Physics 141.
Lecture 20.

Who am I?
Comparing numbers.
Conclusion?

Delta: 6 hour flight.

KLM: 40 minute flight.
Physics 141.
Lecture 20.

- Course Information.

- Quiz

- Topics to be discussed today:
  - Equilibrium.
Physics 141.
Course information.

- **Homework # 9 (WebWork only) is due on Friday November 18.**

- **No homework due during the week of Thanksgiving.**

- **Experiment # 5:**
  - Data collection completed.
  - Data analysis about to start.
  - Details on the analysis will be providing during lecture on Thursday.
Physics 141: Concept Test. Did you really fully understand angular momentum?

- Let us practice what we have learned so far.

- This test allows me to assess your understanding of the material, but will not be effect your Physics 141 grade.

- Your PRS will be used to enter your answers.
Equilibrium.

- An object is in equilibrium if the following conditions are met:
  
  \[
  \text{Net force} = 0 \text{ N (first condition for equilibrium)}
  \]

  and

  \[
  \text{Net torque} = 0 \text{ Nm (second condition for equilibrium)}
  \]

- 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.
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:
  - $P = 0 \text{ kg m/s}$
  - $L = 0 \text{ kg m}^2/\text{s}$
Using rotational motion to study equilibrium: equilibrium conditions.

- **Equilibrium in 3D:**
  
  \[
  \sum F_x = 0 \quad \sum \tau_x = 0 \\
  \sum F_y = 0 \quad \text{and} \quad \sum \tau_y = 0 \\
  \sum F_z = 0 \quad \sum \tau_z = 0
  \]

- **Equilibrium in 2D:**
  
  \[
  \sum F_x = 0 \\
  \sum F_y = 0 \\
  \sum \tau_z = 0
  \]
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?
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.
Using rotational motion to study equilibrium: equilibrium conditions.

- The first condition for equilibrium requires that

\[ \sum F_x = F_W - F_{gx} = 0 \]

and

\[ \sum F_y = F_{gy} - Mg - mg = 0 \]

- Two equations with three unknown. We need more information! But we still have the third condition for equilibrium.
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 to resting point on the ground as out 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:

\[ F_w = \frac{1}{h} \left( Mg \frac{a}{2} + mg \frac{a}{3} \right) = \frac{ga}{h} \left( \frac{1}{2} M + \frac{1}{3} m \right) \]
Using rotational motion to study equilibrium: equilibrium conditions.

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

\[ F_{gx} = F_w = \frac{ga}{h} \left( \frac{1}{2} M + \frac{1}{3} m \right) \]

- 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.
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.
Equilibrium.
Be sure to include all forces!!!
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?
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

\[ \sum \vec{F} = (F' - \sum \Delta mg) \hat{y} = (F' - g \sum \Delta m) \hat{y} = (F' - Mg) \hat{y} \]

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

\[ F' = Mg \]
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

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

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

$$
M \vec{r}_{cm} \times \vec{g} = 0
$$
Equilibrium.
The force of gravity.

- The system will be in equilibrium if
  \[ M\vec{r}_{cm} \times \bar{g} = 0 \]
- The 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 (\( r_{cm} = 0 \))
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:

\[ \sum F_y = F_l + F_r - Mg - mg = 0 \]
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:

\[ \sum \tau_z = F_l 0 + F_r L - Mg \frac{L}{4} - mg \frac{L}{2} = 0 \]
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:

\[ F_l = Mg + mg - F_r = \frac{3}{4} Mg + \frac{1}{2} mg \]
Done for today!
Next: thermodynamics.