Workshop Tutorials for Introductory Physics

MI11: **Rotational Dynamics**

A. Review of Basic Ideas:

Use the following words to fill in the blanks:
distance, maximum, conserved, v / r, different, ω, velocity, torque, I, second, force, angle

Spinning around
When we want to describe the movement of an object we can talk about its velocity and its acceleration. But what about something like a CD which stays in the same place but spins around? Different points on the CD are moving at ______ velocities, but they all trace out the same _____, θ, in a given time. For spinning objects we can define an angular velocity and an angular acceleration.

The angular velocity, ____, is the change in angle divided by the time taken, which for a given point is also equal to the velocity, v, of that point divided by its distance, r, from the centre.

$\omega = \Delta\theta / \Delta t =$ ______

The angular acceleration, α, is the rate of change of the angular ______, just like linear acceleration is the rate of change of linear velocity. To make something accelerate you need to apply a ______, and to give something an angular acceleration you need to apply a ______. The torque is equal to the force times the ______ from the pivot point. We also need to allow for the angle at which the force is applied. If the force is applied pointing directly towards the pivot point then it won't make the body rotate. A force applied at right angle to this direction will have the _____ effect. The torque is given by

$\tau = r \times F = rF \sin\theta$.

When we want to calculate the acceleration of a body subject to a force we use Newton's ______ law, $F_{net} = ma$. To find the angular acceleration of a body subject to a torque we use the rotational equivalent to Newton's second law which is $\tau_{net} = I\alpha$. The quantity _____ is called the moment of inertia of a body, and is a measure of how hard it is to change the rotational motion of the body.

We can define a rotational energy and an angular momentum associated with the rotation. If there is no net torque these are _______, just like energy and momentum are conserved in linear motion.

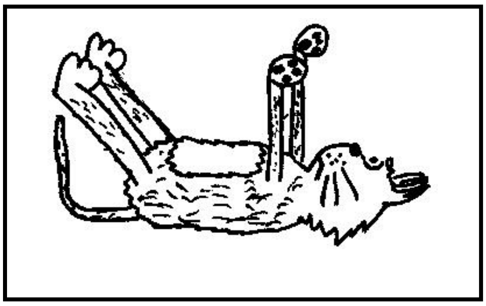
Discussion questions
List the terms used to describe linear motion in the paragraph and their rotational counterparts.
Give the relationships between the linear and rotational terms.

B. Activity Questions:

1. Clocks
What is the angular speed of the second hand?
What are the angular speeds of the minute and hour hands?
Does the size of the clock affect the angular speeds of the hands?
Does it affect the linear speed of the ends of the hands?

2. The rotating stool
Sit on the stool and start rotating with equal weights held in your hands.
Start with the hands in close to your chest and slowly stretch your hands outwards.
What do you observe?
What happens when you pull them back in again? Why?

3. Falling cats



The diagram on display shows how a cat can rotate itself around so that it always lands on its feet. Sit on the rotating stool and see if you can turn yourself around the way a cat does.
How is it possible to do so without violating conservation of angular momentum?

4. Rotation platform

What affects the 'slipping off' of the block?
Which way does the block go as it slips off?
Where is it more likely to slip, and why?

C. Qualitative Questions:

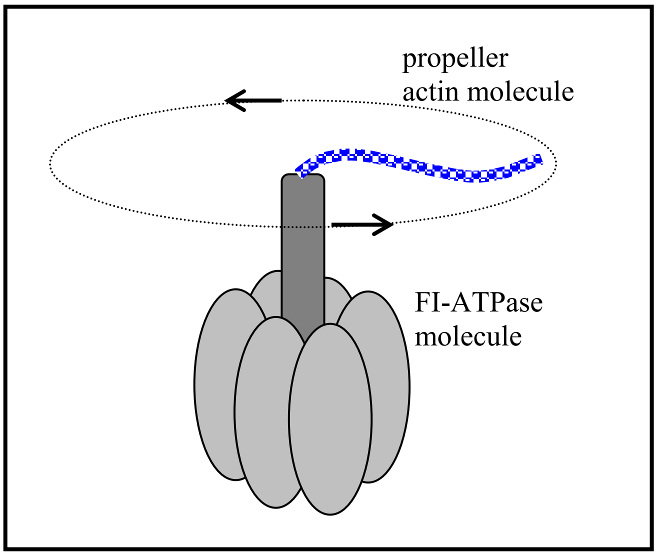
1. Rebecca has gone to a conference in Cairns in north Queensland, leaving Brent at home in Sydney to look after Barry the dog.

a. Which one of them has the greater angular velocity, ω?
b. Which of them has the greater velocity, v?
Use a diagram showing their positions on the Earth to explain your answers.

2. Most bicycles have spoked wheels, with thin spokes holding the rim and tyre. In the Olympic cycling events there are restrictions on the weight and diameter of the wheels used on the bicycles.
Discuss why solid wheels rather than spoked wheels are used in the Olympics. What are the advantages? Why are spoked wheels commonly used on ordinary bicycles?

D. Quantitative Question:

Many bacteria have flagella or cilia, tiny little waving appendages, which they use to propel themselves. These were always believed to just wave around to move the bacteria, but it turns out that some of them actually act as tiny propellers. However the smallest natural propeller is part of an ATPase molecule. An ATPase is an enzyme which either breaks down or builds up an ATP (Adenosine tri-phosphate) molecule. ATP is the energy currency of cells: energy is liberated by breaking one of the phosphate bonds, or stored by attaching a phosphate. The FI-ATPase molecule has seven sub-units, six of which form a ring around the seventh sub-unit, as shown below. This middle piece actually spins around like the rotor of an electric motor, but it was only by attaching another molecule like a propeller blade that it was possible to observe this movement.



a. If each rotation takes 100 ms, what is the angular velocity of the attached actin molecule?
b. If the actin molecule is 1 μm long and has a mass of 2×10^{-22}kg, what is the moment of inertia of the propeller?
c. What is the angular momentum of the actin at this velocity?
d. Assuming constant angular acceleration, if it takes 100 ms to perform a rotation starting from rest, what is the angular acceleration of the actin?

$I_{\text{rod}} = \frac{1}{3} ml^2$.