Review… A new mathematical tool: the Cross Product

- On formula sheet, written explicitly
- You try one…

Vector nature of rotation

Two examples of how Right Hand Rule (rhr) is used:

1. Angular velocity
2. Torque
   - Direction: right hand rule
   - Magnitude

A torque is applied to a bolt by hanging a weight \( w \) from the end of the wrench, as shown. The coordinate axis along which the torque vector is directed is

A. \( y \)  
B. \( x \)  
C. \( -y \)  
D. \( -x \)  
E. \( z \)

As a particle with a velocity in the negative \( x \) direction passes through the point \((0, 0, 1)\), it has an angular velocity relative to the origin that is best represented by vector

A. \( \vec{i} \)  
B. \( \vec{j} \)  
C. \( \vec{k} \)  
D. \( \vec{3} \)  
E. \( \vec{5} \)

The vector \( \vec{C} \) could represent

A. \( \vec{A} \times \vec{B} \)  
B. \( \vec{B} \cdot \vec{A} \)  
C. \( -\vec{A} \times \vec{B} \)  
D. \( \vec{B} \times \vec{A} \)  
E. None of these is possible

A 7-kg mass and a 4-kg mass are mounted on a spindle that is free to turn about the \( x \) axis as shown. Assume the mass of the arms and the spindle to be negligible. If the system is free to rotate and is released from rest, there will initially be a resultant torque in which of the following directions?

A. \( z \)  
B. \( -z \)  
C. \( y \)  
D. \( -x \)  
E. \( x \)
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 particle of mass $m$ is moving with a velocity $\mathbf{v}$, in the $yz$ plane as shown. The vector that most nearly represents the angular momentum about the $x$ axis is

Example 10-2
Find the angular momentum about the origin for the following situations:

a) A car of mass 1200 kg moves in a circle of radius 20 m (centered at the origin in the $xy$ plane) with a speed of 15 m/s (counterclockwise).

b) The same car moves in the $xy$ plane with velocity $-15 \text{m/s}$ along the line $y = y_0 = 20 \text{ m}$.

c) A uniform disk in the $xy$ plane of radius 20 m and mass 1200 kg rotates at 0.75 rad/s about its axis, which is also the $z$ axis.

Newton’s second law, again!

- Net torque is related to angular momentum just as the net force was related to momentum.
Example 10-3
An Atwood’s machine has two blocks with masses m1 and m2 (m1 > m2) connected by a string of negligible mass that passes over a pulley with frictionless bearings. The pulley is a uniform disk of mass M and radius R. The string does not slip on the pulley. Find the angular acceleration of the pulley and the linear acceleration of the blocks.

Conservation of Angular momentum
If the net external torque acting on a system about some point is zero, the angular momentum of the system about that point remains constant.

Spinning tops
How do you find ω for a spinning top?
• Use the right hand rule: curl your fingers from the direction of the radius vector towards the linear momentum vector at a point on the rotating object.
• This is the same as the direction of the angular momentum vector.

How does a spinning top remain upright?
• Angular momentum is parallel to the axis of rotation. In the absence of outside forces, conservation of angular momentum causes the top’s rotation axis to keep a constant orientation. The top will stay vertical as long as its angular velocity is great enough.

Copernicus and Galileo: finally, a sun-centered solar system
A Brief History of Gravity

1. Copernicus and Galileo: sun at center
2. 16th century, Tycho Brahe observations
3. Kepler’s laws of planetary motion
4. 1686: Newton’s law of gravity
5. 1700’s: Henry Cavendish
6. 1900’s: Einstein’s theory of general relativity
7. Modern day “Holy Grail” for physicists…

Kepler’s Laws of Planetary Motion:

1. All planets move in elliptical orbits with the sun at one focus
2. A line joining any planet to the sun sweeps out equal areas in equal time
3. The square of the period of any planet is proportional to the cube of the semimajor axis of its orbit

Example 11.1: Jupiter’s mean orbital radius is 5.20 AU. What is the period of Jupiter’s orbit around the sun? Use the constant C for a planet you know…

Newton’s Law of Gravity

- Newton: “There is a gravitational force of attraction between any two massive objects in the universe!”
- G, “Universal Gravitational Constant”
- Is there a gravitational attraction between two people standing next to each other? (estimate)
- Derive Earth’s acceleration due to gravity

Example 11.2

What is the free-fall acceleration of an object at a space shuttle’s orbit, about 400km above Earth’s surface?

Unfinished business

- Newton derived the constant in Kepler’s third law, just like you will now…

Example 11.3

You are trying to view the international space station, which travels in a roughly circular orbit around Earth. If its altitude is 385km above Earth’s surface, how long do you have to wait between sightings?