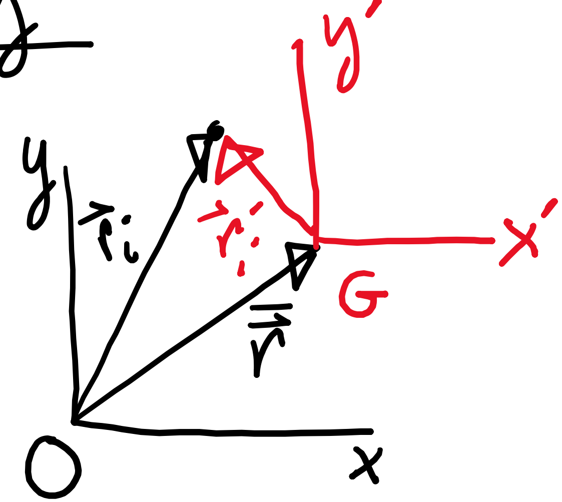
Kinetic energy

$$T = \frac{1}{2}\sum_i m_i v_i^2$$



Kinetic energy

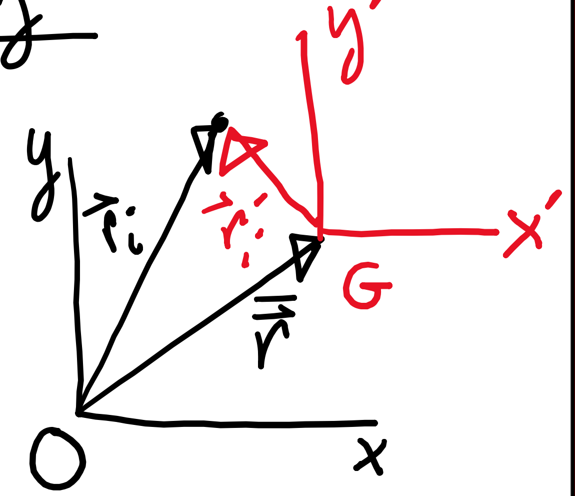
$T = \frac{1}{2}\sum_i m_i v_i^2$ But $\vec{r}_i = \bar{\vec{r}} + \vec{r}_i{}'$



Kinetic energy

$$T = \frac{1}{2}\sum_i m_i v_i^2 \qquad \text{But} \qquad \vec{r}_i = \vec{\bar{r}} + \vec{r}_i{}'$$

$$\Rightarrow \vec{v}_i = \vec{\bar{V}} + \vec{v}_i{}'$$



Kinetic energy

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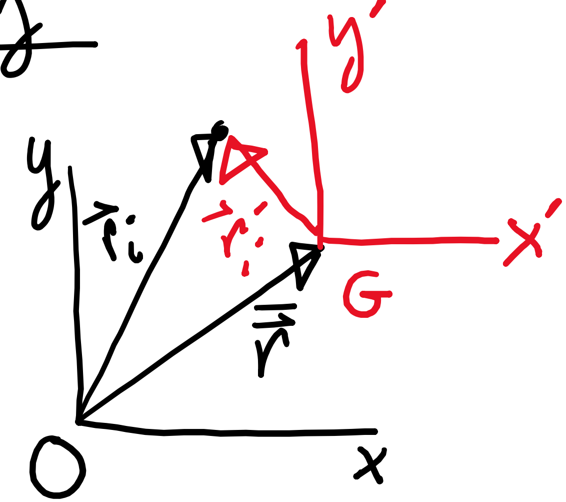

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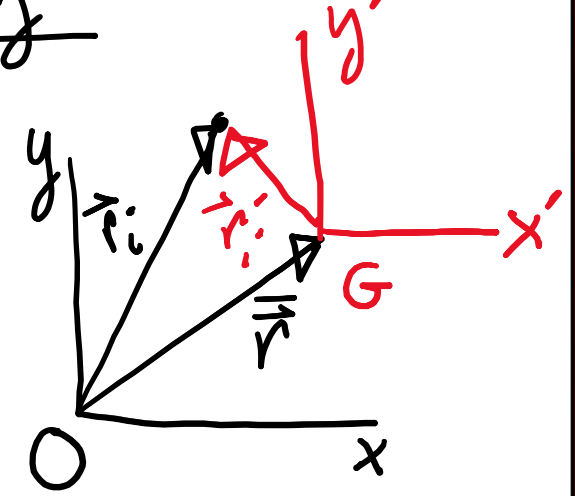
$= \vec{v}_i \cdot \vec{v}_i$



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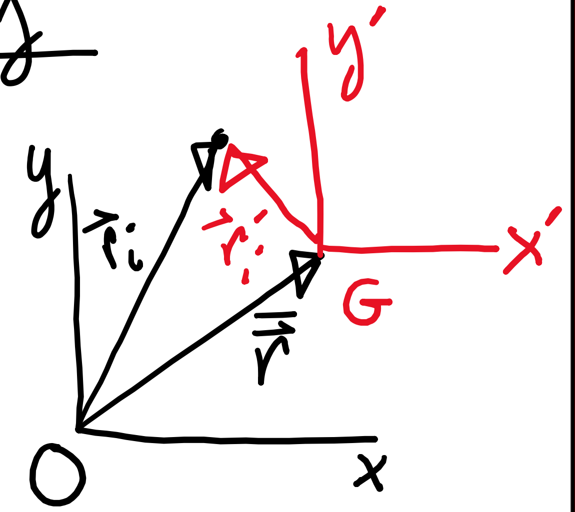

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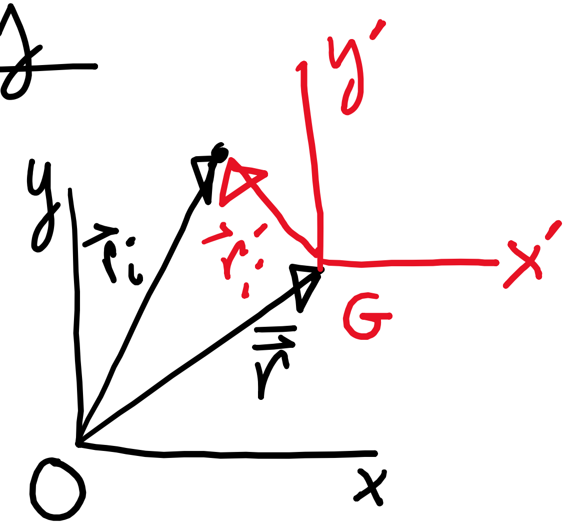
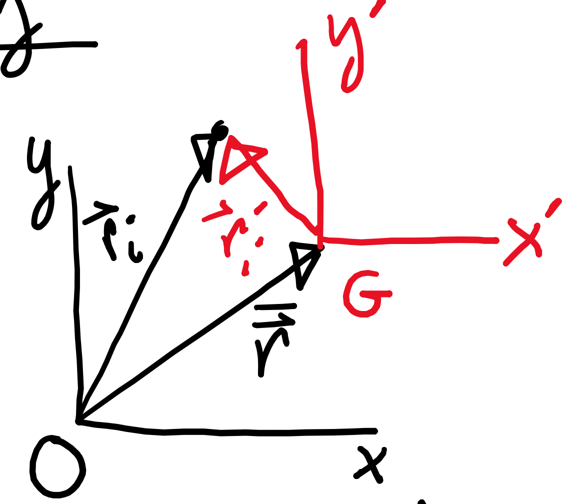


Kinetic energy

$T = \frac{1}{2}\sum_i m_i v_i^2$ But $\vec{r}_i = \vec{\bar{r}} + \vec{r}_i\,'$



$\Rightarrow \vec{v}_i = \vec{\bar{V}} + \vec{v}_i\,'$ Also $v_i^2 = |\vec{v}_i|^2$

$= \vec{v}_i \cdot \vec{v}_i = (\vec{\bar{V}} + \vec{v}_i\,') \cdot (\vec{\bar{V}} + \vec{v}_i\,')$

$= |\vec{\bar{V}}|^2 + |\vec{v}_i\,'|^2 + 2\vec{\bar{V}} \cdot \vec{v}_i\,'$ This means that

$$T = \frac{1}{2}\bar{V}^2 \sum_i m_i + \frac{1}{2}\sum_i m_i (v_i\,')^2 + \vec{\bar{V}} \cdot \left(\sum_i m_i \vec{v}_i\,'\right)$$

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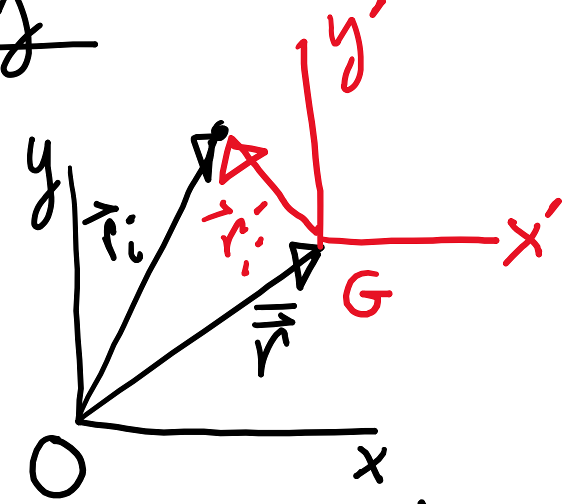

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Kinetic energy

$T = \frac{1}{2}\sum_i m_i v_i^2$ But $\vec{r}_i = \vec{\bar{r}} + \vec{r}_i^{\,\prime}$

$\Rightarrow \vec{v}_i = \vec{\bar{V}} + \vec{v}_i^{\,\prime}$ Also $v_i^2 = |\vec{v}_i|^2$

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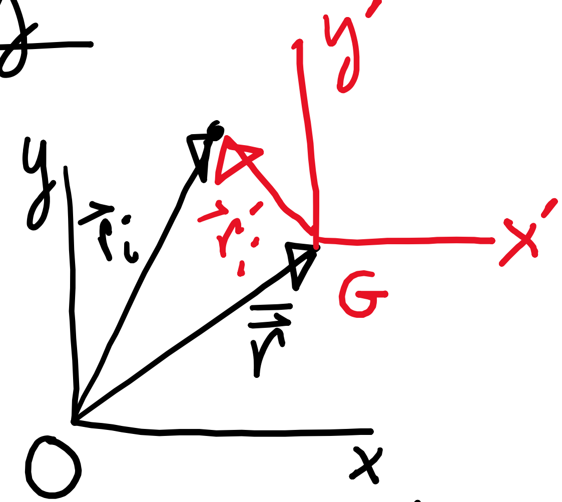
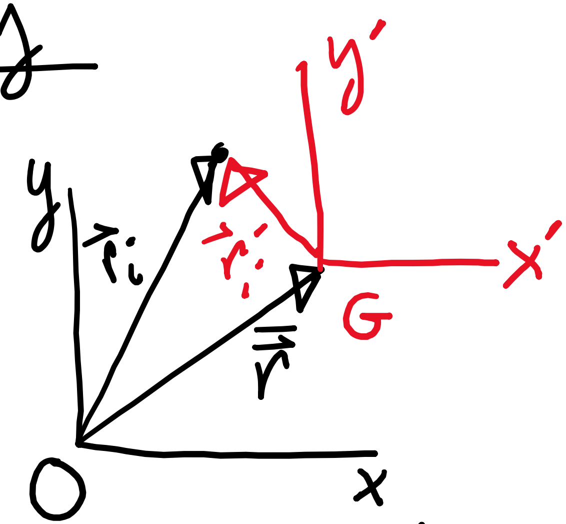


$T = \frac{1}{2}\bar{V}^2 \sum_i m_i + \frac{1}{2}\sum_i m_i (v_i^{\prime})^2 + \vec{\bar{V}} \cdot \left(\sum_i m_i \vec{v}_i^{\,\prime}\right)$ Note: $\sum_i m_i = M$

& $\sum_i m_i \vec{v}_i^{\,\prime} = \vec{L}_G = \emptyset$ → Linear momentum in CM frame

So $T = \frac{1}{2} M \bar{V}^2 + \frac{1}{2}\sum_i m_i (\vec{v}_i^{\,\prime})^2$

Kinetic energy



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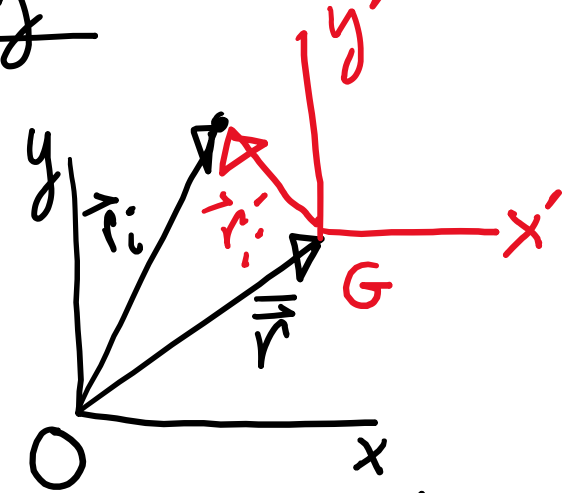
& $\sum_i m_i \vec{v}_i' = \vec{L}_G = 0$ → Linear momentum in CM frame

So $T = \frac{1}{2} M \bar{v}^2 + \frac{1}{2}\sum_i m_i (\vec{v}_i')^2$ → K.E. as seen in the CM frame

Kinetic energy

$T = \frac{1}{2}\sum_i m_i v_i^2$ But $\vec{r}_i = \vec{\bar{r}} + \vec{r}_i\,'$



$\Rightarrow \vec{v}_i = \vec{\bar{v}} + \vec{v}_i\,'$ Also $v_i^2 = |\vec{v}_i|^2$

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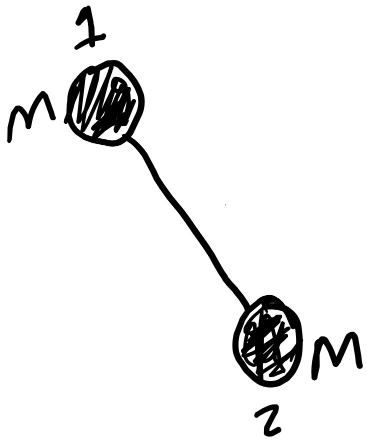
& $\sum_i m_i \vec{v}_i\,' = \vec{L}_G = \theta$ → Linear momentum in CM frame

So $T = \underbrace{\frac{1}{2} M \bar{v}^2}_{\text{K.E. for single particle of mass } M = \sum_i m_i \text{ with velocity of CM frame } \vec{\bar{v}}} + \underbrace{\frac{1}{2}\sum_i m_i (\vec{v}_i\,')^2}_{\text{K.E. as seen in the CM frame}}$

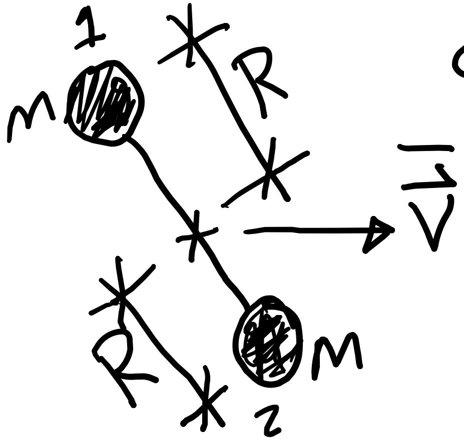
→ K.E. as seen in the CM frame

→ K.E. for single particle of mass $M = \sum_i m_i$ with velocity of CM frame $\vec{\bar{v}}$

Example: Two equal masses held together by a massless string.



Example: Two equal masses held together by a massless string. For this case, the center of mass is at the mid-point along the string & is moving with velocity $\vec{V}$



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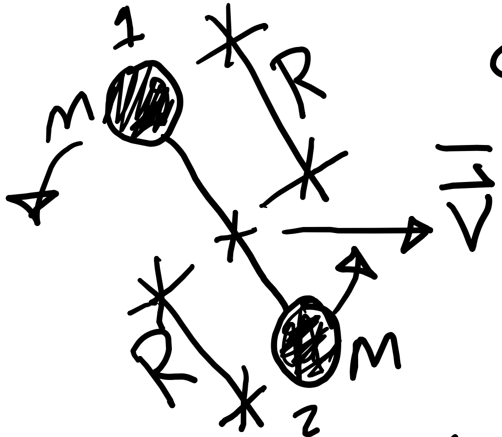
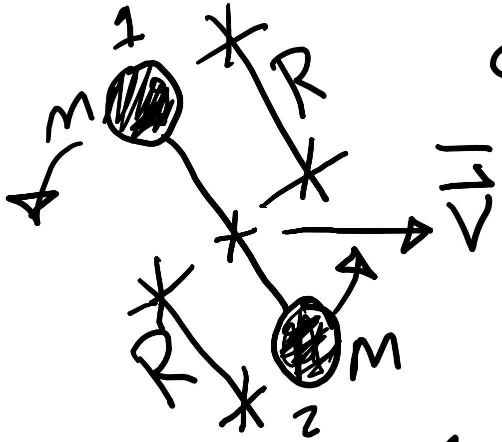


Example: Two equal masses held together by a massless string. For this case, the center of mass is at the mid-point along the string & is moving with velocity $\vec{V}$. Given that the masses revolve about center of mass with angular speed $\dot{\theta}$, find an expression for the kinetic energy T:



$v_1' = v_2' = R\dot{\theta}$

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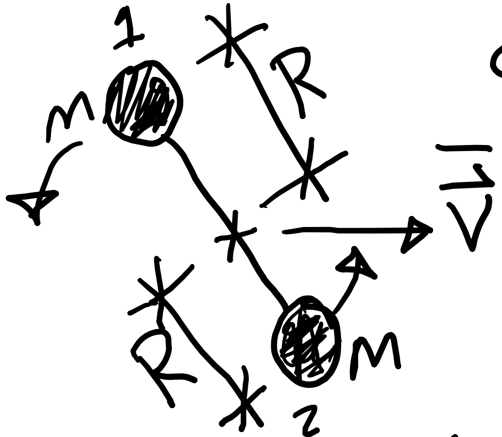

center of mass is at the mid-point along the string & is moving with velocity $\bar{\vec{V}}$. Given that the masses revolve about center of mass with angular speed $\dot{\Theta}$, find an expression for the kinetic energy T:

$$V_1' = V_2' = R\dot{\Theta} \Rightarrow T = \frac{1}{2}M\bar{V}^2 + \frac{1}{2}m_1R^2\dot{\Theta}^2 + \frac{1}{2}m_2R^2\dot{\Theta}^2$$

But $M = \sum_i m_i = m_1 + m_2$ & $m_1 = m_2 = m$

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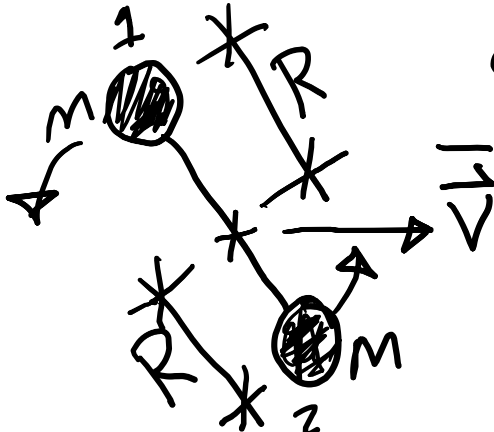

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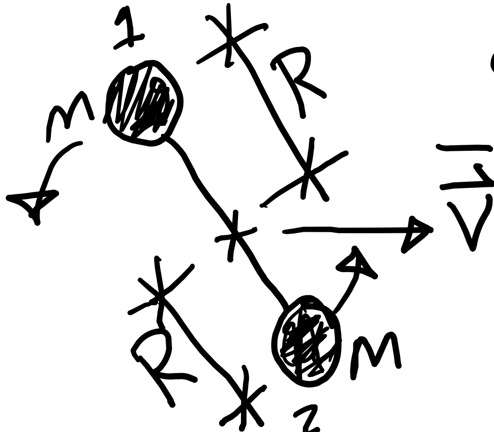

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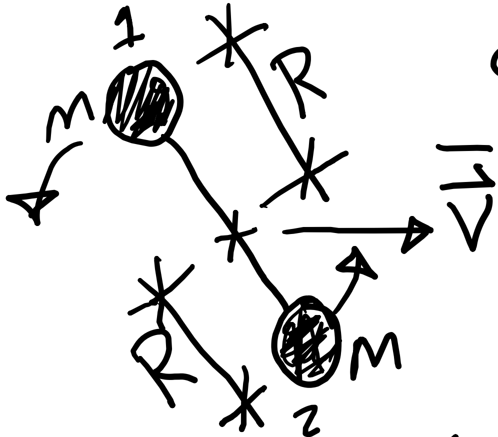

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But $M = \sum_i m_i = m_1 + m_2$ & $m_1 = m_2 = m$ so

$$T = \frac{1}{2}M\bar{V}^2 + \frac{1}{2}MR^2\dot{\theta}^2.$$ Now find $\vec{L}$ & $\vec{H}_G$ $\rightarrow$

The evaluation of $\vec{L}$ & $\vec{H}_G'$ are straight-forward

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$\vec{L} = m\bar{\vec{v}}$ & $\vec{H}_G' = [m_1 R v_1' + m_2 R v_2'] \circlearrowleft = mR^2\dot{\theta} \circlearrowleft$

The evaluation of $\vec{L}$ & $\vec{H}_G'$ are straight-forward

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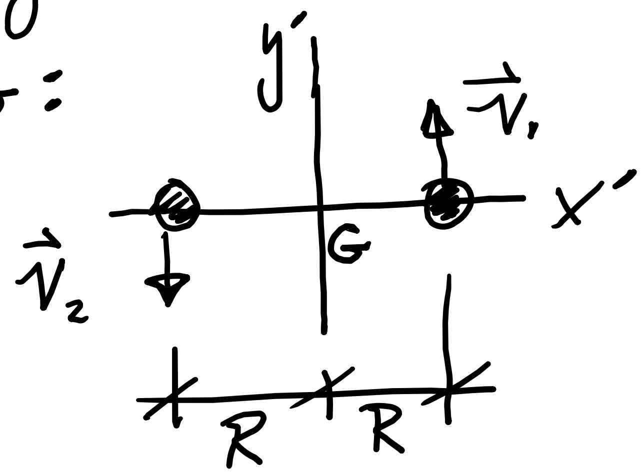
Now string breaks such that in C.M. Frame G:



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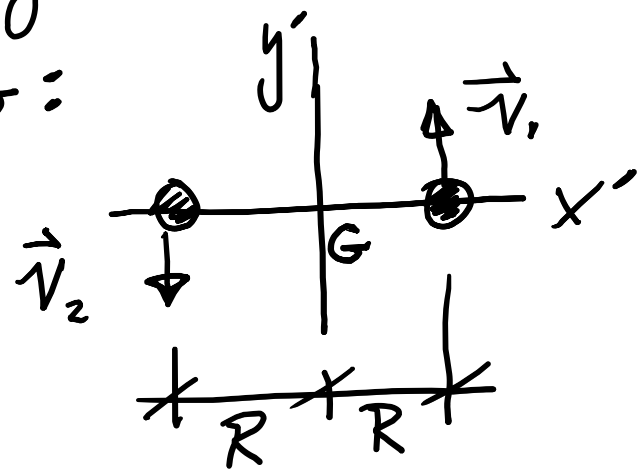

Find $\vec{H}_G'$:

The evaluation of $\vec{L}$ & $\vec{H}_G'$ are straight-forward

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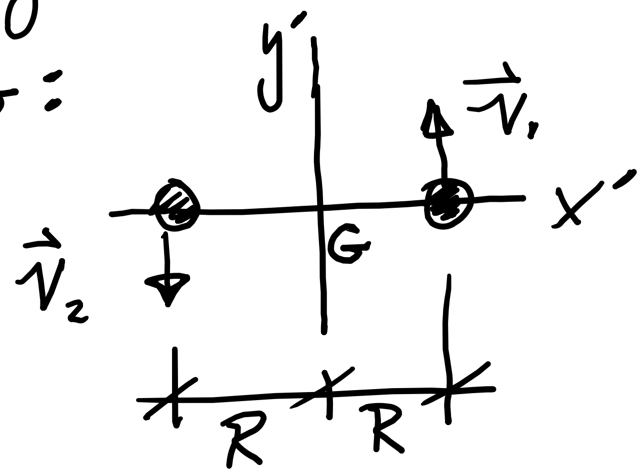

Find $\vec{H}_G'$:

No more spinning but $\vec{H}_G' = \sum_i \vec{r}_i' \times m_i \vec{v}_i'$

The evaluation of $\vec{L}$ & $\vec{H}_G'$ are straight-forward

$$\vec{L} = M\vec{V} \quad \& \quad \vec{H}_G' = \left[m_1 R v_1' + m_2 R v_2'\right] \circlearrowleft = mR^2\dot{\theta} \circlearrowleft$$

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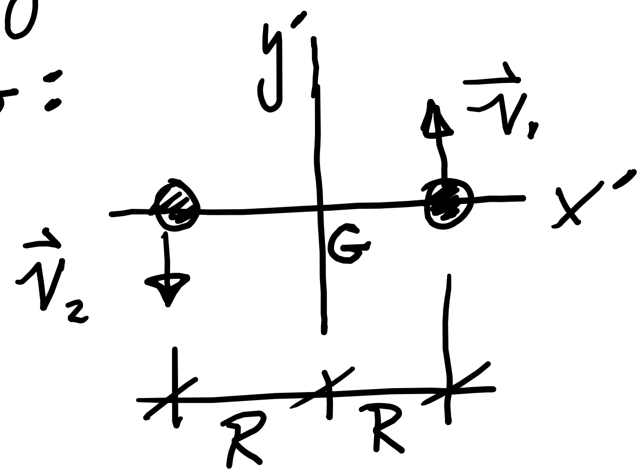

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$$= (R\hat{i}) \times (m_1 v_1' \hat{j}) + (-R\hat{i}) \times (-m_2 v_2 \hat{j})$$

The evaluation of $\vec{L}$ & $\vec{H}_G'$ are straight-forward

$$\vec{L} = m\vec{\bar{v}} \quad \& \quad \vec{H}_G' = [m_1 R v_1' + m_2 R v_2'] \circlearrowleft = mR^2\dot{\theta} \circlearrowleft$$

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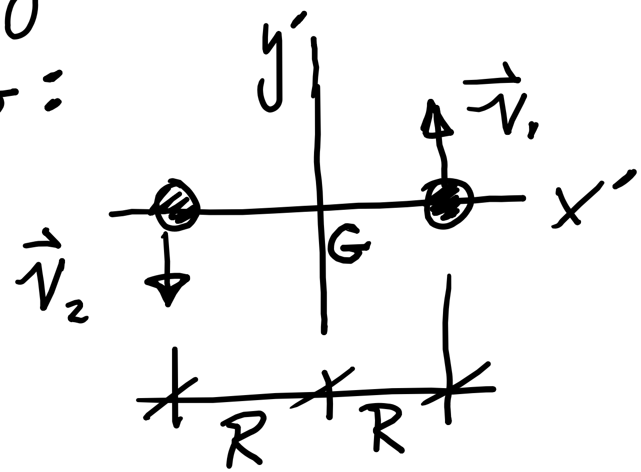

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The evaluation of $\vec{L}$ & $\vec{H}_G'$ are straight-forward

$$\vec{L} = m\vec{v} \quad \& \quad \vec{H}_G' = [m_1 R v_1' + m_2 R v_2'] = mR^2\dot{\theta}$$

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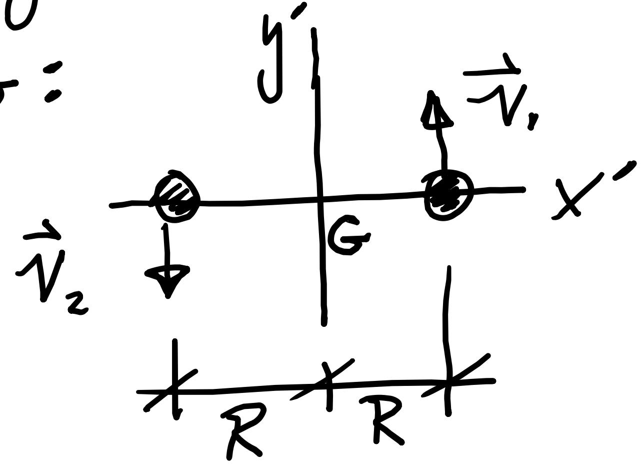

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[as it should]

What if we measured v_i from the Stationary frame?

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$$= \left(\sum_i m_i \vec{r}_i'\right) \times \bar{\vec{v}} + \sum_i m_i \vec{r}_i' \times \vec{v}_i'$$

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$$= \left(\sum_i m_i \vec{r}_i'\right) \times \bar{\vec{v}} + \sum_i m_i \vec{r}_i' \times \vec{v}_i'$$ But $\sum m_i \vec{r}_i' = 0$

$\therefore$ $$\vec{H}_G' = \sum_i m_i \vec{r}_i' \times \vec{v}_i'$$

What if we measured v_i from the stationary frame?*

Since $\vec{v}_i = \bar{\vec{v}} + \vec{v}_i'$ then

$$\vec{H}_G = \sum_i \vec{r}_i' \times m_i \vec{v}_i = \sum_i \vec{r}_i' \times m_i (\bar{\vec{v}} + \vec{v}_i') = \sum_i m_i \vec{r}_i' \times (\bar{\vec{v}} + \vec{v}_i')$$

$$= \Big(\sum_i m_i \vec{r}_i'\Big) \times \bar{\vec{v}} + \sum_i m_i \vec{r}_i' \times \vec{v}_i'$$ But $\sum m_i \vec{r}_i' = 0$

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For $\vec{H}_G$ we can use $\vec{v}_i$ or $\vec{v}_i'$ and obtain the same result ☺

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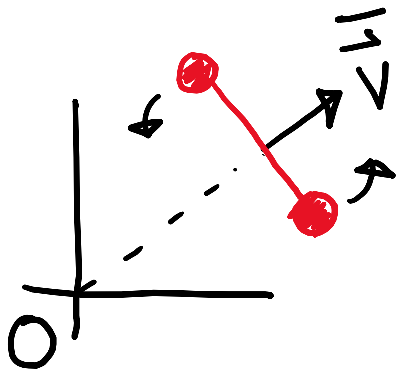

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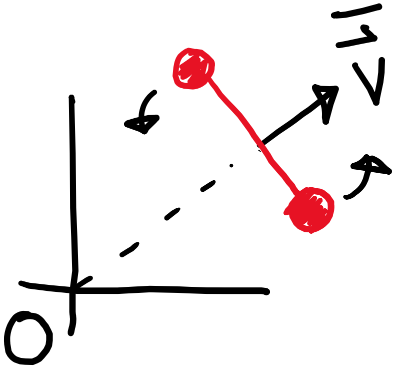

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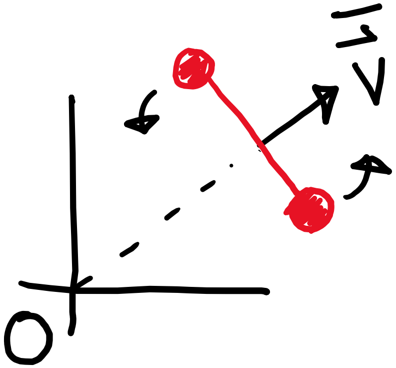

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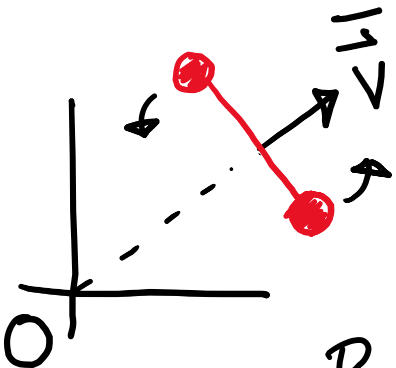

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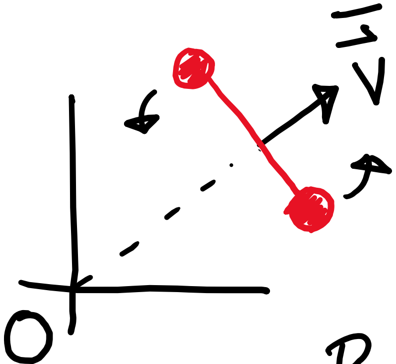

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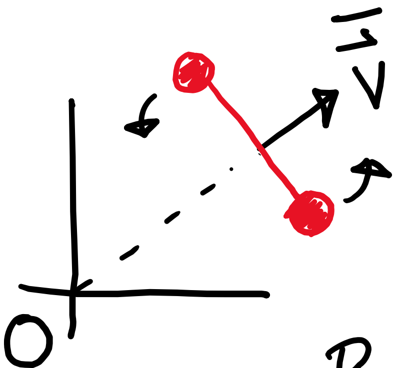

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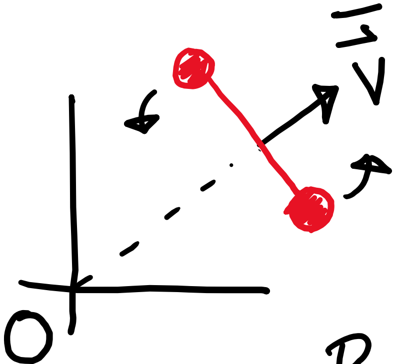

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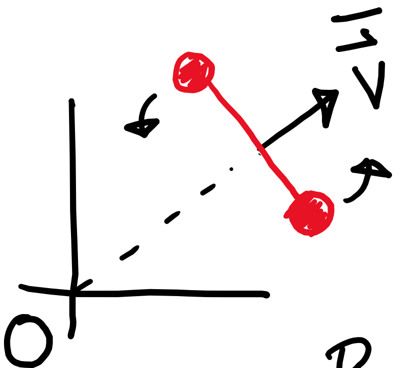

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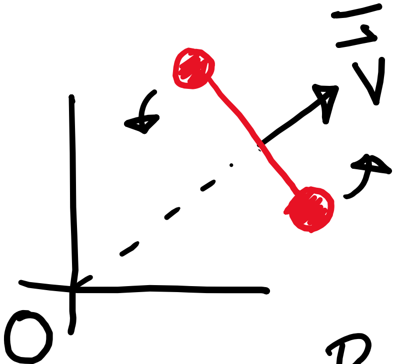

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But $\vec{\bar{r}} \times \vec{\bar{v}} = 0$ since they are in line

$\Rightarrow$ $\vec{H}_O = \vec{H}_G$ (for this special case). If, however, $\vec{\bar{r}} \times \vec{\bar{v}}$ is non-zero, we would have

$$\vec{H}_O = \vec{\bar{r}} \times m \vec{\bar{v}} + \vec{H}_G$$

Work : $T_1 + U_{1\to 2} = T_2$

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Work & Energy : $T_1 + V_1 + U^{NC}_{1\to 2} = T_2 + V_2$

ASU

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Just as one would Naively expect ☺

Mass center

Mass center $m\vec{\bar{r}} = \sum m_i \vec{r}_i$

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we saw that $\Sigma \vec{F} = m\vec{\bar{a}} \Rightarrow$ can treat entire system as a single particle at $\vec{\bar{r}}$ with mass $m = \Sigma m_i$

& if $\Sigma \vec{F} = \vec{0}$ [No ext. forces]

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& if $\sum \vec{F} = \theta$ [No ext. forces]

then $\vec{L}$ is conserved $\Rightarrow \vec{L}_I = \vec{L}_F$

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then $\vec{H}_0$ is conserved

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& if $\sum \vec{F} = \vec{0}$ [No ext. forces]

then $\vec{L}$ is conserved $\Rightarrow \vec{L}_I = \vec{L}_F$

& if $\sum \vec{M}_0 = \vec{0}$ [No ext. torques]

then $\vec{H}_0$ is conserved $\Rightarrow \vec{H}_{0I} = \vec{H}_{0F}$

We also saw that $\sum \vec{M}_G = \dot{\vec{H}}_G$

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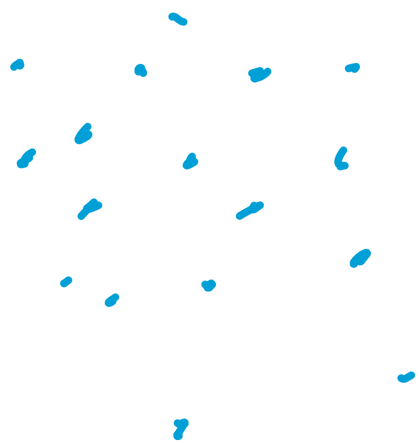

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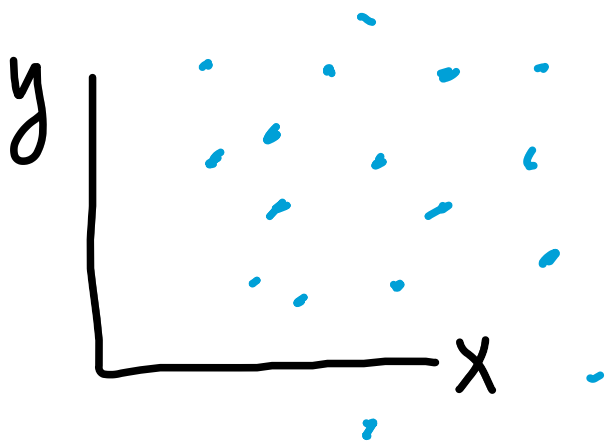

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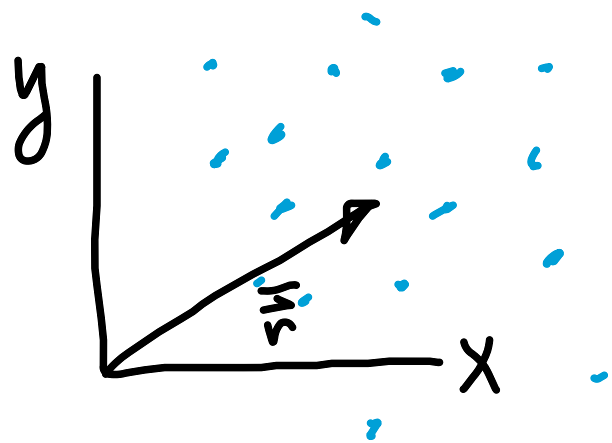

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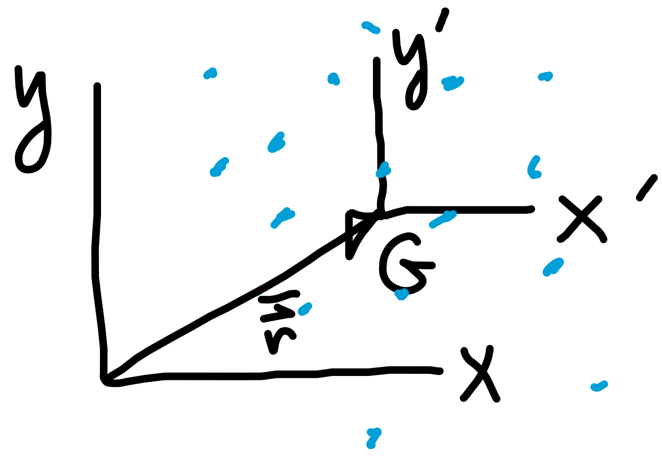

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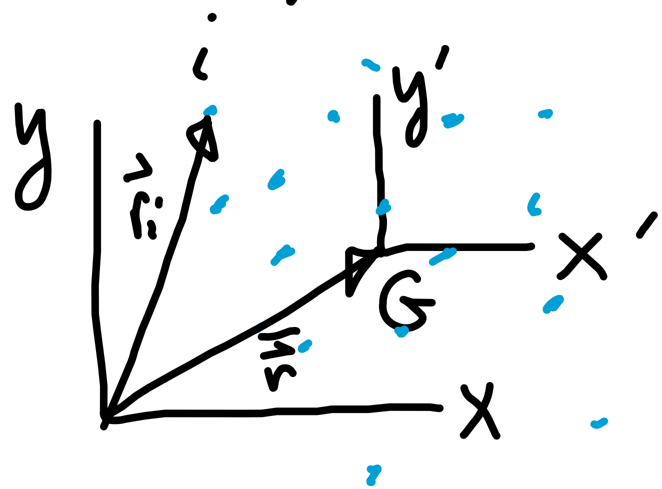

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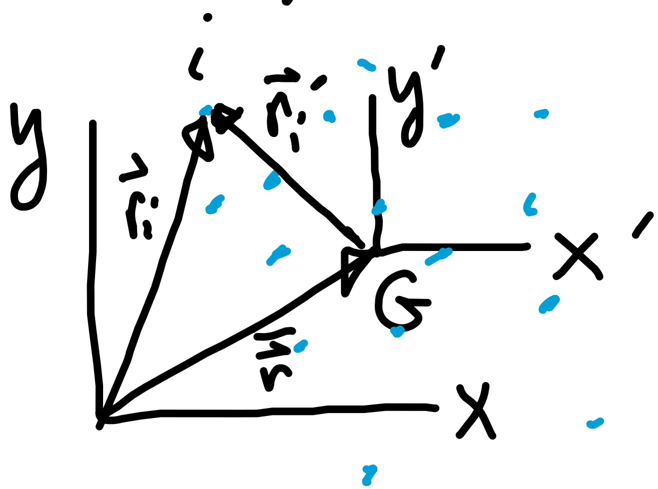

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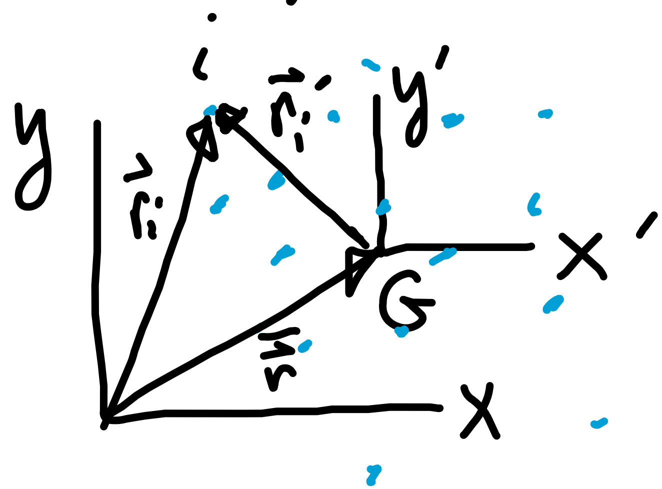

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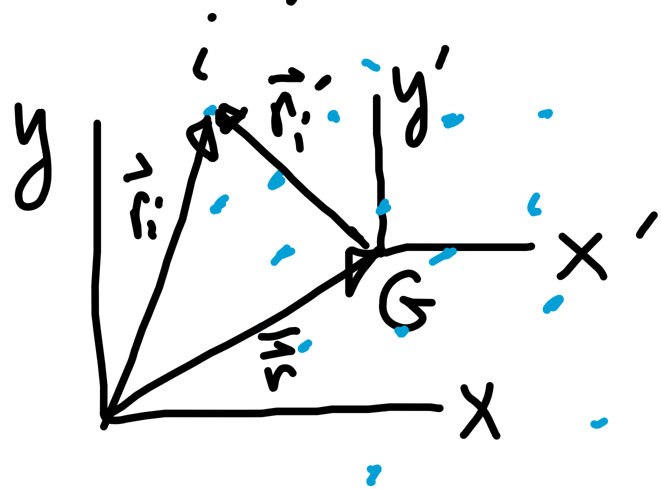

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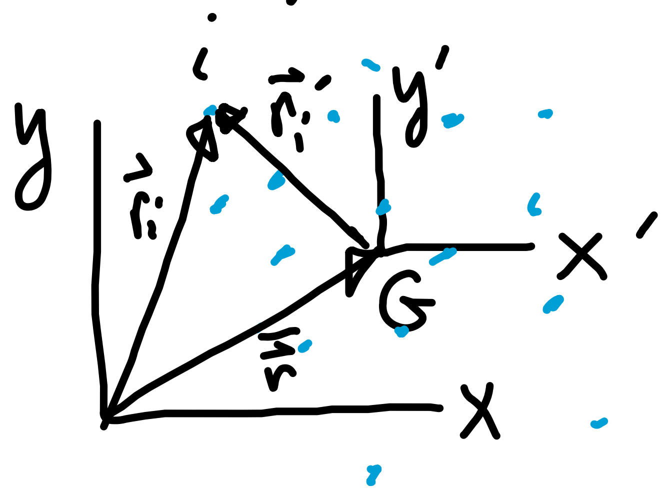

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{Does not matter if using $\vec{v}_i'$ or $\vec{v}_i$}

Special case:

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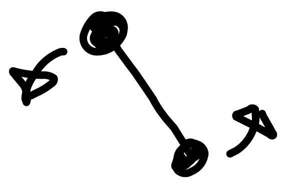

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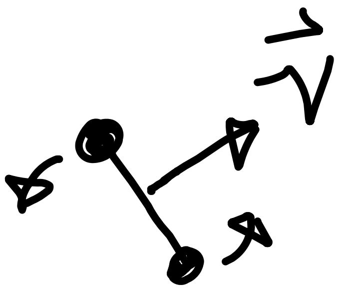
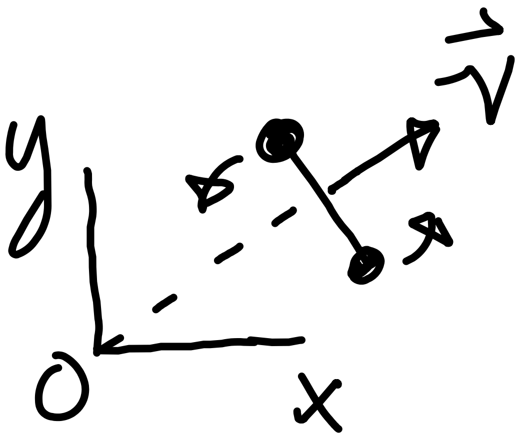
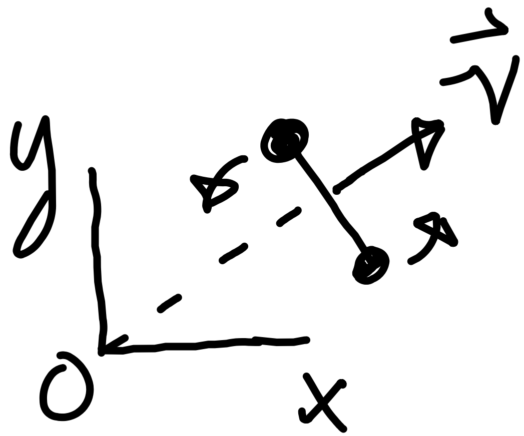


Special case: What if we measure $\vec{H}_O$, where origin O is directly in line with $\vec{v}$?



Special case: What if we measure $\vec{H}_0$, where origin O is directly in line with $\vec{v}$?

$$\vec{H}_0 = \sum \vec{r}_i \times m\vec{v}_i$$



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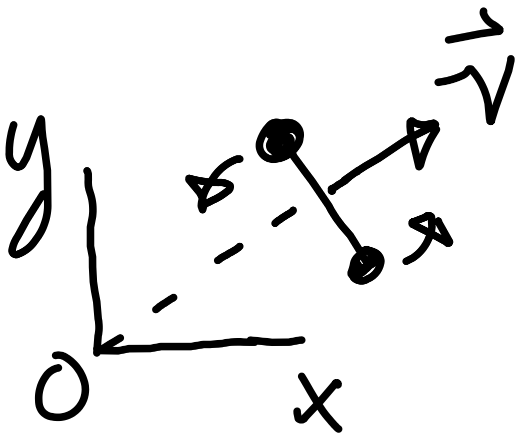
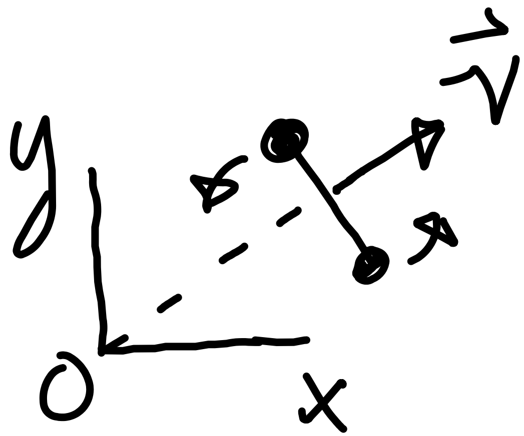


$$\vec{H}_O = \sum \vec{r}_i \times m\vec{v}_i$$
$$= \sum (\vec{r}_i{}' + \vec{\bar{r}}) \times m\vec{v}_i$$

Special case: What if we measure $\vec{H}_O$, where origin O is directly in line with $\vec{v}$?

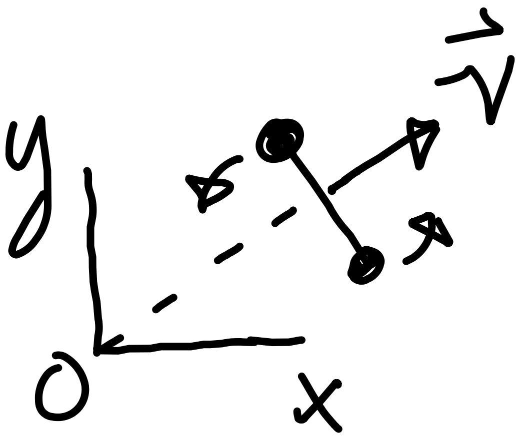


$$\vec{H}_O = \sum \vec{r}_i \times m\vec{v}_i$$

$$= \sum (\vec{r}_i' + \vec{\bar{r}}) \times m\vec{v}_i$$

$$= \sum \vec{r}_i' \times m\vec{v}_i + \sum \vec{\bar{r}} \times m\vec{v}_i$$

Special case: What if we measure $\vec{H}_O$, where origin O is directly in line with $\vec{v}_x$?



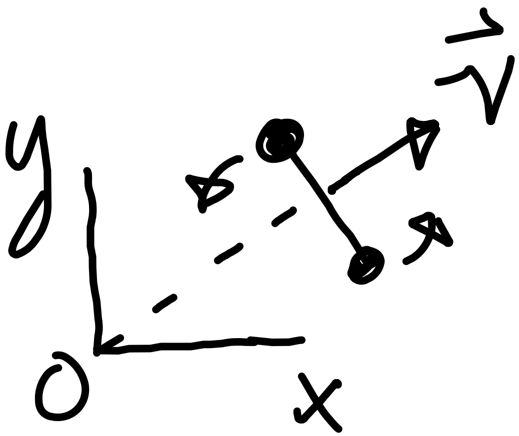
$$\vec{H}_O = \sum \vec{r}_i \times m\vec{v}_i$$

$$= \sum (\vec{r}_i' + \vec{\bar{r}}) \times m\vec{v}_i$$

$$= \sum \vec{r}_i' \times m\vec{v}_i + \sum \vec{\bar{r}} \times m\vec{v}_i$$

But $\sum \vec{r}_i' \times m\vec{v}_i = H_G$

Special case: What if we measure $\vec{H}_o$, where origin O is directly in line with $\vec{v}_x$?



$$\vec{H}_o = \Sigma \vec{r}_i \times m\vec{v}_i$$

$$= \Sigma (\vec{r}_i' + \vec{\bar{r}}) \times m\vec{v}_i$$

$$= \Sigma \vec{r}_i' \times m\vec{v}_i + \Sigma \vec{\bar{r}} \times m\vec{v}_i$$

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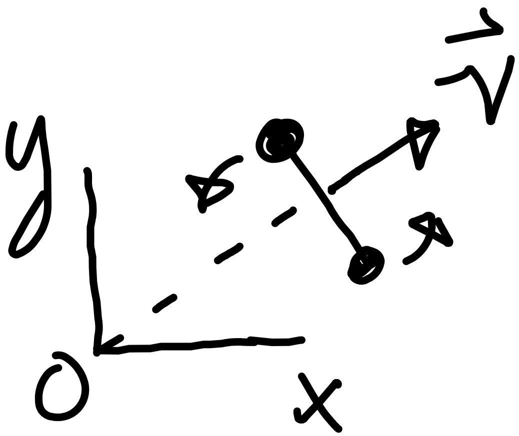
Special case: What if we measure $\vec{H}_o$, where origin O is directly in line with $\vec{v}$?



$$\vec{H}_o = \sum \vec{r}_i \times m\vec{v}_i$$

$$= \sum (\vec{r}_i' + \vec{\bar{r}}) \times m\vec{v}_i$$

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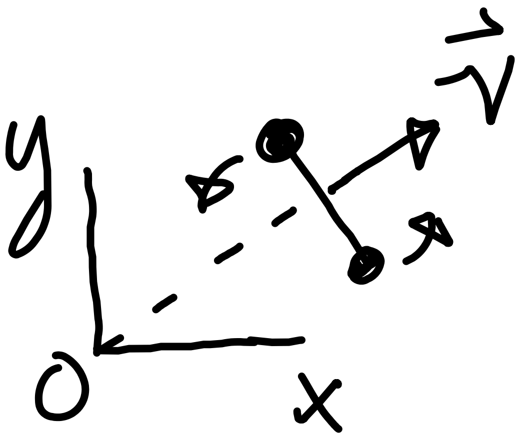
But $\sum \vec{r}_i' \times m\vec{v}_i = \vec{H}_G = \vec{H}_G'$

Special case: What if we measure $\vec{H}_O$, where origin O is directly in line with $\vec{\bar{v}}_x$?



$$\vec{H}_O = \sum \vec{r}_i \times m \vec{v}_i$$
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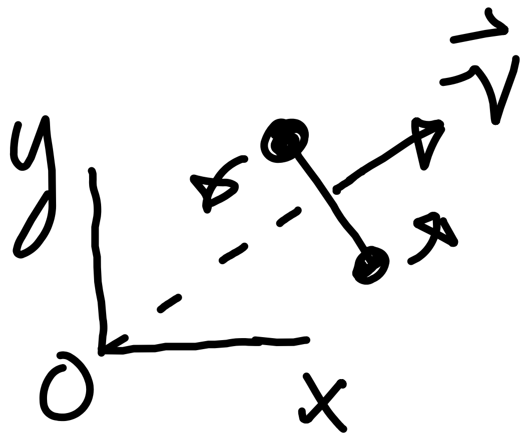
But $\sum \vec{r}_i' \times m \vec{v}_i = \vec{H}_G = \vec{H}_G'$

& since $\sum m_i \vec{v}_i = m \vec{\bar{v}}_i$

<u>Special case:</u> What if we measure $\vec{H}_O$, where origin O is directly in line with $\vec{\bar{v}}$?



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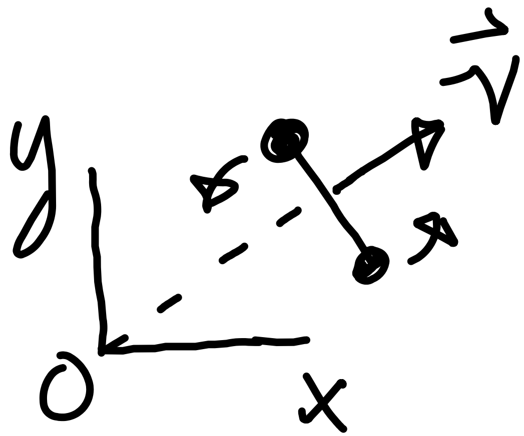
& since $\sum m_i \vec{v}_i = m\vec{\bar{v}}_i$ & $\vec{\bar{r}} \times \vec{\bar{v}} = 0$

<u>Special case</u>: What if we measure $\vec{H}_0$, where origin O is directly in line with $\vec{v}$?



$$\vec{H}_0 = \sum \vec{r}_i \times m\vec{v}_i$$
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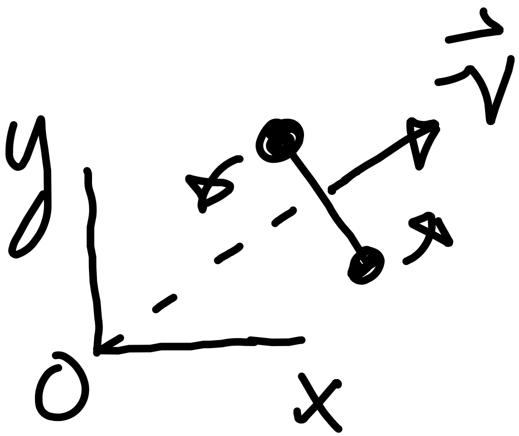
& since $\sum m_i \vec{v}_i = m\vec{\bar{v}}_i$ & $\vec{\bar{r}} \times \vec{\bar{v}} = 0$

we set $\vec{\bar{v}}$ in line with origin

Special case: What if we measure $\vec{H}_O$, where origin O is directly in line with $\vec{\bar{v}}$?



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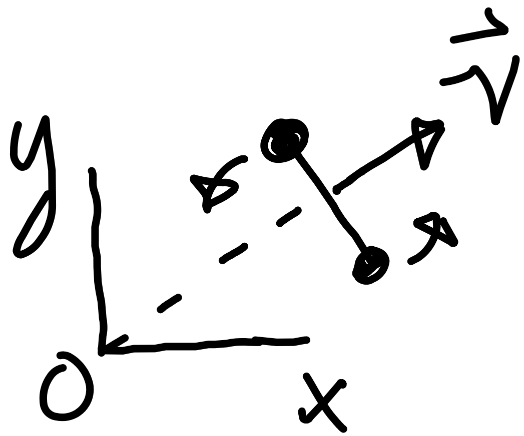
then, for this special case $\vec{H}_O = \vec{H}_G$

Special case: What if we measure $\vec{H}_O$, where origin O is directly in line with $\vec{\bar{v}}$?



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But $\sum \vec{r}_i' \times m\vec{v}_i = \vec{H}_G = \vec{H}_G'$

& since $\sum m_i \vec{v}_i = m\vec{\bar{v}}_i$ & $\vec{\bar{r}} \times \vec{\bar{v}} = 0$

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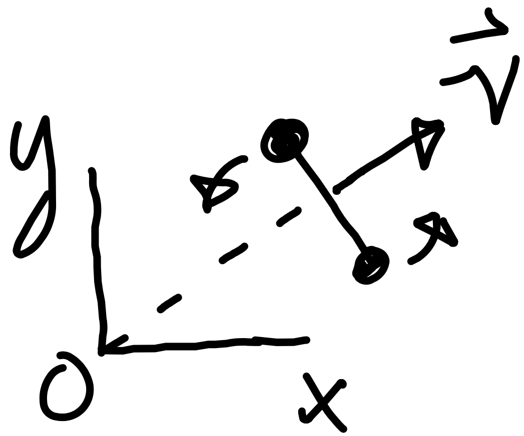
If, however, $\vec{\bar{r}} \times \vec{\bar{v}}$ is non-zero

Special case: What if we measure $\vec{H}_O$, where origin O is directly in line with $\vec{v}$?



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$$= \sum \vec{r}_i{}' \times m\vec{v}_i + \sum \bar{\vec{r}} \times m\vec{v}_i$$

But $\sum \vec{r}_i{}' \times m\vec{v}_i = \vec{H}_G = \vec{H}_G{}'$

& since $\sum m_i \vec{v}_i = m\bar{\vec{v}}$ & $\bar{\vec{r}} \times \bar{\vec{v}} = 0$

then, for this special case $\vec{H}_O = \vec{H}_G$

If, however, $\bar{\vec{r}} \times \bar{\vec{v}}$ is non-zero we would have $\vec{H}_O = \vec{H}_G + m\bar{\vec{r}} \times \bar{\vec{v}}$

We also saw that

Work: $T_1 + U_{1\to 2} = T_2$

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Work & Energy: $T_1 + V_1 + U_{1\to2}^{NC} = T_2 + V_2$

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Work: $T_1 + U_{1\to 2} = T_2$

Work & Energy: $T_1 + V_1 + U_{1\to 2}^{NC} = T_2 + V_2$

Impulse-momentum: $\sum \int_{t_1}^{t_2} \vec{F}\,dt = \Delta \vec{L}$

Torque-impulse: $\sum \int_{t_1}^{t_2} \vec{M}_o\,dt = \Delta \vec{H}_o$

Notes on problem 14.38

Notes on problem 14.38: Bound energy

$= 120\,J$

Notes on problem 14.38: Bound energy $= 120\,J$, $v_0 = 8\,m/s$

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This is in center of mass frame

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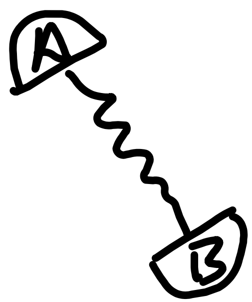
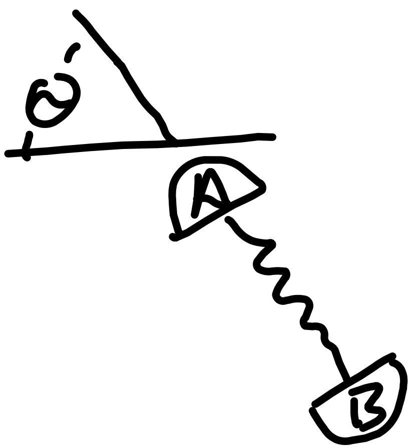
∟This is in center of mass frame



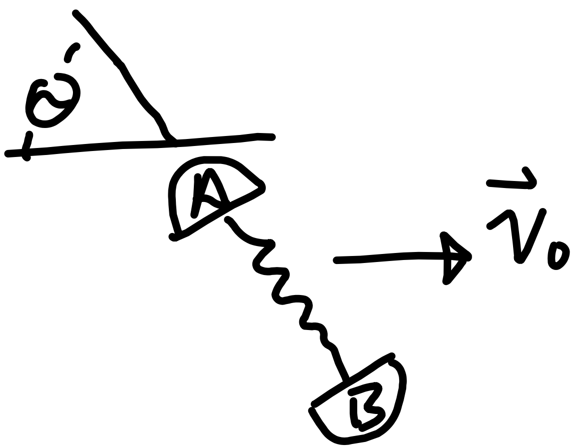
Notes on problem 14.38: Bound energy $= 120\,J$, $v_0 = 8\,m/s$ & $\theta = 30°$

This is in center of mass frame



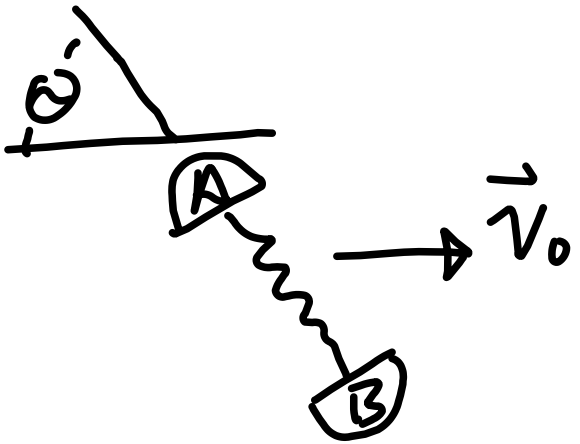
Notes on problem 14.38: Bound energy $= 120\,J$, $v_0 = 8\,m/s$ & $\theta = 30^\circ$

This is in center of mass frame



Notes on problem 14.38: Bound energy $=120\,J$, $v_0 = 8\,m/s$ & $\underline{\theta = 30°}$

↳ This is in center of mass frame

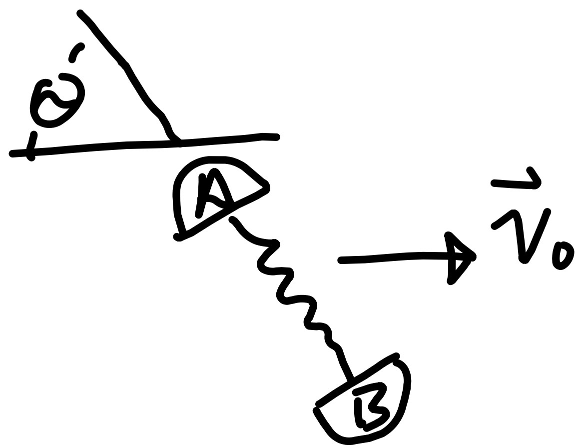


* Go into the c-m frame

Notes on problem 14.38: Bound energy

$= 120\,J$, $v_0 = 8\, m/s$ & $\underline{\underline{\theta = 30^\circ}}$

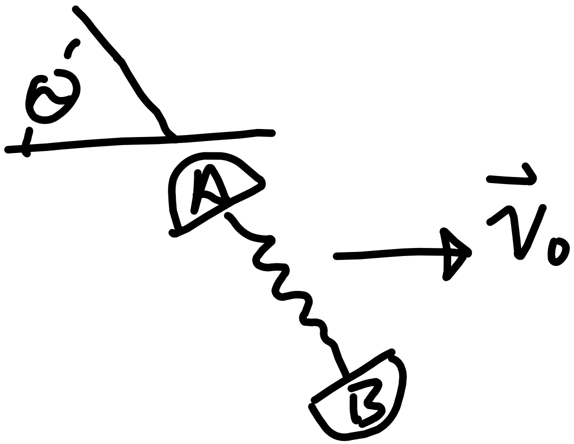
This is in center of mass frame



* Go into the c-m frame
* Release the bound energy in c-m frame

Notes on problem 14.38: Bound energy $= 120\,J$, $v_0 = 8\,m/s$ & $\theta = 30°$

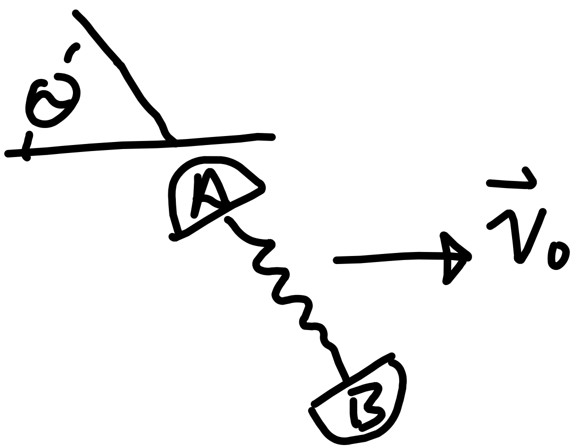
↳This is in center of mass frame



* Go into the c-m frame
* Release the bound energy in c-m frame
* Conserve momentum in c-m frame

Notes on problem 14.38: Bound energy $= 120\,J$, $v_0 = 8\,m/s$ & $\theta = 30°$

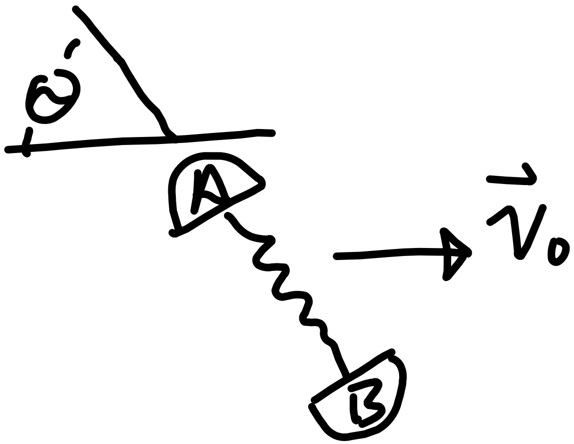
↳ This is in center of mass frame



* Go into the c-m frame
* Release the bound energy in c-m frame
* Conserve momentum in c-m frame $\vec{L}_{cm_I} = \vec{L}_{cm_F}$

Notes on problem 14.38: Bound energy $= 120\,J$, $v_0 = 8\,m/s$ & $\theta = 30^\circ$

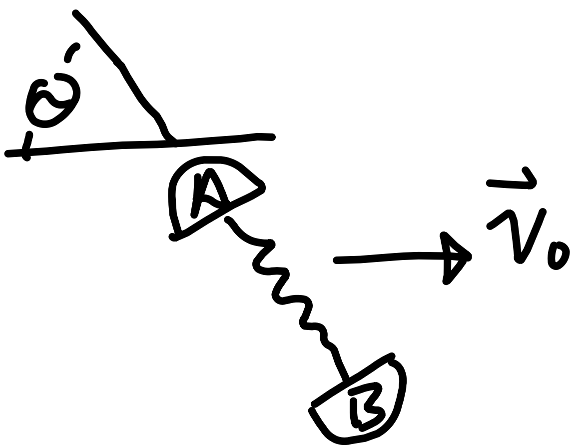
↳This is in center of mass frame



* Go into the c-m frame
* Release the bound energy in c-m frame
* Conserve momentum in c-m frame $\vec{L}_{cm_I} = \vec{L}_{cm_F}$
* Boost back into the lab frame

Notes on problem 14.38: Bound energy $=120\,J$, $v_0 = 8\,m/s$ & $\theta = 30^\circ$

↳ This is in center of mass frame



* Go into the c-m frame
* Release the bound energy in c-m frame
* Conserve momentum in c-m frame $\vec{L}_{cm_I} = \vec{L}_{cm_F}$
* Boost back into the lab frame [add $\vec{v}_0$ to each velocity]

Notes on problem 14.52:

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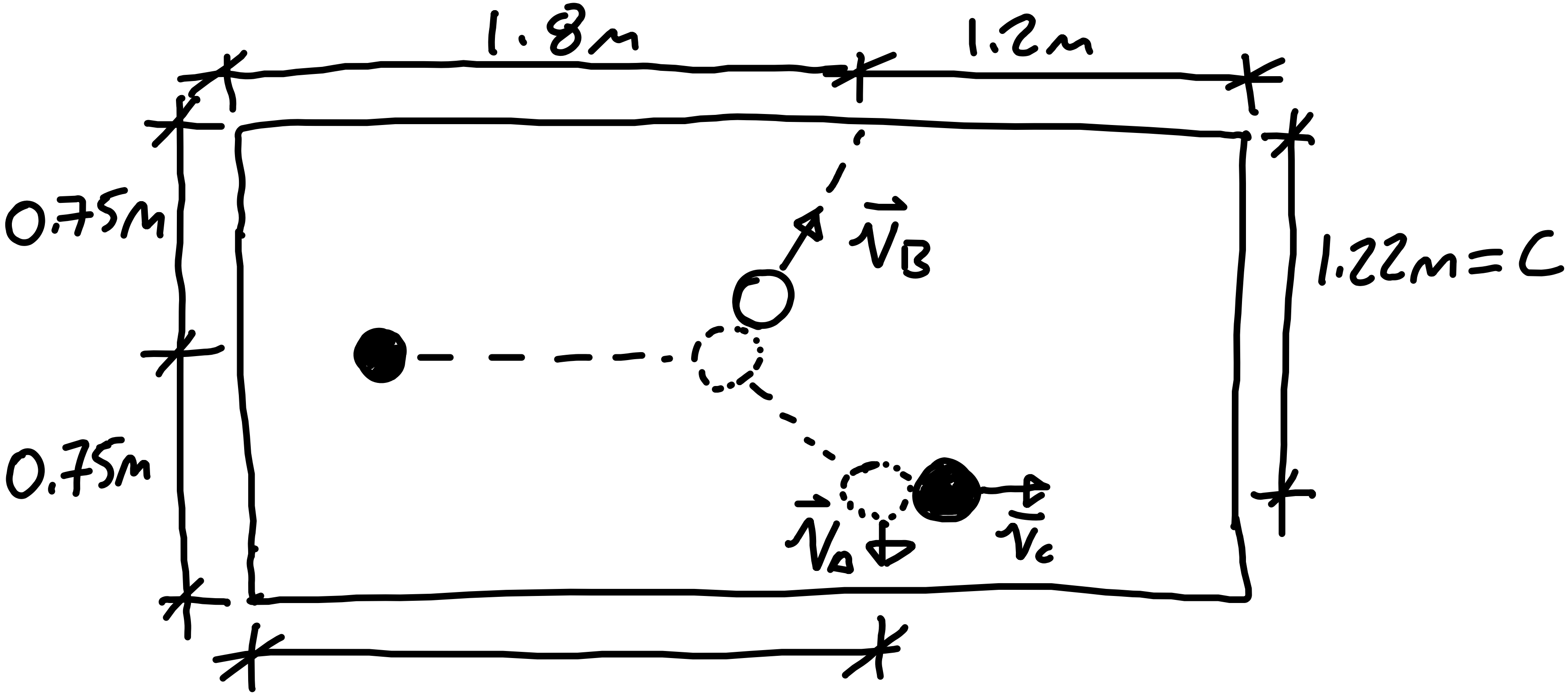
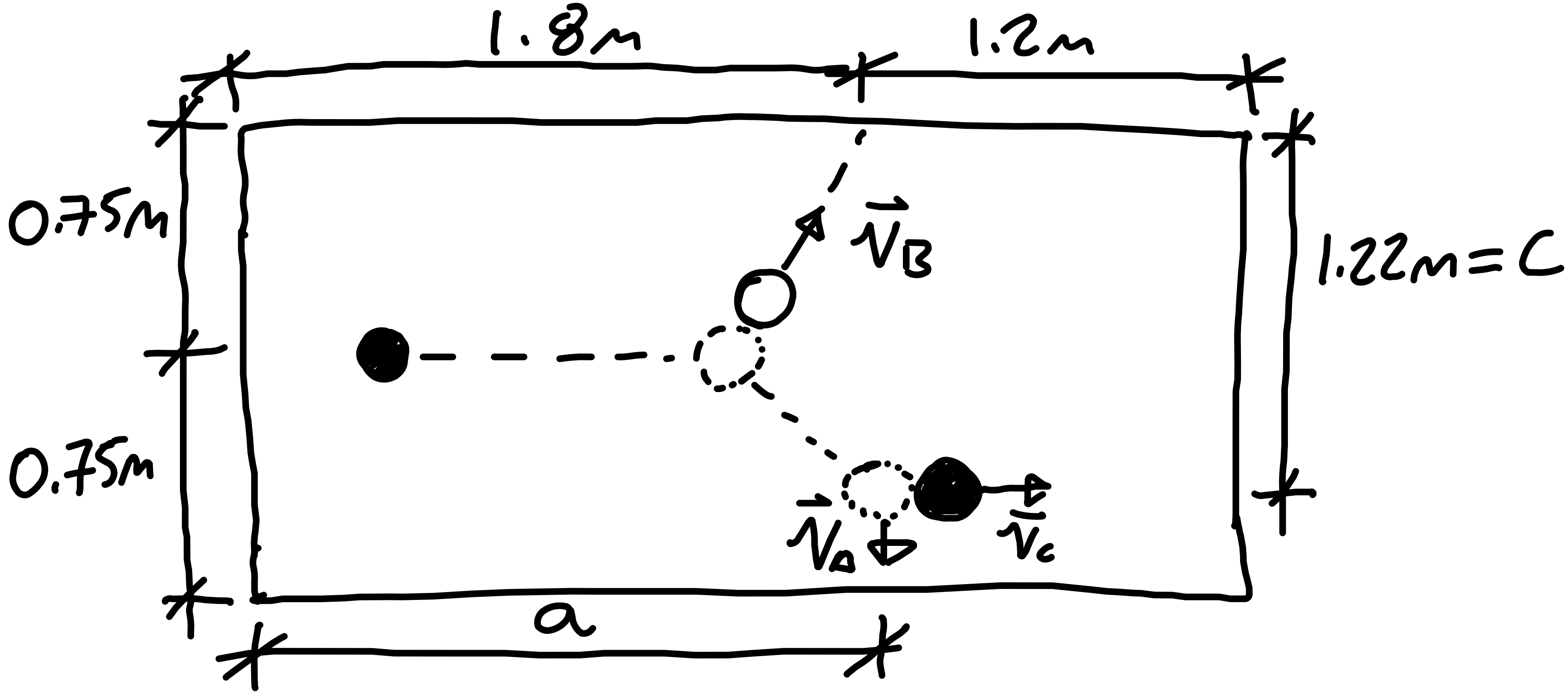
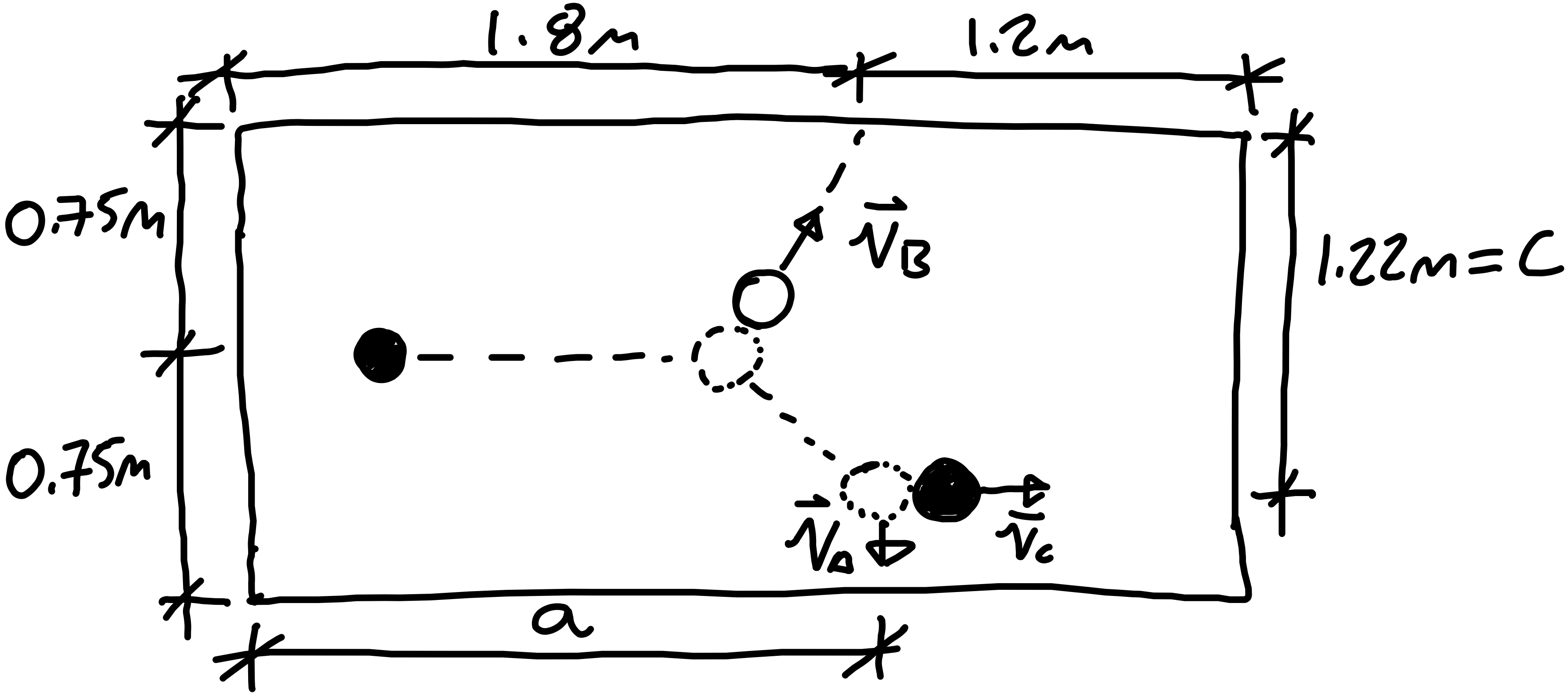


Notes on problem 14.52:



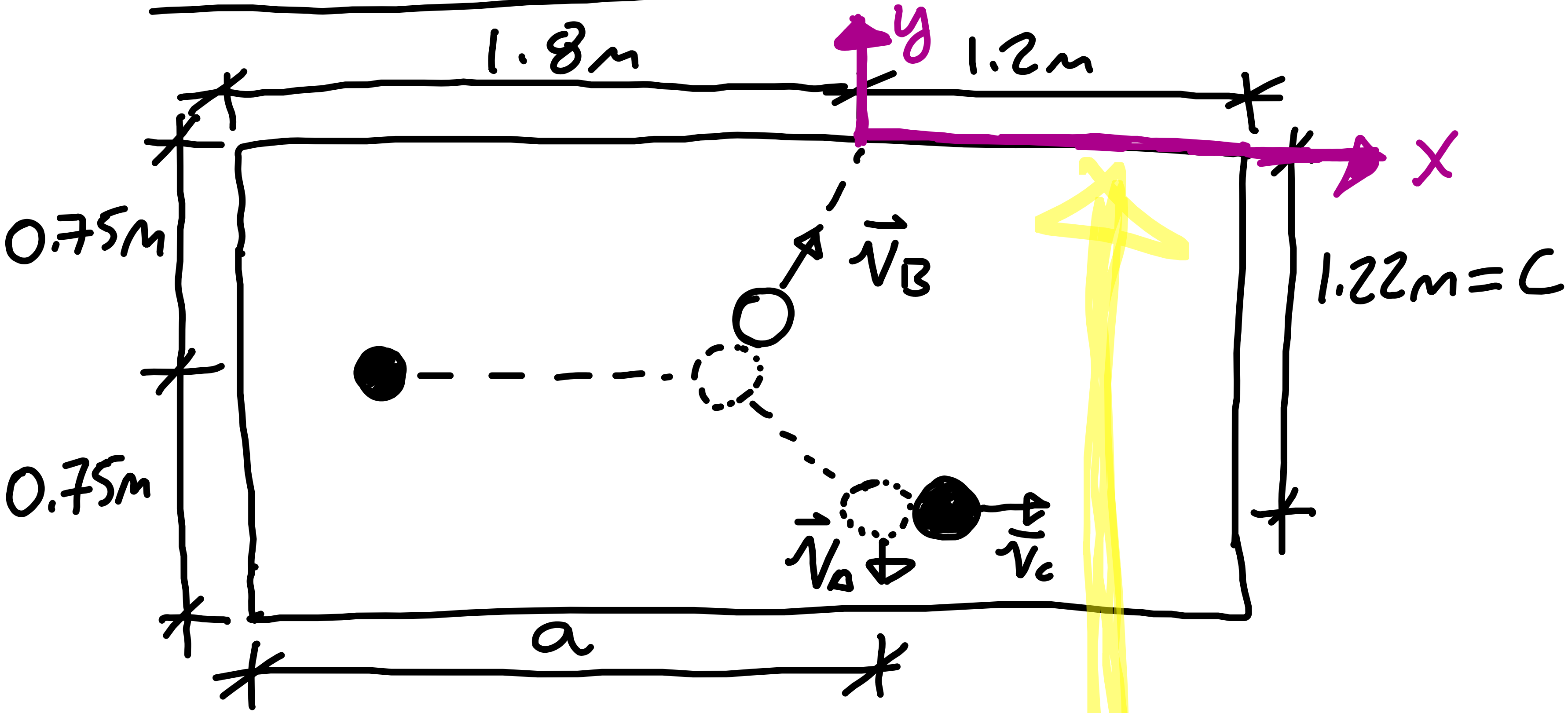
* Conserve momentum & energy to find $\vec{v}_A$ & $\vec{v}_B$

Notes on problem 14.52:



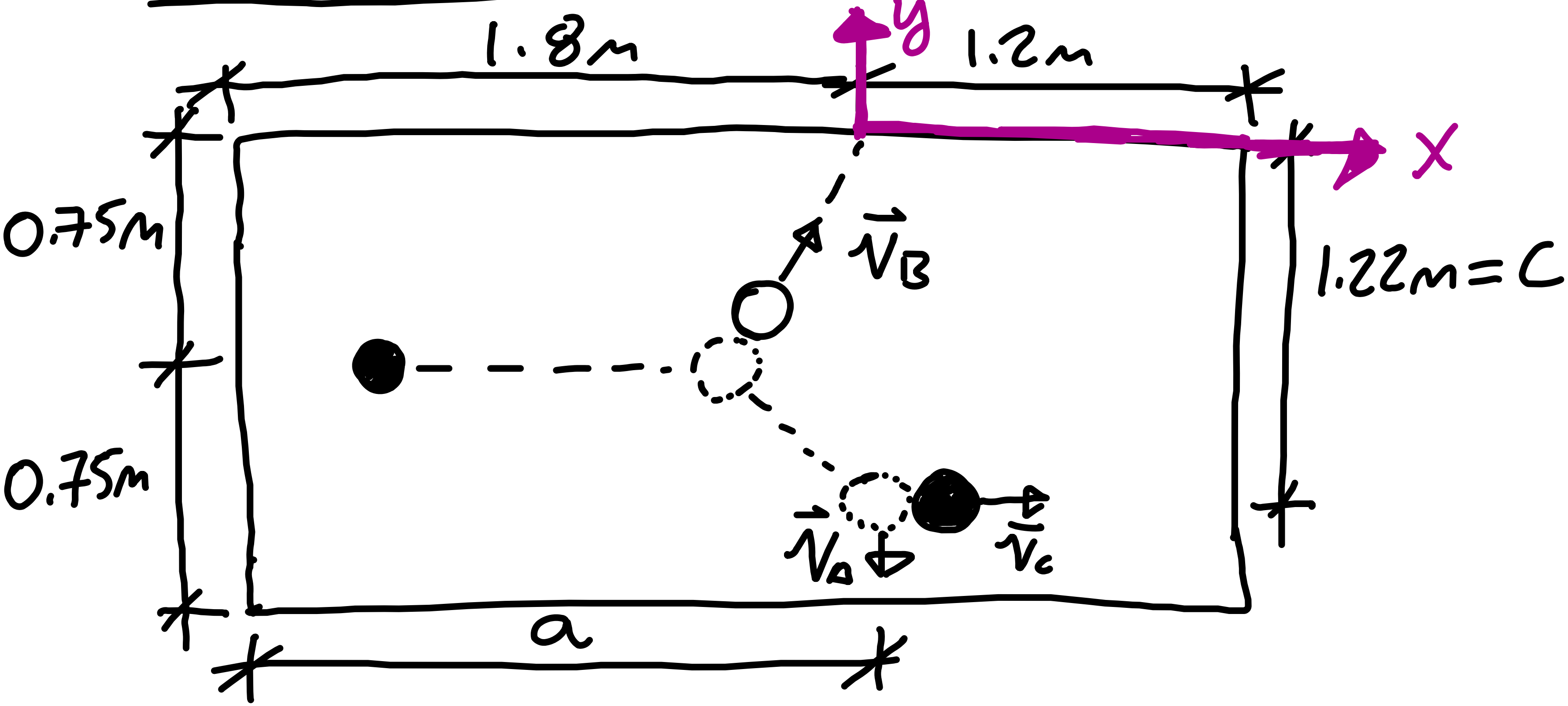
* Conserve momentum & energy to find $\vec{v}_A$ & $\vec{v}_B$
* Several ways to find a.

Notes on problem 14.52:



* Conserve momentum & energy to find $\vec{v}_A$ & $\vec{v}_B$
* Several ways to find a. One way is to put coordinate system as shown

Notes on problem 14.52:



* Conserve momentum & energy to find $\vec{v}_A$ & $\vec{v}_B$
* Several ways to find a. One way is to put coordinate system as shown & conserve $\vec{H}_O$