Physics 141.
Review Exam # 3.

Fuel efficient aviation.

(see http://www.treehugger.com/files/2009/02/fuel-efficient-aviation.php)

Before we start:
From PHY 141 to Realta Fusion.

- Since 2007, I have worked with Dev Ashish Khaitan who was an undergraduate student, a graduate student, post-doc, and a senior scientist in my group.
- Next week, he will start solving other problems at Realta Fusions: "Making fusion real and tackling today's clean energy issues with innovative technology".
- Dev is a great example of where PHY 141 can take you!

11/2007

9/2019

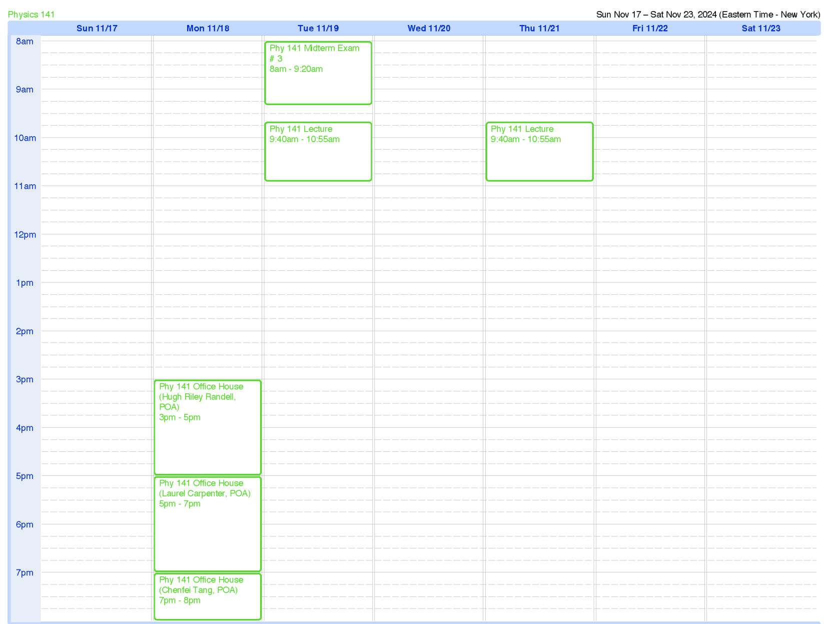
Physics 141 Exam # 3.

- Exam # 3 will take place on Tuesday 11/19 between 8 am and 9.20 am in Hoyt.
- Exam # 3 will cover the material of Chapters 8, 9, 10, and 11.

- General remarks:
  - You must answer question 11 and 12 in one blue booklet.
  - You must answer question 13 in the second blue booklet.
  - **If you answer all analytical questions in one blue booklet, question 13 will not be graded.**
  - You must enter your student ID in the appropriate place on the scantron form. **No ID on the form, no grade for the multiple-choice questions.**
  - If you arrive after 8.45 am, you will not be allowed to take the exam.
  - You cannot leave the exam before 8.45 am.

Extra office hours on Monday 11/18.

- There will be extra office hours on 11/18 to answer any last-minute questions about exam # 3.
- There will be no recitations and office hours on Tuesday, Wednesday, Thursday, and Friday during the week of the exam.



Surviving Phy 141 Exams.

- Time your work:
  - Exam has 10 MC + 3 analytical questions.
  - Work 15 minutes on the MC questions.
  - Work 15 minutes on each of the analytical questions (45 minutes total).
  - You now have 30 minutes left to finish those questions you did not finish in the first 15 minutes.
- Write neatly – you cannot earn credit if we cannot read what you wrote!
- Write enough so that we can see your line of thought – you cannot earn credit for what you are thinking!

Surviving Phy 141 Exams.

- Every problem should start with a diagram, showing all forces (direction and approximate magnitude) and dimensions. All forces and dimensions should be labeled with the variables that will be used in your solution.
- Indicate what variables are known and what variables are unknown.
- Indicate which variable needs to be determined.
- Indicate the principle(s) that you use to solve the problem.
- If you make any approximations, indicate them.
- Check your units!

Review exam # 3.
Chapter 8.

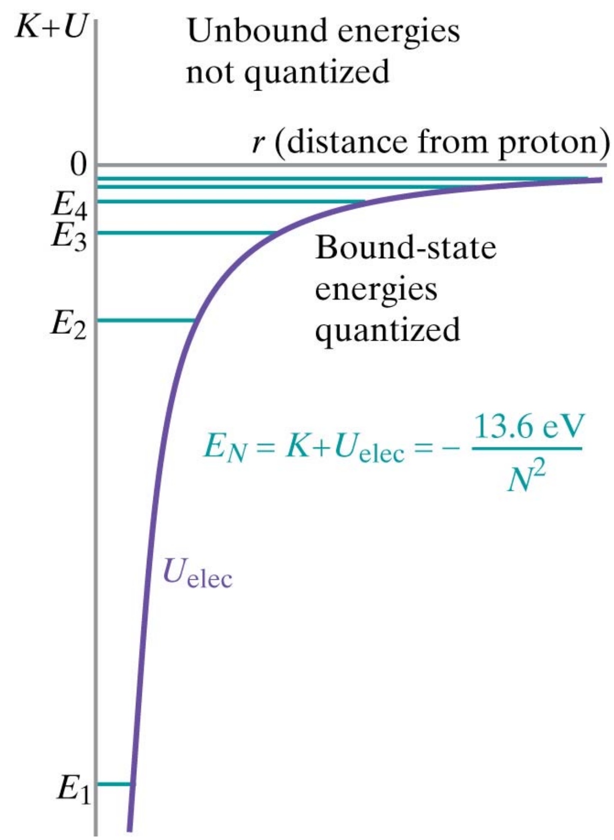
- In Chapter 8 quantization of energy is discussed.
- Quantization of energy leads to well defined emission and absorption patterns in atomic spectra.
- Quantization of energy is observed both at the nuclear and at at the atomic level.
- Sections not included: none (sorry).

Review exam # 3.
Chapter 8.

- Terminology introduced :
  - Energy quantization.
  - Emission and absorption spectra.
  - Temperature dependence of emission and absorption spectra.
  - Vibrational and rotational spectra.

Review chapter 8.
Energy quantization in the hydrogen atom.

- Experiments examining the details of atomic structure showed that the electrons can only occupy certain specific energy levels.
- The measurements show that the total energy of the electron, $K + U$, is equal to $-13.6/N^2$ eV where N is an integer ($N = 1, 2, \ldots$).
- The quantization of the energy levels is a result of quantum-mechanical effects (to be discussed in more detail in Physics 143). Also see chapter 11.

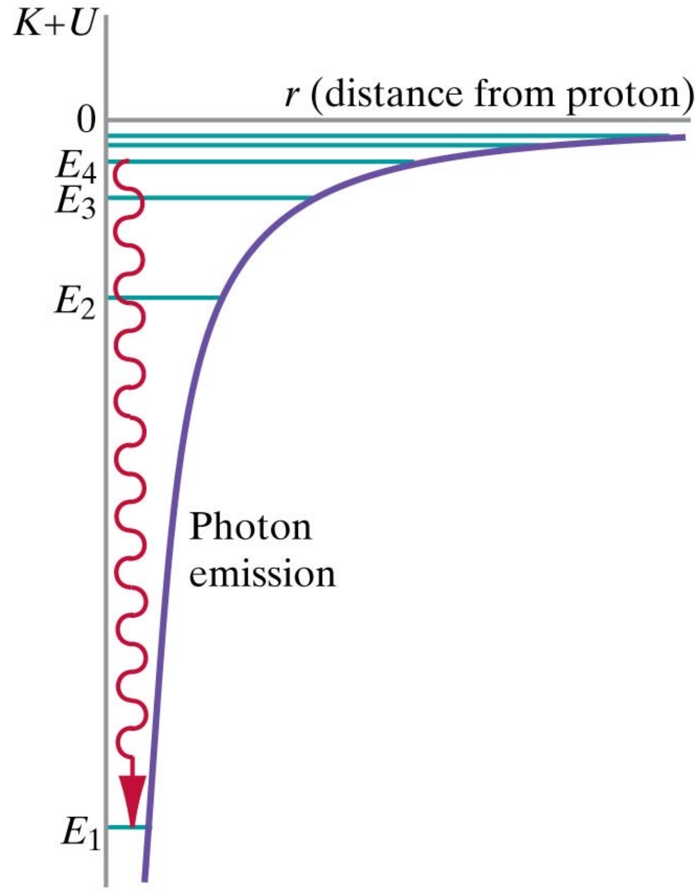


Review chapter 8.
Energy quantization: emission patterns.

- Light is emitted when an excited atom makes a transition to a lower energy level.

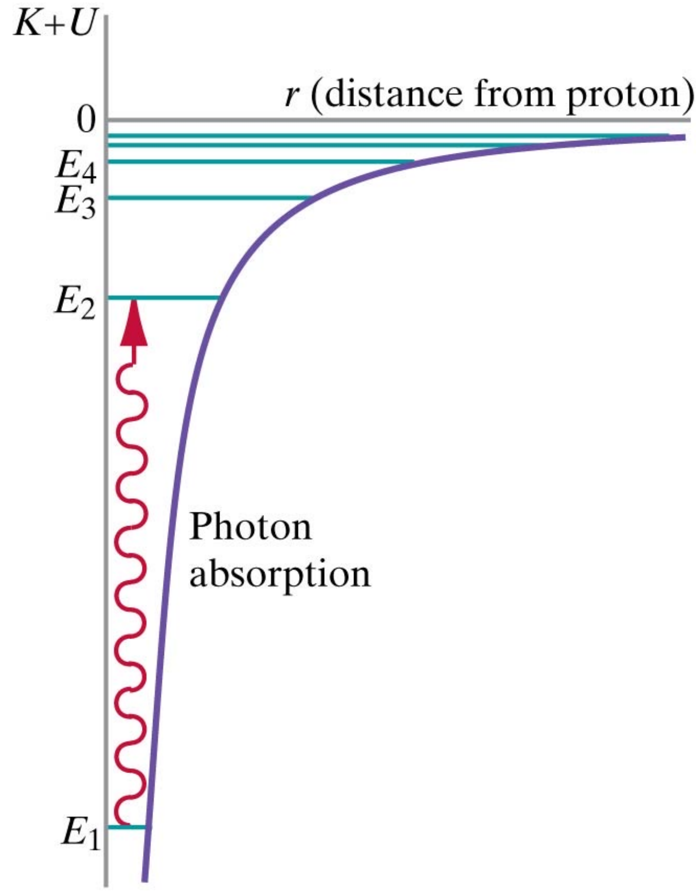
- Since the energy level of atoms are quantized, the light emitted will have discrete wavelengths (energies).

- The energy levels serve as a signature (finger print) for the atom, and the emission pattern can be used to identify the atom.



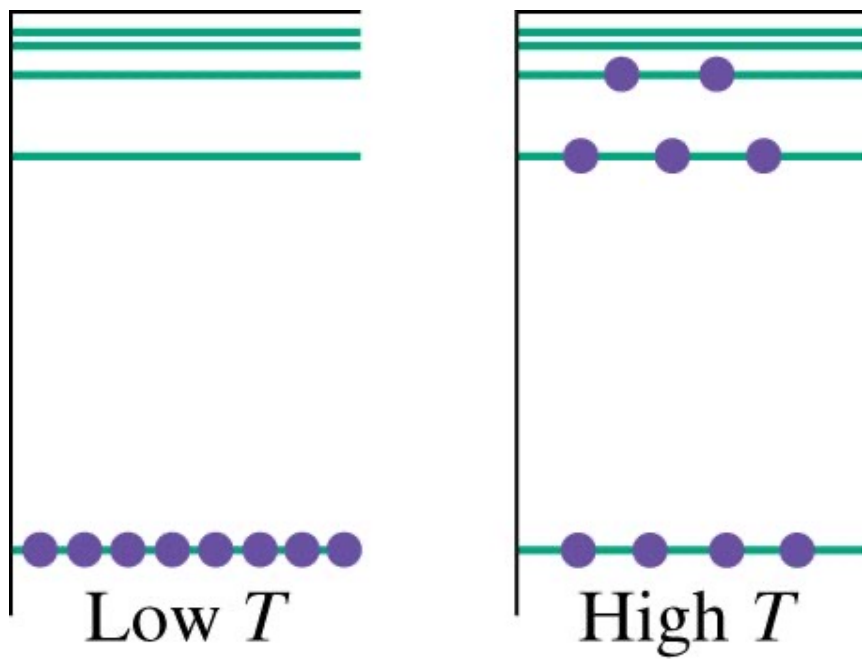
Review chapter 8.
Energy quantization: absorption patterns.

- When an atom is in its ground state, it can only absorb photons of specific frequencies.
- Only photons with an energy that exactly match possible transitions between energy levels in the atom are absorbed by the atom.
- The absorption spectrum can also be used as a signature of the atoms.



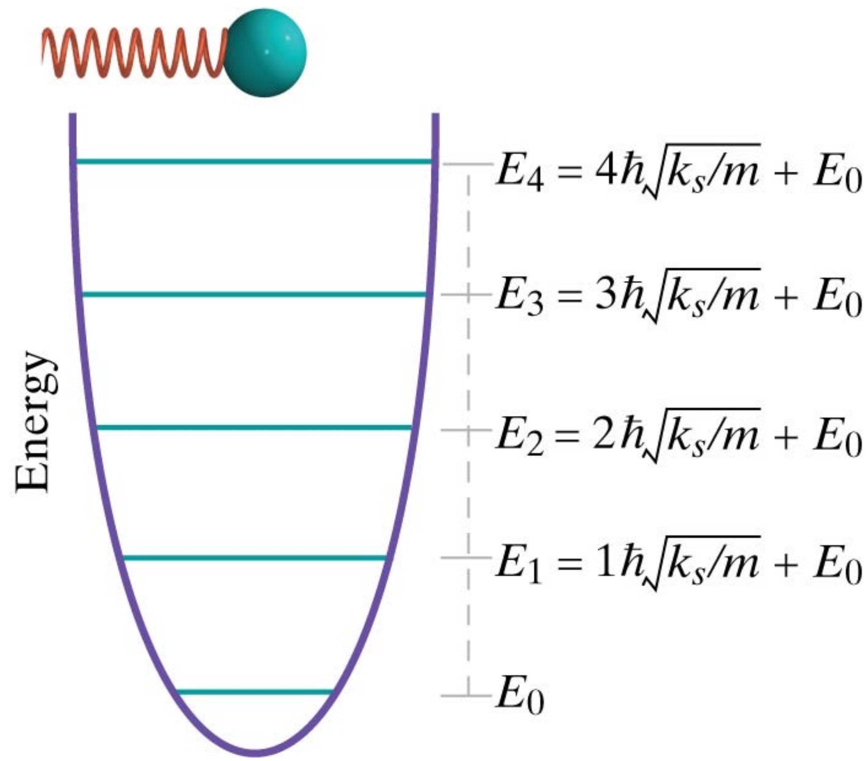
Review chapter 8.
Temperature dependence of absorption.

- The absorption pattern depends on the population of states in the sample.
- Atoms with excited states populated are able to absorb lower-energy light (longer wavelength) since the energy spacing between atomic levels decreases with increasing energy.
- Since the population patterns depends on temperature, we expect to see a temperature dependence of the absorption spectrum.



Review chapter 8.
The vibrational model.

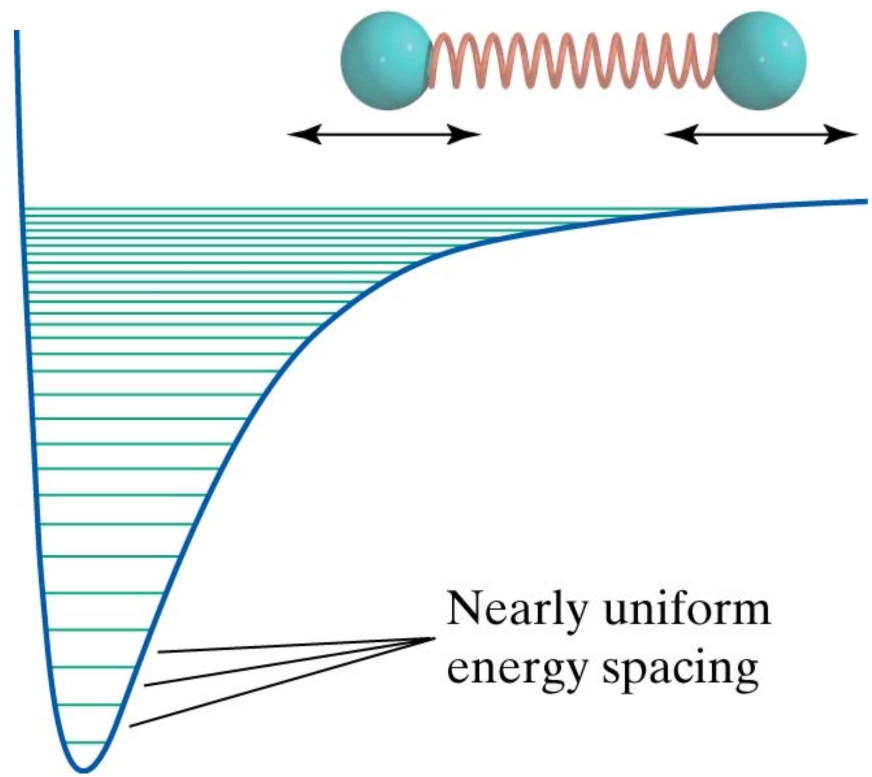
- The effect of the quantum treatment of the "spring" (the vibrational model) is that the energy of the system is quantized.
- It turns out that in many cases a potential well consistent with the spring force is consistent with the observed atomic properties.
- The energy levels in this well are quantized and the spacing between the levels is $(h/2\pi)\sqrt{(k_S/m)}$.
- One important consequence of this quantization is that atoms can only transfer energy to each other in discrete amounts.



Review chapter 8.
The vibrational model.

- When we measure the vibrational energy levels for a two-atomic molecule we find that at low energies the vibrational model works fine (**nearly uniform energy spacing**).

- At higher energies, the potential well starts to deviate from a harmonic oscillator well, and the vibrational energy levels are no longer uniformly spaced.

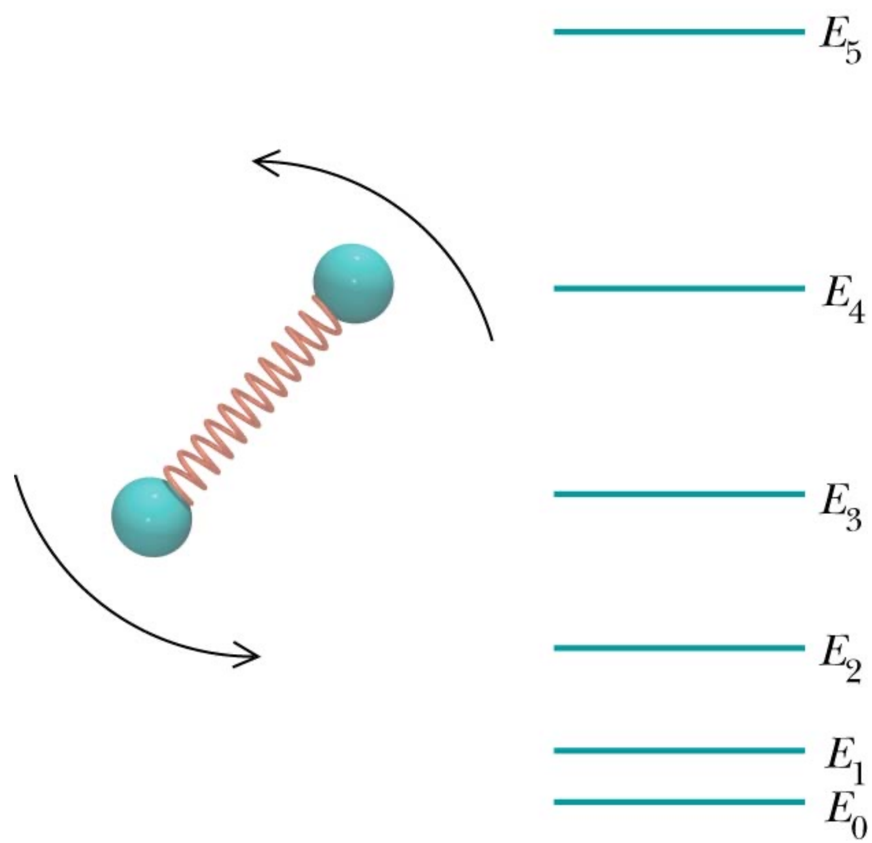


Review chapter 8.
The rotational model.

- Molecules can also carry rotational energy.
- The rotational energy of a molecule is also quantized, but the spacing between levels increases with increasing excitation energy.
- The rotational energy is found to be equal to

$$E_l = \frac{1}{2I} l(l+1)\hbar^2$$

where l is an integer (0, 1, …) and I is the moment of inertia (depends on mass and shape).



Review chapter 8.
Different systems, different energies.

State	Energy level spacing (eV)
Hadronic	100,000,000
Nuclear	1,000,000
Atomic	1
Molecular (vibrational)	0.01
Molecular (rotational)	0.0001

Problem 8.P14.

••P14 Hydrogen atoms: **(a)** What is the minimum kinetic energy in electron volts that an electron must have to be able to ionize a hydrogen atom that is in its ground state (that is, remove the electron from being bound to the proton)? **(b)** If electrons of energy 12.8 eV are incident on a gas of hydrogen atoms in their ground state, what are the energies of the photons that can be emitted by the excited gas? **(c)** If instead of electrons, photons of all energies between 0 and 12.8 eV are incident on a gas of hydrogen atoms in the ground state, what are the energies at which the photons are absorbed?

Review chapter 8.

End of Chapter 8.

Review exam # 3.
Chapter 9.

- In this Chapter, the motion of multi-particle systems is discussed.
- It is found to be useful to describe the motion of a multi-particle systems in terms of the motion of its center of mass.
- The potential and the kinetic energy of a multi-particle system is discussed.
- Excluded sections: 9.5 and 9.6 (but you are expected to understand the outcome of the derivations discussed in these sections).

Review exam # 3.
Chapter 9.

- Terminology introduced :
  - The center of mass.
  - The momentum principle for multi-particle systems.
  - The kinetic energy for multi-particle systems:
    - Translational kinetic energy.
    - Rotational kinetic energy.
    - Vibrational kinetic energy.

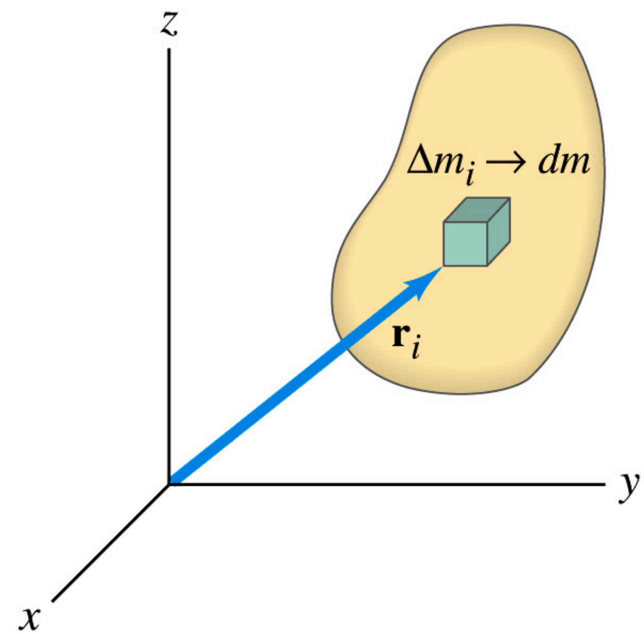
Review chapter 9.
The position of the center of mass.

- The **position of the center of mass** is defined as

$$x_{cm} = \frac{1}{M}\sum_i m_i x_i$$

- If we are not dealing with discreet point masses we need to replace the sum with an integral:

$$\vec{r}_{cm} = \frac{1}{M}\int_V \vec{r}\,dm$$



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Review chapter 9. Motion of the center of mass.

To examine the **motion of the center of mass** we start with its position and then determine its velocity and acceleration:

$$M\vec{r}_{cm} = \sum_i m_i \vec{r}_i$$

$$M\vec{v}_{cm} = \sum_i m_i \vec{v}_i$$

$$M\vec{a}_{cm} = \sum_i m_i \vec{a}_i$$

Review chapter 9.
Motion of the center of mass.

- The expression for $M\vec{a}_{cm}$ can be rewritten in terms of the forces on the individual components:

$$M\vec{a}_{cm} = \frac{d}{dt}(M\vec{v}_{cm}) = \frac{d\vec{P}_{cm}}{dt} = \sum_i m_i \vec{a}_i = \sum_i \vec{F}_i = \vec{F}_{net,ext}$$

- We conclude that **the motion of the center of mass is only determined by the external forces**. Forces exerted by one part of the system on other parts of the system are called internal forces. According to Newton's third law, the sum of all internal forces cancel out (for each interaction there are two forces acting on two parts: they are equal in magnitude but pointing in an opposite direction and cancel if we take the vector sum of all internal forces).

Review chapter 9.
Motion of the center of mass.

- Now consider the special case where there are no external forces acting on the system:

$$\frac{d\vec{P}_{cm}}{dt} = 0$$

- This equations tells us that the total linear momentum of the system is constant.
- In the case of an extended object, we find the total linear momentum by adding the linear momenta of all of its components:

$$\vec{P}_{tot} = M\vec{v}_{cm} = \sum_i m_i \vec{v}_i = \sum_i \vec{p}_i$$

Review chapter 9. Energy of a multi-particle system.

- In order to determine the (mechanical) energy of a multiple-particle system we need to determine both its kinetic energy and its potential energy:
  - The kinetic energy of the system will be the sum of the kinetic energy of the center-of-mass and the kinetic energy of the motion of the particles with respect to the center of mass.
  - The potential energy of the system may or may not depend on the position of the center of mass:
    - The gravitational potential energy can be expressed in terms of the position of the center of mass.
    - The electrostatic potential energy depends on the position of charges, not on the position of mass, and does not depend on the position of the center of mass.

Review chapter 9.
Kinetic energy of a multi-particle system.

- The kinetic energy of a multiple-particle system will have two components:

$$K = \frac{1}{2} M v_{cm}^2 + \frac{1}{2} \sum_i m_i v_i^2 = K_{translational} + K_{relative}$$

  - The **translational component**: the kinetic energy associated with the motion of the center of mass.
  - The **relative component**: the kinetic energy associated with the motion of the particles with respect to the center of mass. This type of motion can be vibrational, rotational, a combination of these two, etc.

Review chapter 9.
Potential energy of a multi-particle system.

- Consider a multi-particle system located close to the surface of the earth.
- The gravitational potential energy of this system is equal to

$$U = \sum_i m_i g y_i = g \sum_i m_i y_i = g M y_{cm}$$

- The gravitational potential energy thus depends on the vertical position of the center of mass of the system.

Problem 9.P43.

••**P43** A string is wrapped around a uniform disk of mass M and radius R. Attached to the disk are four low-mass rods of radius b, each with a small mass m at the end (Figure 9.63).

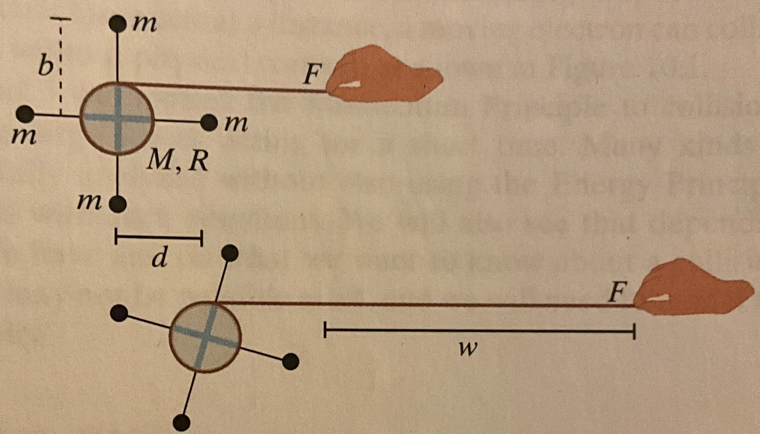


Figure 9.63

The apparatus is initially at rest on a nearly frictionless surface. Then you pull the string with a constant force F. At the instant when the center of the disk has moved a distance d, an additional length w of string has unwound off the disk. **(a)** At this instant, what is the speed of the center of the apparatus? Explain your approach. **(b)** At this instant, what is the angular speed of the apparatus? Explain your approach.

Review chapter 9.

End of Chapter 9.

Review exam # 3.
Chapter 10.

- In this Chapter the momentum principle is used to establish a connection between the collision force and the change in the linear momentum of the collision partners.
- If the collision force is the only force acting on the collision partners, then the total linear momentum (the sum of the momenta of the partners) will be conserved.
- Excluded sections: none (sorry).

Review exam # 3.
Chapter 10.

- Terminology introduced:
  - The collision force.
  - Conservation of linear momentum.
  - Elastic and inelastic collisions.
  - Motion of the center of mass.
  - Describing collisions in the center-of-mass frame.
  - Scattering experiments (Rutherford scattering).

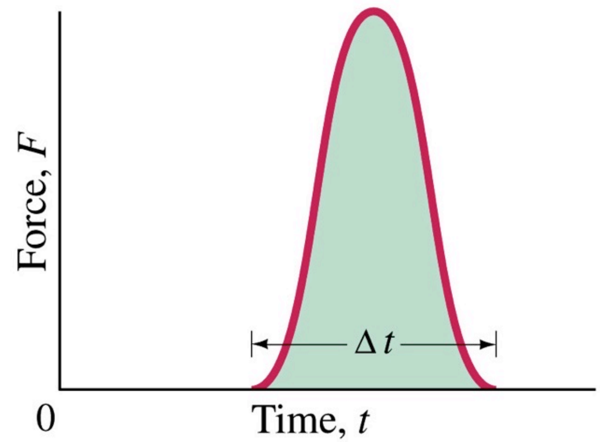
Collisions.
The collision impulse.

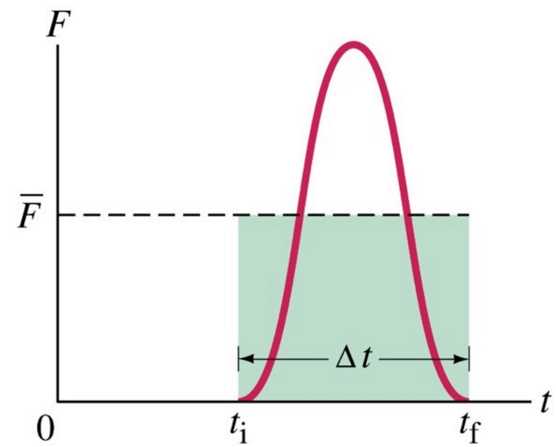
- If we measure the change in the linear momentum of an object, we will obtain information about the integral of the force acting on it:

$$\vec{p}_f - \vec{p}_i = \int_{t_i}^{t_f} \vec{F}(t)dt$$

- The integral of the force is called the collision impulse *J*:

$$\vec{J} = \int_{\vec{p}_i}^{\vec{p}_f} d\vec{p} = \int_{t_i}^{t_f} \vec{F}(t)dt$$





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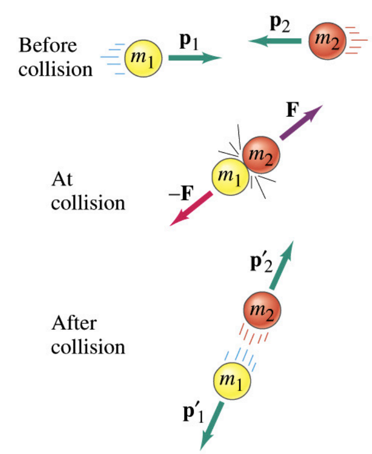
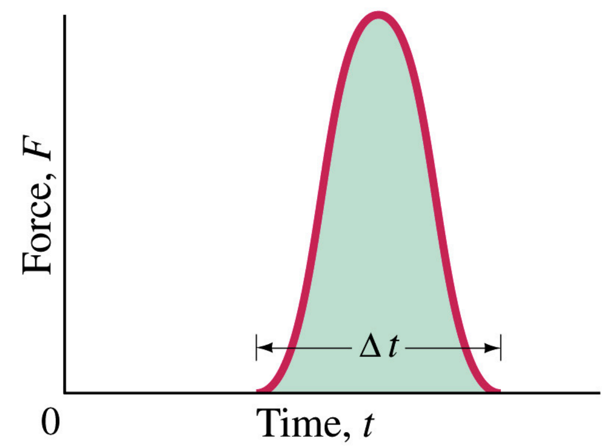
Review chapter 10.
Elastic and inelastic collisions.

- If we consider both colliding object, then the collision force becomes an internal force and the total linear momentum of the system must be conserved if there are no external forces acting on the system.
- Collisions are usually divided into two groups:
  - **Elastic collisions**: kinetic energy is conserved.
  - **Inelastic collisions**: kinetic energy is NOT conserved.





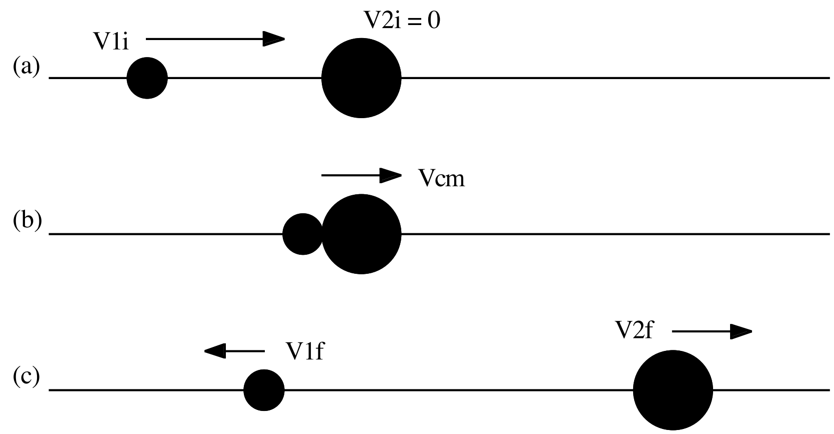
Review chapter 10.
Elastic collisions in one dimension.

- The final state of elastic collisions in one dimension is completely defined if we know the initial conditions.
- The final velocity of mass m_1 is:

$$v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_{1i}$$

- The final velocity of mass m_2 is:

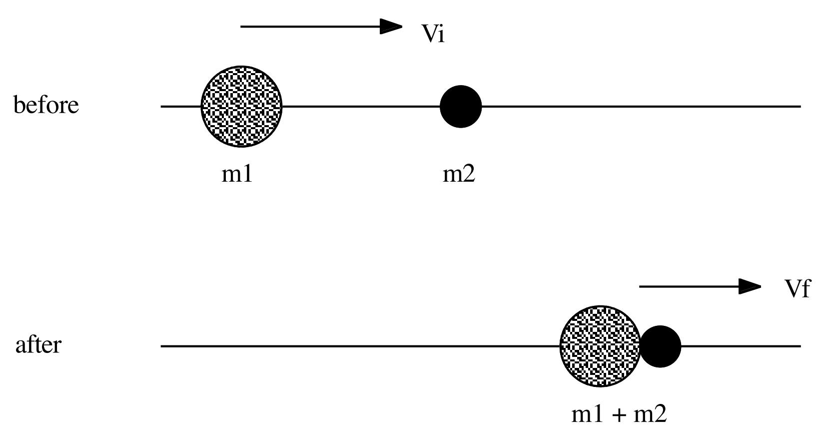
$$v_{2f} = \frac{2m_1}{m_1 + m_2} v_{1i}$$



Review chapter 10.
Inelastic collisions in one dimension.

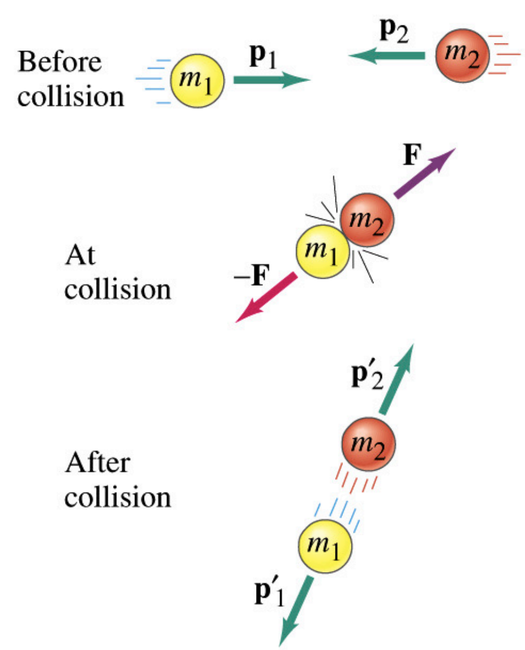
- In inelastic collisions, kinetic energy is not conserved.
- A special type of inelastic collisions are the completely inelastic collisions, where the two objects stick together after the collision.
- Conservation of linear momentum in a completely inelastic collision requires that

$$m_1 v_i = (m_1 + m_2) v_f$$

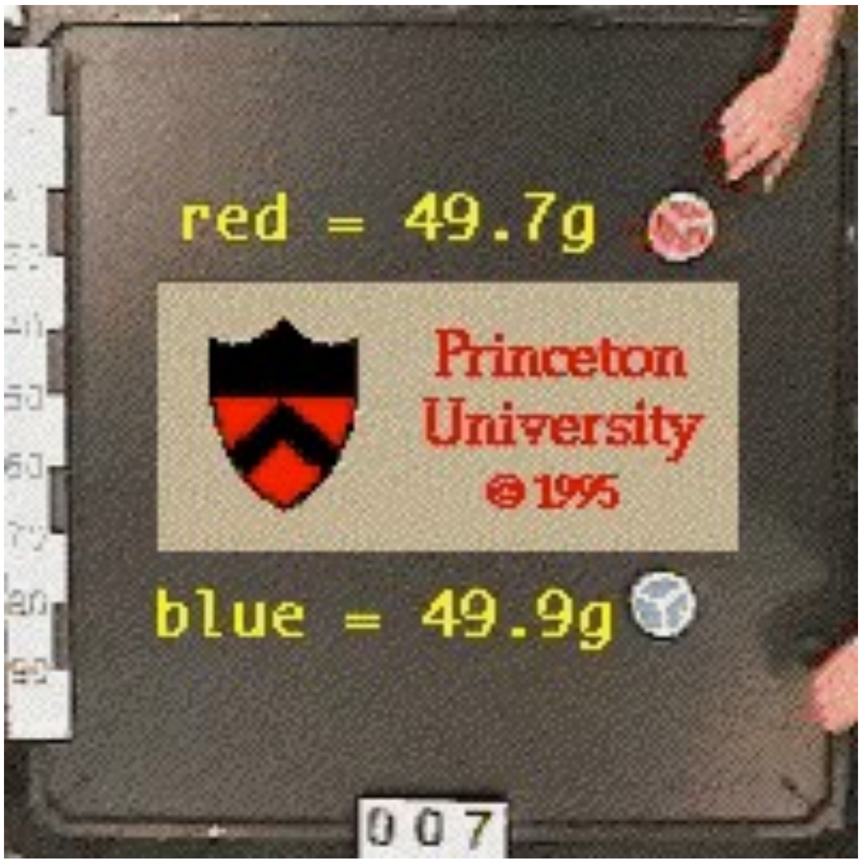


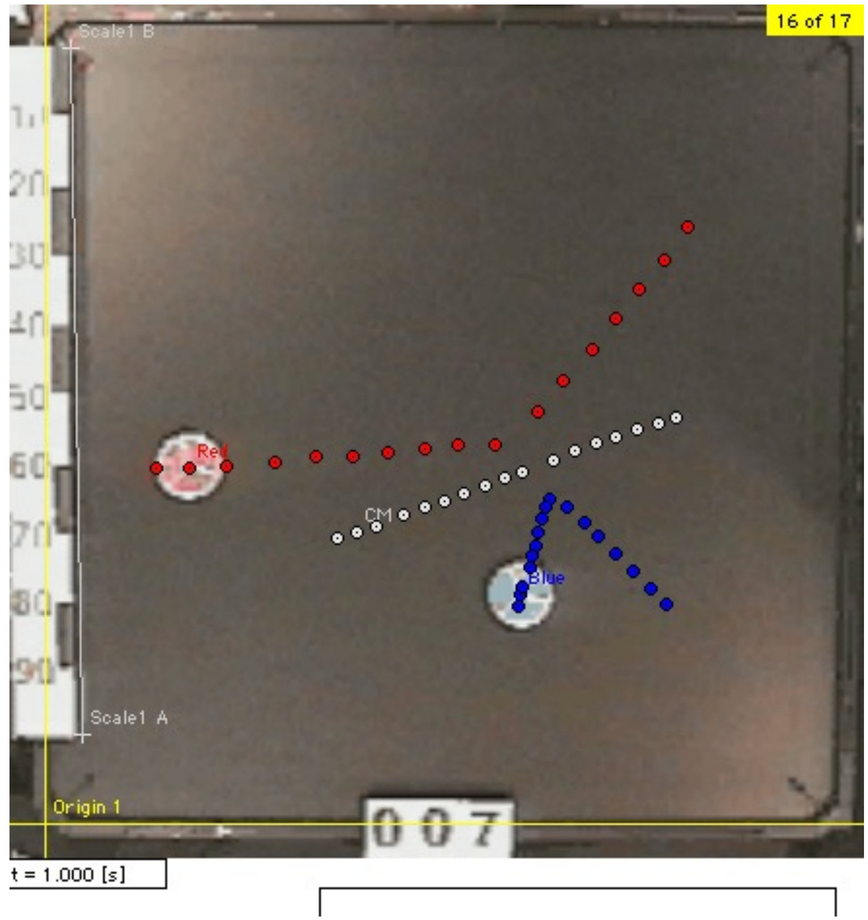
Review chapter 10.
Collisions in two or three dimensions.

- Collisions in two or three dimensions are approached in the same way as collisions in one dimension.
- The x, y, and z components of the linear momentum must be conserved if there are no external forces acting on the system.
- The collisions can be elastic or inelastic.



Review chapter 10.
Motion of the center of mass.





Problem 10.P.30

10.P.37 At the PEP II facility at the Stanford Linear Accelerator Center (SLAC) in California and at the KEKB facility in Japan, electrons with momentum 9.03 GeV/c were made to collide head-on with positrons whose momentum is 3.10 GeV/c ($1\text{ GeV} = 10^9\text{ eV}$); see Figure 10.42. That is, pc for the electron is 9.03 GeV and pc for the positron is 3.10 GeV. The values of pc and the corresponding energies are so large with respect to the electron or positron rest energy (0.5 MeV = 0.0005 GeV) that for the purposes of this analysis you may, if you wish, safely consider the electron and positron to be massless.

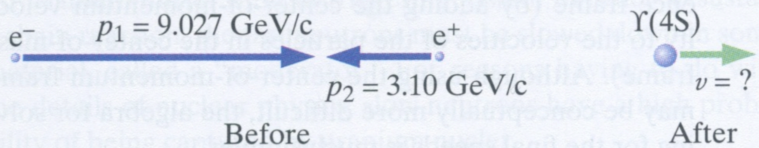


Figure 10.42

(a) The electron-positron collision produces in an intermediate state a particle called the $\Upsilon(4S)$ ("Upsilon 4S"), in the reaction $e^- + e^+ \rightarrow \Upsilon(4S)$. Show that the rest energy of the $\Upsilon(4S)$ is 10.58 GeV.

(b) What is the speed of the $\Upsilon(4S)$ produced in the collision?

(c) The $\Upsilon(4S)$ decays almost immediately into two "B" mesons: $\Upsilon(4S) \rightarrow B^0 + \overline{B^0}$. The $\overline{B^0}$ is the antiparticle of the B^0 and has the same rest energy $Mc^2 = 5.28$ GeV as the B^0. Consider the case in which both "B" mesons are emitted at the same angle θ to the direction of the moving $\Upsilon(4S)$, as shown in Figure 10.43. Calculate this angle θ.

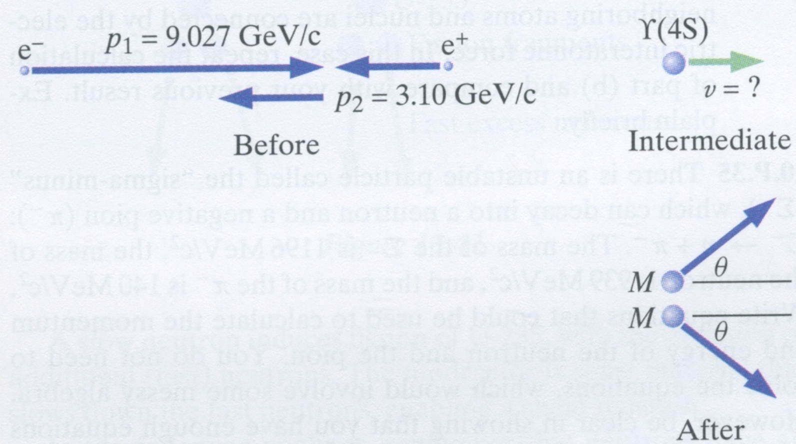


Figure 10.43

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Review Midterm Exam # 3.
Chapter 11.

- The focus of this Chapter is rotational motion and angular momentum.
- Rotational motion and angular momentum is described in terms of angular variables, such as angular position, velocity, and acceleration, and torque.
- There is a great deal of symmetry between the way we use linear variables and the way we use of angular variables.
- We discussed the requirements of conservation of angular momentum (no external torques)
- We also discussed the concept and consequences of the quantization of angular momentum.

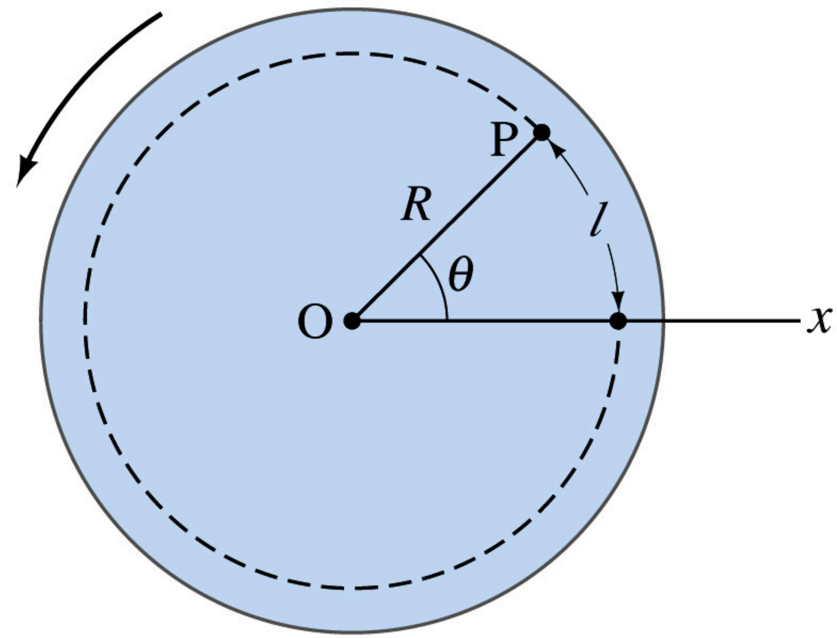
- Sections excluded: 11.12 (page 453 – 455), and 11.13.

Review Midterm Exam # 3. Chapter 11.

- Terminology introduced:
  - Angular position, velocity, and acceleration.
  - Rotation axis.
  - Moment of inertia.
  - Rolling motion.
  - Torque.
  - Angular momentum.

Review Chapter 11. Rotational variables.

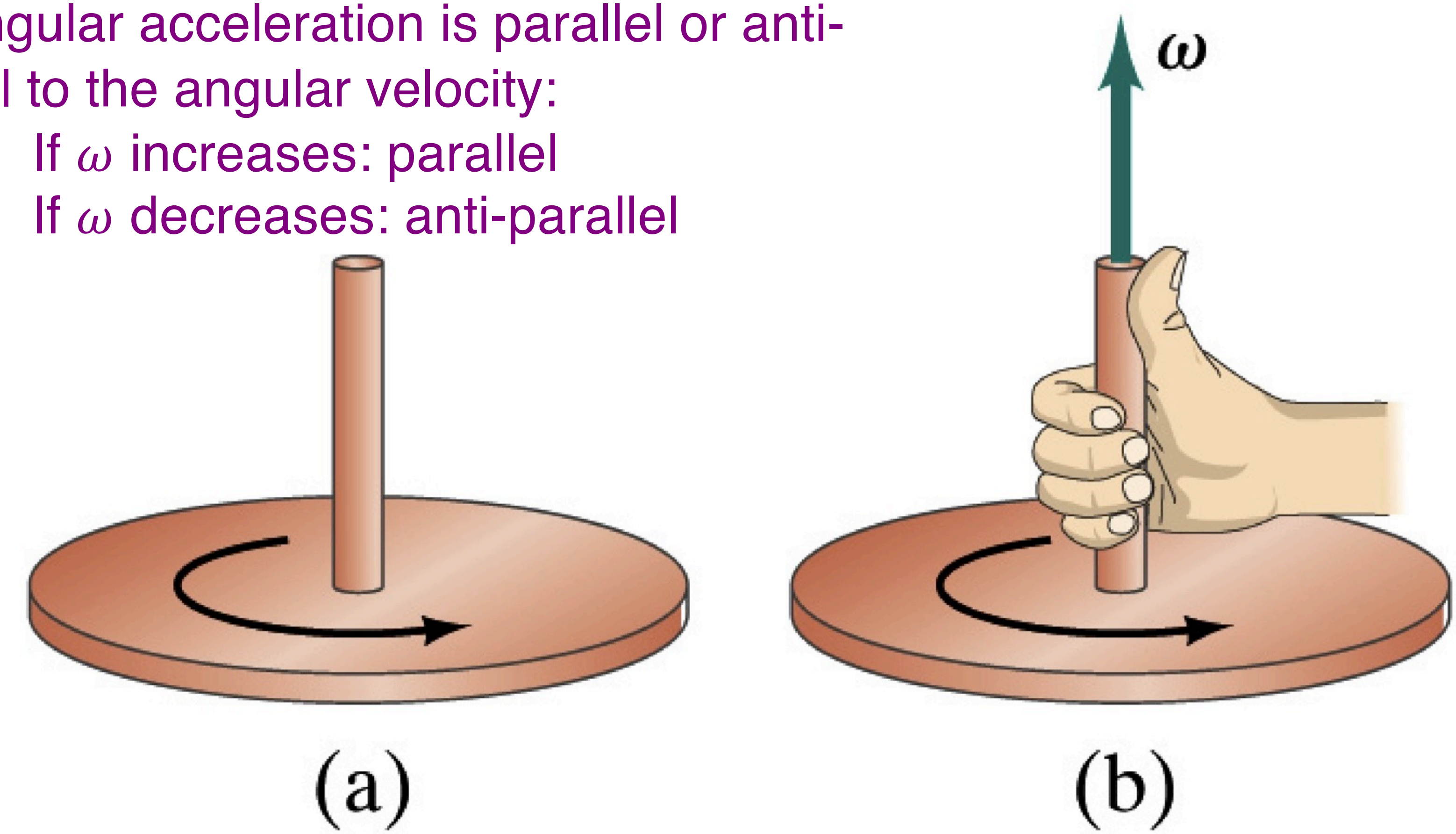
- The variables that are used to describe rotational motion are:
  - Angular position θ
  - Angular velocity $\omega = d\theta/dt$
  - Angular acceleration $\alpha = d\omega/dt$
- The rotational variables are related to the linear variables:
  - Linear position $l = R\theta$
  - Linear velocity $v = R\omega$
  - Linear acceleration $a = R\alpha$



Review Chapter 11.
Rotational variables.

Angular velocity and acceleration are vectors! They have a magnitude and a direction. The direction of ω is found using the right-hand rule.
The angular acceleration is parallel or anti-parallel to the angular velocity:

If ω increases: parallel
If ω decreases: anti-parallel



Review Chapter 11.
The moment of inertia.

- The kinetic energy of a rotation body is equal to

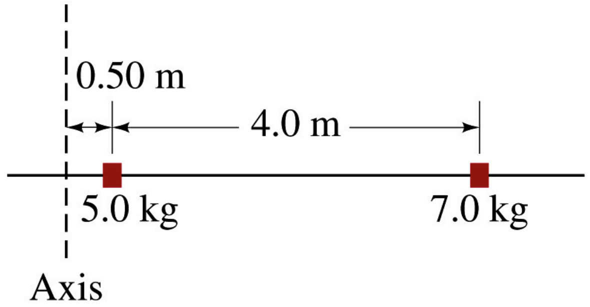
$$K = \frac{1}{2} I\omega^2$$

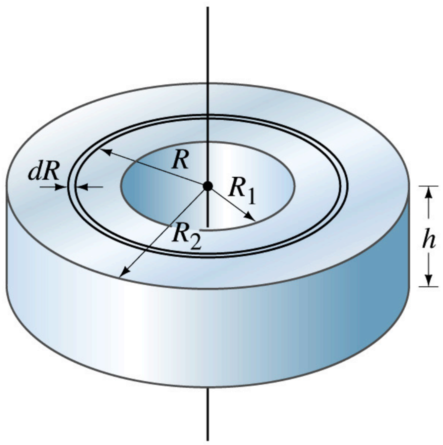
where I is the moment of inertia which is defined (for discrete mass distributions) as

$$I = \sum_i m_i r_i^2$$

- For continuous mass distributions I is defined as

$$I = \int r^2 dm$$





Review Chapter 11.
Moments of inertia.

- As part of the exam, you will receive a table of moments of inertia for various objects (see Figure on the right).

- You need to know who to determine the moment of inertia using the parallel-axis theorem.

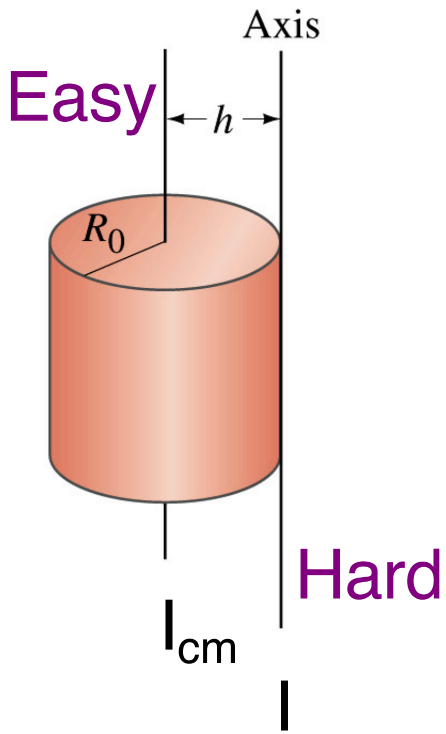
Moments of inertia of various objects of uniform composition.

	Object	Location of axis	Moment of inertia
(a)	Thin hoop of radius R_0	Through center	MR_0^2
(b)	Thin hoop of radius R_0 and width w	Through central diameter	$\frac{1}{2}MR_0^2 + \frac{1}{12}Mw^2$
(c)	Solid cylinder of radius R_0	Through center	$\frac{1}{2}MR_0^2$
(d)	Hollow cylinder of inner radius R_1 and outer radius R_2	Through center	$\frac{1}{2}M(R_1^2 + R_2^2)$
(e)	Uniform sphere of radius r_0	Through center	$\frac{2}{5}Mr_0^2$
(f)	Long uniform rod of length l	Through center	$\frac{1}{12}Ml^2$
(g)	Long uniform rod of length l	Through end	$\frac{1}{3}Ml^2$
(h)	Rectangular thin plate, of length l and width w	Through center	$\frac{1}{12}M(l^2 + w^2)$

Review Chapter 11.
Parallel-axis theorem.

- Calculating the moment of inertial with respect to a symmetry axis of the object is in general easy.
- It is much harder to calculate the moment of inertia with respect to an axis that is not a symmetry axis.
- However, we can make a hard problem easier by using the parallel-axis theorem:

$$I = I_{cm} + Mh^2$$



Review Chapter 11.
Torque.

- Consider rewriting the previous equation in the following way:

$$rF\sin(\phi) = I\alpha$$

- The left-hand-side of this equation is called the torque τ of the force F:

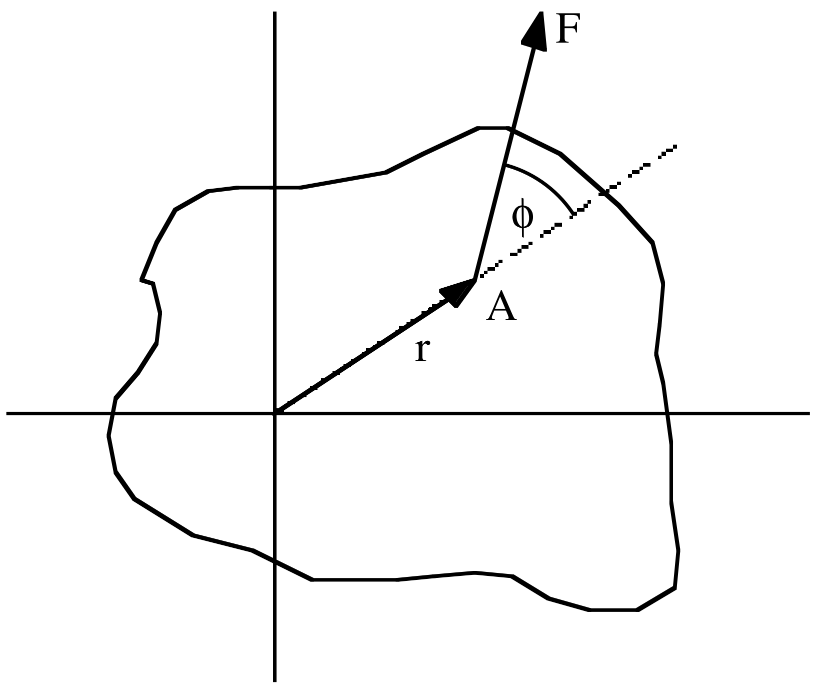
$$\tau = I\alpha$$

- This equation looks similar to Newton's second law for linear motion:

$$F = ma$$

- Note:

linear	rotational
mass m	moment I
force F	torque τ



Review Chapter 11.
Rolling motion.

- Rolling motion is a combination of translational and rotational motion.
- The kinetic energy of rolling motion has thus two contributions:
  - Translational kinetic energy:

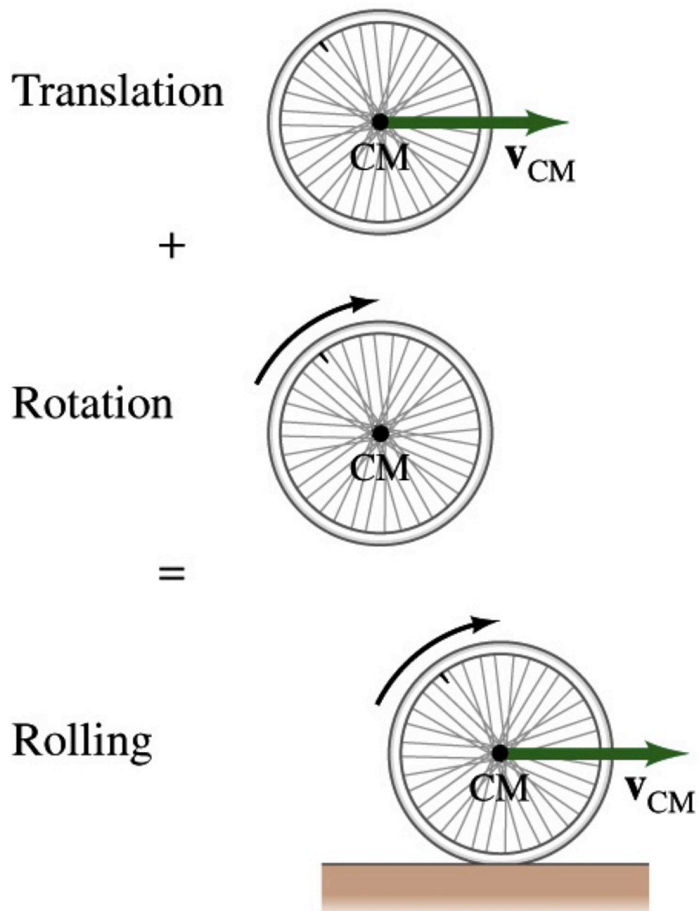
$$K_{translational} = \frac{1}{2} M v_{cm}^2$$

  - Rotational kinetic energy:

$$K_{rotational} = \frac{1}{2} I_{cm} \omega^2$$

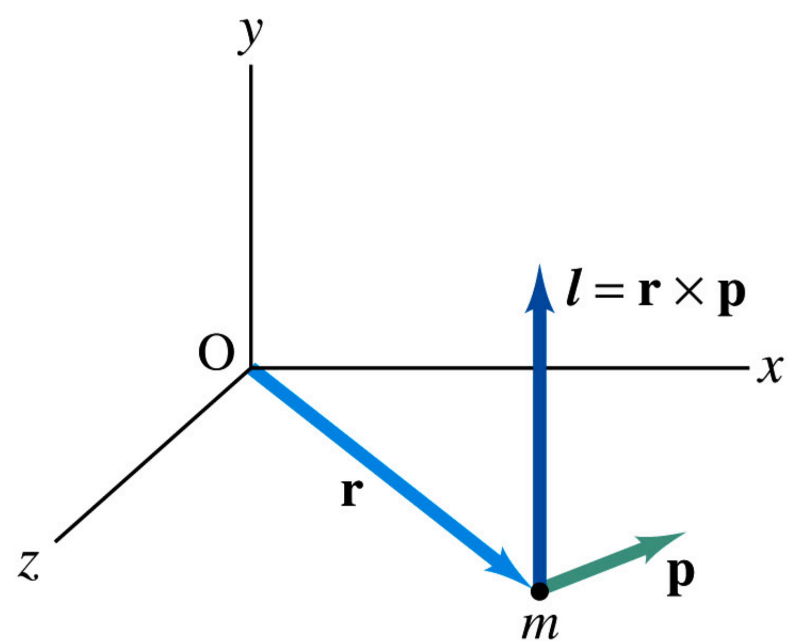
- Assuming that the wheel does not slip we know that

$$\omega = \frac{v_{cm}}{R}$$



Review Chapter 11. Angular momentum.

- The angular momentum is defined as the vector product between the position vector and the linear momentum.
- Note:
  - Compare this definition with the definition of the torque.
  - Angular momentum is a vector.
  - The unit of angular momentum is kg m^2/s.
  - The angular momentum depends on both the magnitude and the direction of the position and linear momentum vectors.
  - Under certain circumstances the angular momentum of a system is conserved!

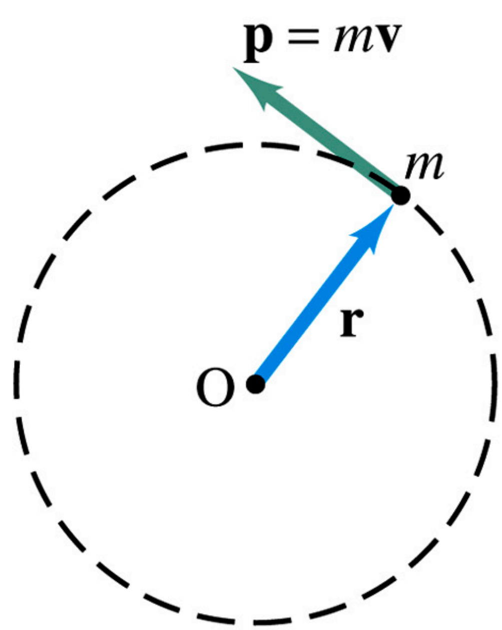


Review Chapter 11.
Angular momentum and circular motion.

- Consider an object carrying out circular motion.
- For this type of motion, the position vector will be perpendicular to the momentum vector.
- The magnitude of the angular momentum is equal to the product of the magnitude of the radius r and the linear momentum p:

$$L = mvr = mr^2 \frac{v}{r} = I\omega$$

- Note: compare this with $p = mv$!



Review Chapter 11.
Conservation of angular momentum.

- Consider the change in the angular momentum of a particle:

$$\frac{d\vec{L}}{dt} = \frac{d}{dt}(\vec{r}\times\vec{p}) = m\left(\vec{r}\times\frac{d\vec{v}}{dt} + \frac{d\vec{r}}{dt}\times\vec{v}\right) = m(\vec{r}\times\vec{a} + \vec{v}\times\vec{v}) =$$

$$= \vec{r}\times m\vec{a} = \vec{r}\times\sum\vec{F} = \sum\vec{\tau}$$

- When the net torque is equal to 0 Nm:

$$\sum\vec{\tau} = 0 = \frac{d\vec{L}}{dt} \Longrightarrow \vec{L} = \text{constant}$$

- When we take the sum of all torques, the torques due to the internal forces cancel and the sum is equal to torque due to all external forces.

Review Chapter 11.
Quantization of angular momentum.

- Consider the "classical" picture of the motion of electrons in atoms.
- If the angular momentum is a integer multiple of $\hbar$, the orbit must be such that

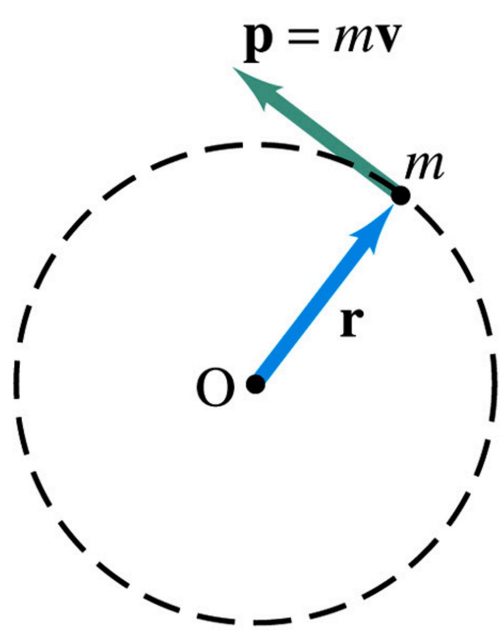
$$rp = N\hbar$$

- In order to carry out circular motion, the force on the electron must be equal to

$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r} = \frac{p^2}{mr}$$

- These requirements can be used to determine the total energy of the electron

$$E = -\frac{1}{2}\left(\frac{1}{4\pi\varepsilon_0}\right)^2 \frac{me^4}{N^2\hbar^2} = -\frac{13.6}{N^2}\ \text{eV}$$



Review Chapter 11.
Quantization of angular momentum.

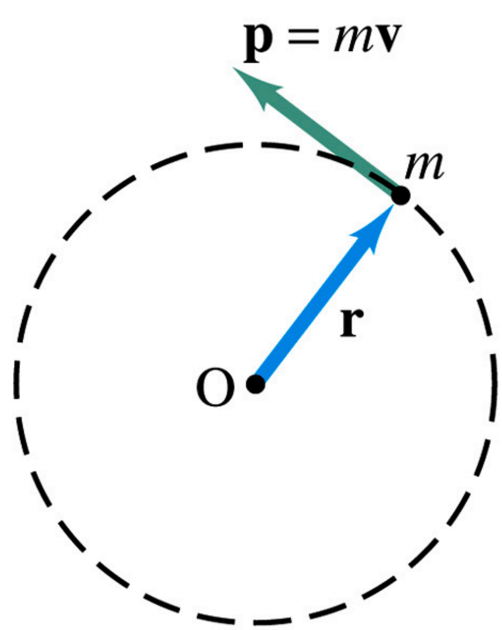
- Consider the "classical" picture of the motion of electrons in atoms.
- The angular momentum is a integer multiple of $h/2\pi$, the orbit must be such that

$$rp = N\frac{h}{2\pi} = N\hbar$$

- This leads to a quantization of the orbital radius and energy:

$$r = 4\pi\varepsilon_0 \frac{N^2\hbar^2}{me^2}$$

$$E = K + U = -\frac{1}{2}\left(\frac{1}{4\pi\varepsilon_0}\right)^2 \frac{me^4}{N^2\hbar^2} = -\frac{13.6}{N^2}\ \text{eV}$$



Example Problem: Problem 11.P33.

••P33 Let's compare the Momentum Principle and the Angular Momentum Principle in a simple situation. Consider a mass m falling near the Earth (Figure 11.85). Neglecting air resistance, the Momentum Principle gives $dp_y/dt = -mg$, yielding $dv_y/dt = -g$ (nonrelativistic). Choose a location A off to the side, on the ground. Apply the Angular Momentum Principle to find an algebraic expression for the rate of change of angular momentum of the mass about location A.

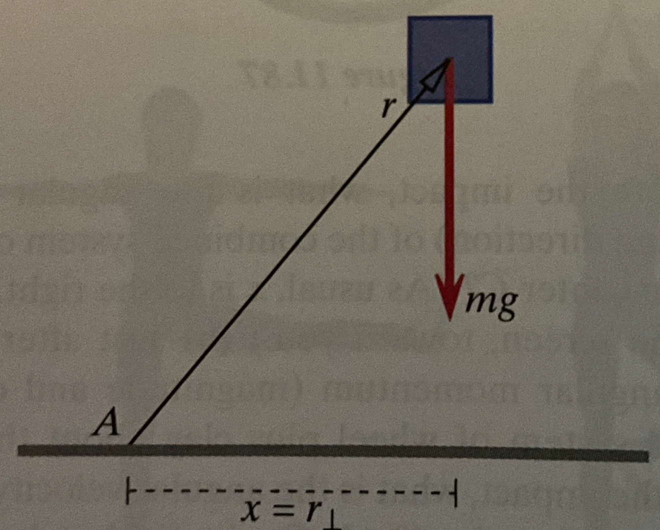


Figure 11.85

Review Midterm Exam # 3. Equilibrium.

- This topics focuses on the conditions for equilibrium.
- The conditions for equilibrium are:
  - First condition: net force = 0 N
  - Second condition: net torque = 0 Nm
- Both conditions must be satisfied for the object to be equilibrium.
- Static equilibrium:
  - The conditions for equilibrium are met.
  - $P = 0$ kg m/s
  - $L = 0$ kg m^2/s

Review Midterm Exam # 3. Equilibrium.

- Equilibrium in 3D:

$$\sum F_x = 0 \qquad \sum \tau_x = 0$$

$$\sum F_y = 0 \qquad \sum \tau_y = 0$$

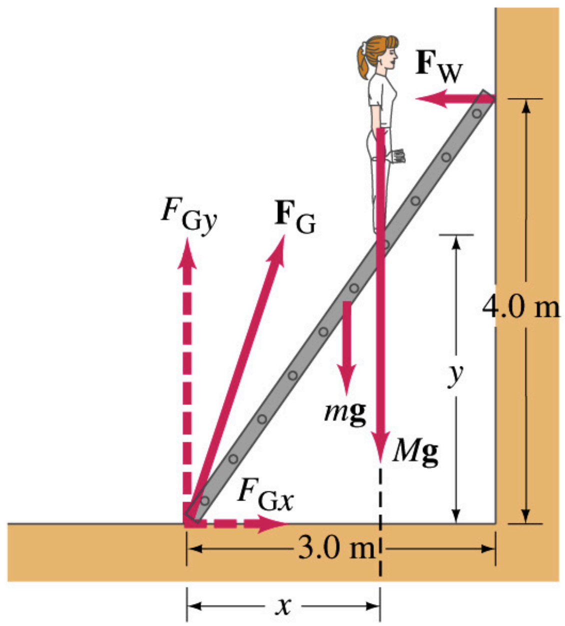
$$\sum F_z = 0 \qquad \sum \tau_z = 0$$

With respect to every reference point!

- Equilibrium in 2D:

$$\sum F_x = 0$$

$$\sum F_y = 0 \qquad \sum \tau_z = 0$$



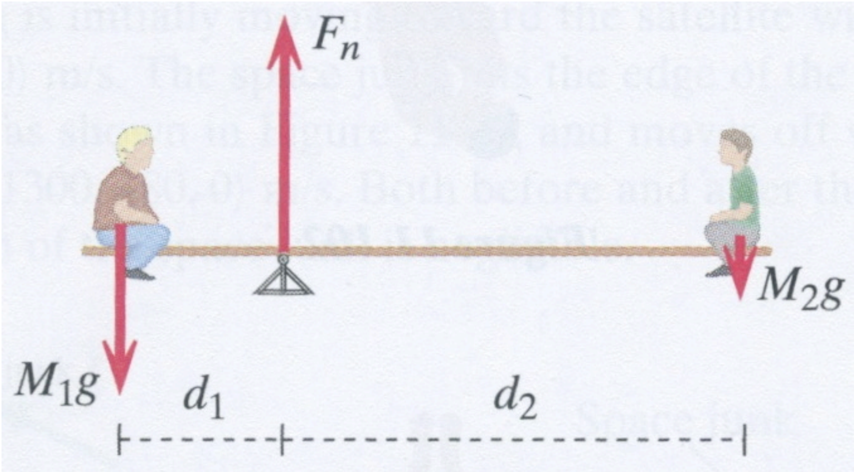
Example Problem
Problem 11.P56

- Calculate the torque due to the gravitational force of each person.

- Can you determine the normal force F_N?

- What is the net torque with respect to the pivot point?

- When will the seesaw
  - Rotate clockwise?
  - Rotate counter clockwise?
  - No rotate?



Study tips.

- Review the homework assignments related to this material and look at the solutions that are posted on the WEB.

- Review the end-of-chapter problems, especially those for which you have received the solutions. However, make sure you read **all** other problems and determine if you know what approach to take to solve them.

- Use the practice exams to determine how well prepared you are for the exam.

Good luck preparing for exam # 3.