Exam answers posted on class website

Clicker Scores now posted on TYCHO. Look in grades for "clicker"

Tycho Typos. 60 not 80 pts for #7, and #8 heading about dates, number of problems, etc is incorrect.

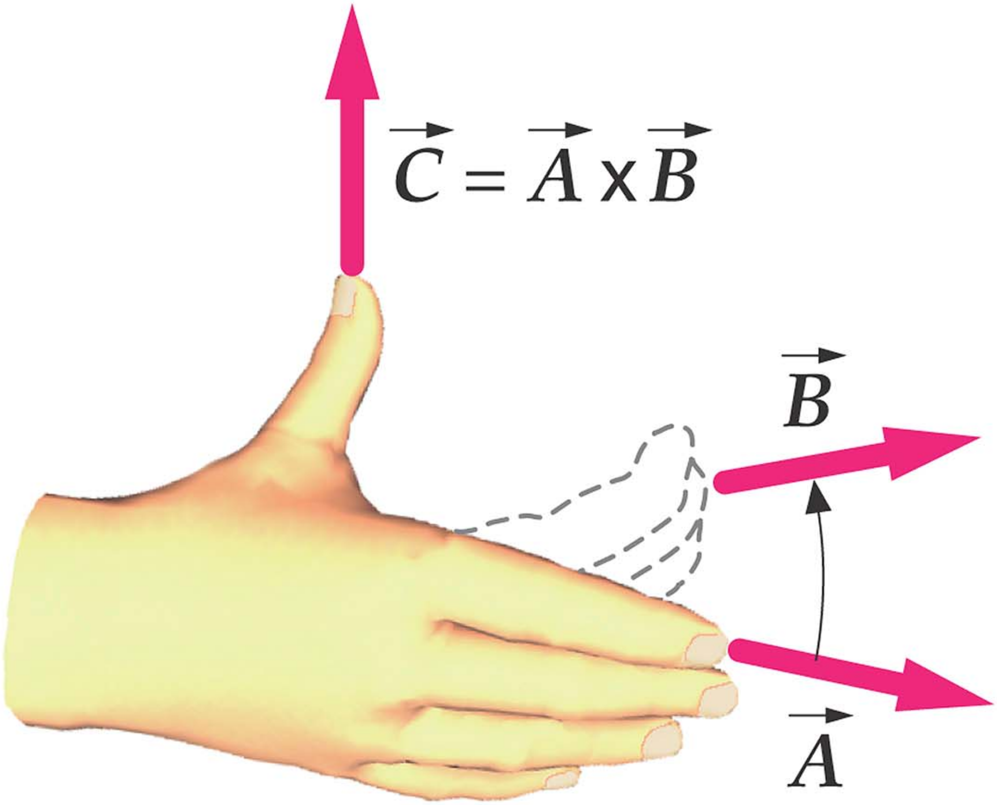
Homework #8 due next Wed (Nov 21) at midnight

Graded exams to be returned at end of class

Getting exam grades posted…..

Overview of HW #8 "hanging sign" and "disk and string"

Chapter 10. Polar vectors



$\vec{C}$ **is perpendicular to each of** $\vec{A}, \vec{B}$

Magnitude is *AB*sin(ϕ). C is Max when $\vec{A}$ **and** $\vec{B}$ **are perpendicular (opposite from dot product).**

$\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}$ **(which may seem peculiar)**

$\vec{\omega} = \vec{r} \times \vec{v} / r^2$ **so COUNTER Clockwise rotation (as you look at it) points toward you.**

I.e. the hands of a clock have $\vec{\omega}$ **pointing into the clock, away from the viewer.**

This is an arbitrary convention.

$\hat{i}\times\hat{j}=\hat{k}$ **for "right handed coordinates"**

$\hat{i}\times\hat{j}=\hat{k}$ **,** $\hat{k}\times\hat{i}=\hat{j}$ **,** $\hat{j}\times\hat{k}=\hat{i}$ **(cyclic perm.)**

$\hat{j}\times\hat{i}=-\hat{k}$ **, etc. and** $\hat{i}\times\hat{i}=0$ **, etc.**

For vectors written as $\vec{A}=A_x\hat{i}+A_y\hat{j}+A_z\hat{k}$

$$\vec{A}\times\vec{B}=$$
$$(A_xB_y-A_yB_x)\hat{k}+(A_yB_z-A_zB_y)\hat{i}+(A_zB_x-A_xB_z)\hat{j}$$

Note pattern in this.

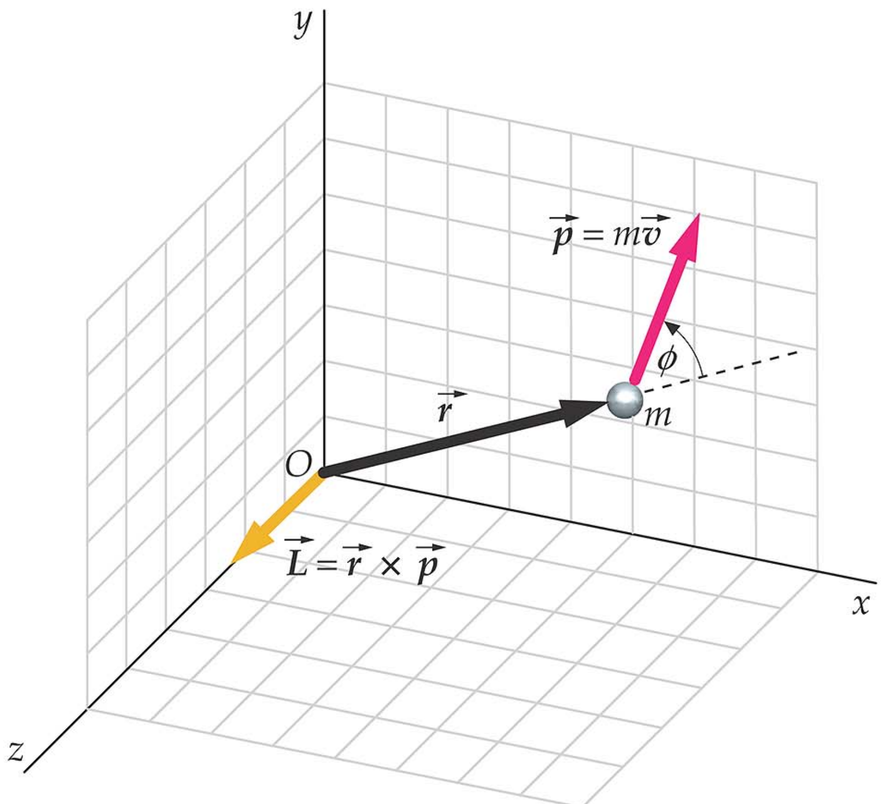
If you like determinants:

$$\vec{A}\times\vec{B}=\det\begin{pmatrix}\hat{i} & \hat{j} & \hat{k}\\ A_x & A_y & A_z\\ B_x & B_y & B_z\end{pmatrix}$$

Angular Momentum

Define, $\vec{L} = \vec{r} \times \vec{p}$ **for a point particle and note that Torque:** $\vec{\tau} = \vec{r} \times \vec{F}$ **and** $\vec{\omega} = \vec{r} \times \vec{v} / r^2$

the $\vec{r}$ **goes first, and the right hand rule works**



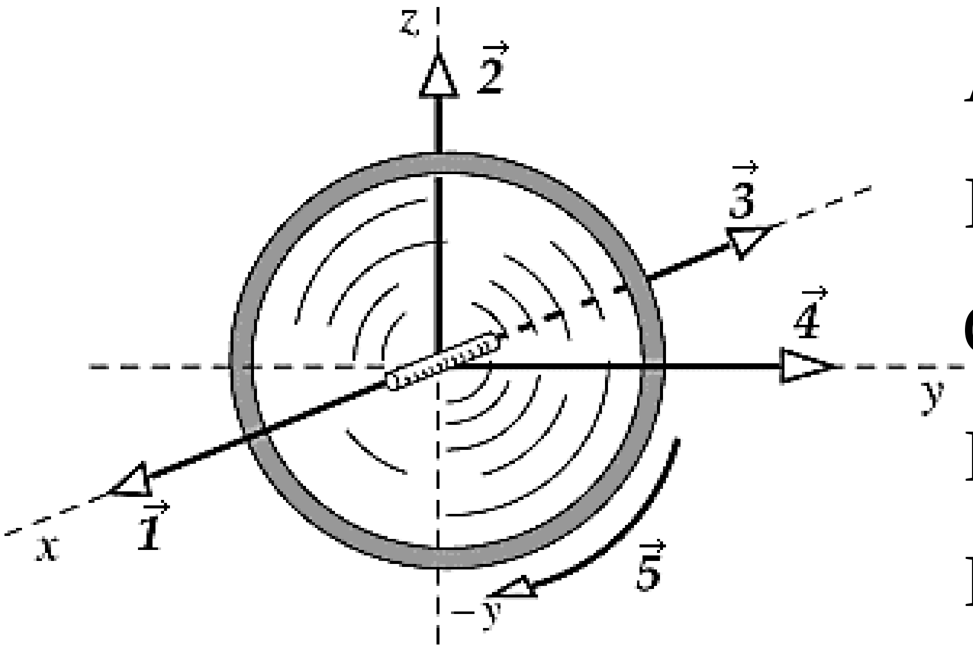
This particle may or may not be going in a circle about O. Often it won't be!!!

Consider a ring, rotating about its center at O.

Then $\vec{L} = \vec{r} \times m\vec{v} = m(\frac{r^2}{r^2})\vec{r} \times \vec{v} = mr^2\vec{\omega} = I\vec{\omega}$

Clicker

A wheel is rotating clockwise as shown. Its rotation axis coincides with the *x*-axis. A torque that causes the wheel to slow down is best represented by the vector



A. $\vec{1}$

B. $\vec{2}$

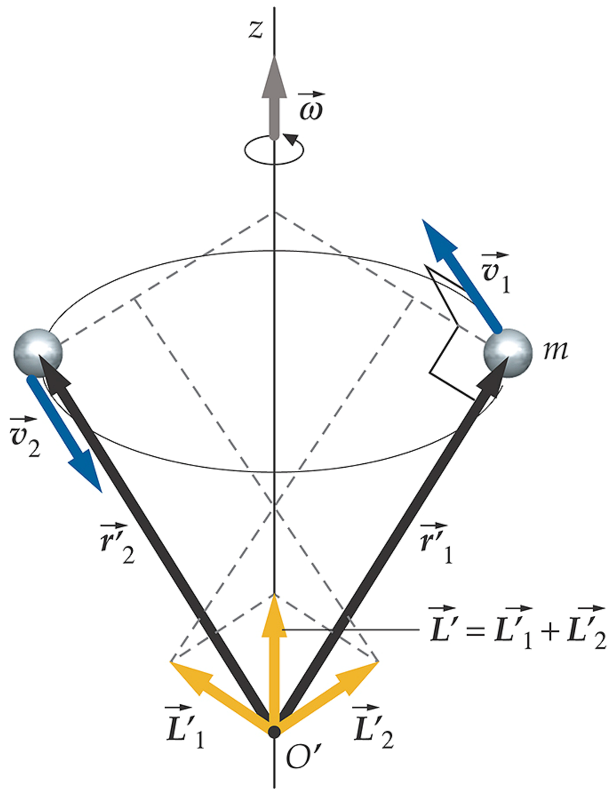
C. $\vec{3}$

D. $\vec{4}$

E. $\vec{5}$

If the ring is displaced from the x-y plane, but still rotates about the z-axis : $\vec{L} = I\vec{\omega}$ about the z-axis.

See cancellation of components.



In general, an object rotating about a symmetry axis has

$$\vec{L} = I\vec{\omega}$$

where I is moment of inertia about that axis.
(Life is complicated for non-symmetry axes.)

Exactly as was the case for linear momentum,

where $\vec{F} = m\vec{a} \rightarrow F = \dfrac{d\vec{p}}{dt}$ **we see**

$\vec{\tau} \equiv \vec{r} \times \vec{F} = I\vec{\alpha} \rightarrow \vec{\tau} = \dfrac{d\vec{L}}{dt}$ **and**

$\vec{\tau}_{\text{net,external}} = \dfrac{d\vec{L}_{\text{system}}}{dt}$ **Likewise, angular impulse:**

$$\Delta\vec{L}_{\text{sys}} = \int_{t_i}^{t_f} \vec{\tau}_{\text{net,ext}}\, dt$$

Splitting motion into that *of* C.M. and *in* C.M.

$\vec{L}_{\text{sys}} = \vec{r}_{\text{cm}} \times M\vec{v}_{\text{cm}} + \vec{L}_{\text{spin}}$ **where**

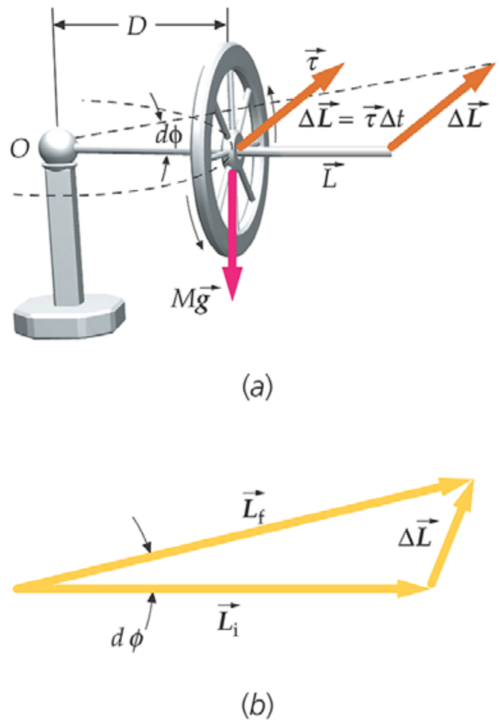
$\vec{r}_{\text{cm}} \times M\vec{v}_{\text{cm}}$ **is called "orbital" angular momentum and is *L* of system associated with its C.M. moving with respect to some point.**

$\vec{L}_{\text{spin}}$ **is the angular momentum of the system about its C.M. – examples of Earth, Moon, Sun.**

Gyroscope: (precession)

$\vec{L}_{\text{spin}}$ is in horizontal plane. Gravity provides torque, also in horizontal plane, perpendicular to $\vec{L}_{\text{spin}}$.

Therefore $\Delta\vec{L}_{\text{spin}}$ changes direction of $\vec{L}_{\text{spin}}$, not its magnitude and it stays in horizontal plane.



$$\Delta L = \tau\Delta t = MgD\Delta t$$ -- **angle axis points is ϕ:**

$$\Delta\phi = \frac{\Delta L}{L_{\text{spin}}} = \frac{MgD\Delta t}{I_g\omega_{\text{spin}}}$$

so precession angular speed is

$$\omega_p = \frac{d\phi}{dt} = \frac{MgD}{I_g\omega_{\text{spin}}}$$