

Physics 141.  
Lecture 20.



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Comparing numbers.  
Conclusion?



Delta: 6 hour flight.



KLM: 40 minute flight.

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Another important fact.  
November 16 is "Dutch-American Heritage Day"

On November 16, 1776, a small American warship, the ANDREW DORIA, sailed into the harbor of the tiny Dutch island of St. Eustatius in the West Indies. Only 4 months before, the United States had declared its independence from Great Britain. The American crew was delighted when the Governor of the island, Johannes de Graaf, ordered that his fort's cannons be fired in a friendly salute. The first ever given by a foreign power to the flag of the United States, it was a risky and courageous act. Indeed, angered by Dutch trading of contraband with the rebellious colonies, the British seized the island a few years later. De Graaf's welcoming salute was also a sign of respect, and today it continues to symbolize the deep ties of friendship that exist between the United States and The Netherlands.

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## Physics 141. Lecture 20.

- Course Information.
- Quiz
- Topic to be discussed today (not discussed in detail in the text book):
  - Equilibrium.

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## Physics 141. Course information.

- Homework # 8 is due on Friday November 17.
- Homework # 9 (WebWork only) is due on Wednesday November 22.
- No recitations and regular office hours during the week of Thanksgiving. Extra office hours on Monday November 20 to answer questions related to homework # 9.
- Exam # 3, scheduled for November 28, covers Chapters 8, 9, 10, and 11. A review of the material covered is scheduled for Tuesday November 21.

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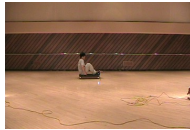
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## Analysis of experiment # 5. Timeline (more details during next lectures).

- ✓ 11/14: collisions in the May room
- 11/20: analysis files available.
  - <https://www.pas.rochester.edu/~tdimino/phy141/lab05/>
- 11/20: each student has determined his/her best estimate of the velocities before and after the collisions (analysis during regular lab periods).
- 11/21: complete discussion and comparison of results with colliding partners and submit final results (velocities and errors).
- 11/25: results will be compiled, linear momenta and kinetic energies will be determined, and results will be distributed.
- 12/4: office hours by lab TA/TIs to help with analysis and conclusions.
- 12/6: students submit lab report # 5.



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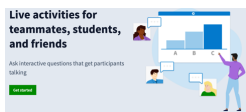
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Quiz lecture 20.  
[PollEv.com/frankwolfs050](https://poll-ev.com/frankwolfs050)

- The quiz today will have three questions.
- I will collect your answers electronically using the Poll Everywhere system.
- You have 30 seconds to answer each question.



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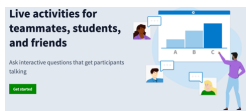
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Concept test lecture 20.  
[PollEv.com/frankwolfs050](https://poll-ev.com/frankwolfs050)

- The concept test today will have two questions.
- I will collect your answers electronically using the Poll Everywhere system.
- After submitting your answer, I will give you time to discuss the question with your neighbor(s) before submitting a new answer.



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Equilibrium.

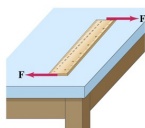
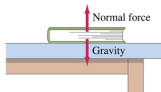
- An object is in equilibrium if the following conditions are met:

Net force = 0 N (**first** condition for equilibrium)

and

Net torque = 0 Nm (**second** condition for equilibrium)

- Note: both conditions must be satisfied. Even if the net force is 0 N, the system can start to rotate if the net torque is not equal to 0 Nm.



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## Static equilibrium.

- What happens when the net force is equal to 0 N?
  - $P = \text{constant}$
- What happens when the net torque is equal to 0 Nm?
  - $L = \text{constant}$
- We conclude that an object in equilibrium can still move (with constant linear velocity) and rotate (with constant angular velocity).
- Conditions for **static** equilibrium:
  - $P = 0 \text{ kg m/s}$
  - $L = 0 \text{ kg m}^2/\text{s}$

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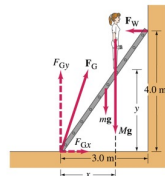
## Using rotational motion to study equilibrium: equilibrium conditions.

- Equilibrium in 3D:

$$\begin{aligned} \sum F_x &= 0 & \sum \tau_x &= 0 \\ \sum F_y &= 0 & \text{and } \sum \tau_y &= 0 \\ \sum F_z &= 0 & \sum \tau_z &= 0 \end{aligned}$$

- Equilibrium in 2D:

$$\begin{aligned} \sum F_x &= 0 \\ \sum F_y &= 0 \\ \sum \tau_z &= 0 \end{aligned}$$



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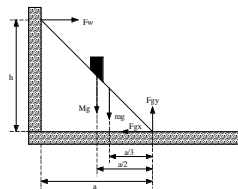
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## Using rotational motion to study equilibrium: equilibrium conditions.

- A ladder with length  $L$  and mass  $m$  rests against a wall. Its upper end is a distance  $h$  above the ground. The center of gravity of the ladder is one-third of the way up the ladder. A firefighter with mass  $M$  climbs halfway up the ladder. Assume that the wall, but not the ground, is frictionless. What is the force exerted on the ladder by the wall and by the ground?



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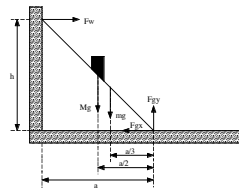
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## Using rotational motion to study equilibrium: equilibrium conditions.

- Forces exerted by the wall and the floor:

- The wall exerts a horizontal force (normal force).
- The floor exerts a vertical force (normal force) and a horizontal force (friction force).

- Note: the friction force must be present in order to ensure that the net force in the horizontal direction is 0 N.



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## Using rotational motion to study equilibrium: equilibrium conditions.

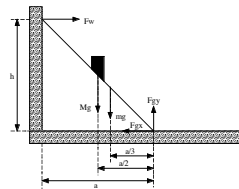
- The first condition for equilibrium requires that

$$\sum F_x = F_w - F_{gx} = 0$$

and

$$\sum F_y = F_{fy} - Mg - mg = 0$$

- Two equations with three unknown. We need more information! But we still have the third condition for equilibrium.



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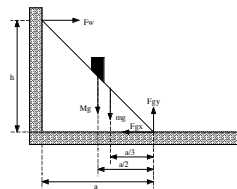
## Using rotational motion to study equilibrium: equilibrium conditions.

- The second condition for equilibrium requires:

$$\sum \tau_z = hF_w - Mg\frac{a}{2} - mg\frac{a}{3} = 0$$

- Note: we have used the resting point on the ground as our reference point. The torque due to the two forces acting on this point do not contribute to the torque with this choice of reference point. We can now determine  $F_w$  easily:

$$F_w = \frac{1}{h} \left( Mg\frac{a}{2} + mg\frac{a}{3} \right) = \frac{ga}{h} \left( \frac{1}{2}M + \frac{1}{3}m \right)$$



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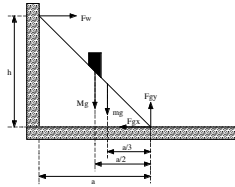
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## Using rotational motion to study equilibrium: equilibrium conditions.

- By examining the net force in the horizontal direction, we can determine the friction force:

$$F_{gx} = F_{fr} = \frac{ga}{h} \left( \frac{1}{2}M + \frac{1}{3}m \right)$$

- Note: the frictional force depends on the position of the firefighter and increases when the firefighter climbs the ladder.
- Since the frictional force must be less than  $\mu_s F_{gy}$ , there may be a maximum height that can be reached by the firefighter above which the ladder will slip.



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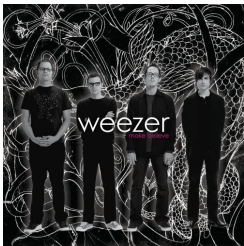
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## 4 Minute 14 Second Intermission.



- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 4 minute 14 second intermission.

- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Solve a WeBWorK problem.



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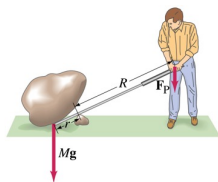
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## Equilibrium. Be sure to include all forces!!!

- When evaluating conditions for equilibrium, you need to make sure to include all forces acting on the system.
- In the system shown in the Figure, there are more forces acting on the system than the forces indicated. For example, there should be an upward force to balance the downward forces.
- Of course, the problem is how to apply the equilibrium conditions correctly.



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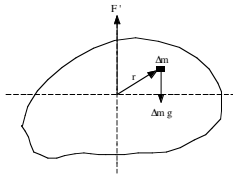
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## Equilibrium. The force of gravity.

- Consider an extended rigid object that can rotate around a specific rotation point.
- If the rotation point coincides with the center-of-gravity of the object, it will be in static equilibrium in any orientation.
- What is the relation between the position of the center of mass and the position of the center of gravity?



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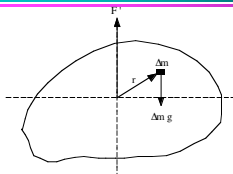
## Equilibrium. The force of gravity.

- If the object is in equilibrium, the net torque and the net force acting on it must be equal to 0.
- The net force acting on the object is equal to

$$\begin{aligned} \sum \vec{F} &= (F' - \sum \Delta m g) \hat{y} = \\ &= (F' - g \sum \Delta m) \hat{y} = (F' - Mg) \hat{y} \end{aligned}$$

- If the net force is equal to 0 N, we must require that

$$F' = Mg$$



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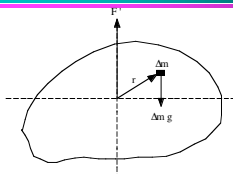
## Equilibrium. The force of gravity.

- The condition that  $F' = Mg$  is not sufficient for static equilibrium. We must also require that the net torque is equal to 0 Nm.
- The net torque acting on the object is equal to

$$\sum \vec{\tau} = \sum \{ \vec{r} \times (\Delta m \vec{g}) \} = (\sum \Delta m \vec{r}) \times \vec{g} = M \vec{r}_{cm} \times \vec{g}$$

- If the net torque must be 0 Nm, we must require that

$$M \vec{r}_{cm} \times \vec{g} = 0$$



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## Equilibrium. The force of gravity.

- The system will be in equilibrium if

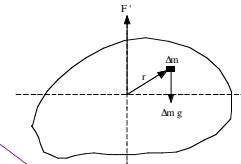
$$M\vec{r}_{cm} \times \vec{g} = 0$$

- This requires that

The center-of-gravity is located exactly below or above the rotation axis ( $r_{cm}$  parallel to vertical axis).

or

The center-of-gravity coincides with the rotation axis ( $r_{cm} = 0$ )



Used to determine the location of the center-of gravity of an object.

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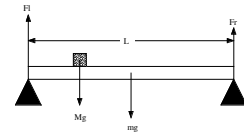
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## Equilibrium. Sample problem.

- A uniform beam of length  $L$  whose mass is  $m$ , rest with its ends on two digital scales. A block whose mass is  $M$  rests on the beam, its center one-fourth away from the beam's left end. What do the scales read?



- If the system is in equilibrium, the net force must be 0 N:

$$\sum F_y = F_l + F_r - Mg - mg = 0$$

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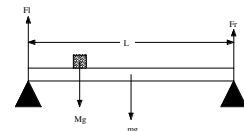
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## Equilibrium. Sample problem.

- If the system is in equilibrium, the net torque must be 0 Nm.
- Note: the torque associated with a force depends on the choice of the origin. The condition that the torque must be 0 Nm must be satisfied with respect to any choice of origin.
- If we choose the left scale as our origin, the left "scale" force does not appear in our torque equation:



$$\sum \tau_z = F_l \cdot 0 + F_r \cdot L - Mg \cdot \frac{L}{4} - mg \cdot \frac{L}{2} = 0$$

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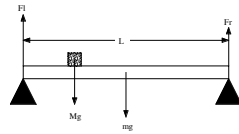
## Equilibrium. Sample problem.

- The force generated by the right scale is thus equal to

$$F_r = \frac{Mg \frac{L}{4} + mg \frac{L}{2}}{L} = \frac{1}{4} Mg + \frac{1}{2} mg$$

- We can not use the first condition of equilibrium to determine the force generated by the left scale:

$$F_l = Mg + mg - F_r = \frac{3}{4} Mg + \frac{1}{2} mg$$



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## Done for today! Next: thermodynamics.



NASA Dryden Flight Research Center Photo Collection  
 NASA Photo ID: 45243107 Date: 1999 Photo by NASA  
 X-43 hypersonic experimental vehicle - Jetted Concept in Flight

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