Chapter 9: Rotation (cont.)
Newton's 2nd Law for rotation: Applications and rolling objects

About Midterm Exam 2

- When and where
  - Thurs March 24th 5:45-7:00 pm
  - Rooms: Same as Exam I, See course webpage.
  - Your TA will give a brief review during the discussion session.
- Coverage: Chaps 5 – 8 (4 chapters)
- Format
  - Closed book, 20 multiple-choices questions (format as in practice exams)
  - 1 page 8x11 formula sheet allowed, must be self prepared, no photo copying/download-printing of solutions, lecture slides, etc.
  - Bring a calculator (but no lap-top computer). Only basic calculation functionality can be used. Bring a 2B pencil for Scantron.
  - Fill in your ID and section # !
- Special requests:
  - If different from Exam I, email me at than@hep.wisc.edu
  - One alternative exam: 3:30pm – 4:45pm, Thurs Mar. 24, Cham 5280 (as before).

“Point” objects with mass m are linearly accelerated according to Newton's 2nd Law.
But what if the objects have size (shape)?
- Divide the problem into two parts
- Linear acceleration: treat the mass as a point
- Rotational acceleration: accounts for the extended size of the object
Rigged body: all points are fixed relative to one another, but the extended object can rotate

\[ \tau = \frac{F}{d} \]
Caused by an offset force
Torque, \( \tau \), accounts for the tendency of a force to rotate an object about some axis
\[ \tau = \frac{F}{d} \]
It is a vector, direction r.h. rule from \( d \) to \( F \).

Lever Arm

- The lever arm, \( d \), is the perpendicular distance from the axis of rotation to a line drawn from the direction of the force
  \[ d = L \sin \phi \]
- The torque that causes a rotation is quantified by the force times the lever arm.
  \[ \tau = FL \sin \phi \]

An Alternative Look at Torque

- The force could also be resolved into its x- and y-components
  - The x-component, \( F \cos \phi \), produces 0 torque
  - The y-component, \( F \sin \phi \), produces a non-zero torque
- Note the definition of \( \phi \)
  \[ \tau = FL \sin \phi \]
Question 1: Opening the door

In which case (a) thru (f) is the torque most positive?

Rotational Kinetic Energy

- Work must be done to rotate objects
- Force expended perpendicular to the radius
- Parallel to the displacement

\[
\tau = r \vec{F} \sin \theta
\]

- Force
- Point of application
- Distance to center of rotation

Newton's 2nd Law for Rotation:

- From a point-like particle:
  \[ F_i = m a_i \]
  \[ r F_i = m r^2 a_i \]

Define a torque:

\[ \tau = r \vec{F} \]

TORQUE ABOUT AN AXIS

\[ \tau = m r^2 a_i \]

Most general:

\[ \sum \tau_{\text{net}} = \sum m r_i a_i = \sum F_i a_i = I a \]

\[ \tau_{\text{net}} = \sum \tau_{\text{net}} = I a \]

NEWTON'S SECOND LAW FOR ROTATION

Torque due to gravity:

\[ \tau_{\text{grav net}} = M g x_R \]

Newton's 2nd Law for Rotation:

The net gravitational torque can be calculated by considering the total gravitational force (the sum of the microscopic gravitational forces) to act at a single point—the center of gravity.
Application: Rolling without Slipping Down Incline: Find \( v_{CM} \)

\[
\Delta KE_{\text{total}} + \Delta PE_g = 0
\]

\[
\Delta PE_g = -Mgh
\]

Solve:

\[
\Delta KE_{\text{total}} = \frac{1}{2} M v_{CM}^2 \left(1 + \frac{1}{1 + \frac{1}{MR^2}}\right) = Mgh
\]

\[
v_{CM} = \sqrt{2gh \left(1 + \frac{1}{1 + \frac{1}{MR^2}}\right)}
\]

\[
M g \sin \theta - f = M a_{CM}
\]

(f variable)

\[
f R = I \alpha = I a_{CM}/R
\]

\[m_2 g - T_2 = m_2 a
\]

\[T_1 - m_1 g = m_1 a
\]

\[(T_2 - T_1) R = I \alpha = I a/R\]