Physics 141.
Lecture 20.

Comparing numbers.
Conclusion?

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.

Physics 141.
Lecture 20.

- Course Information.
- Quiz
- Topic to be discussed today:
  - Equilibrium.

Physics 141.
Lab # 5. Now what?

Analysis lab # 5: know the goals before you start your video analysis!

- The analysis of lab # 5 will involve the following steps:
  - The videos will be analyzed using LoggerPro.
  - Each student will analyze the two or three collisions in which they were involved and determine the two velocities before and after each collision.
  - The two students involved in each collision compare the velocities they determined and use them to either catch "silly" mistakes or obtain their best estimates of their velocities and the errors in their estimates.
  - All velocities are converted to momenta and kinetic energies, and the entire data sets forms the basis of lab report # 5.

Physics 141.
Lab # 5.

- The analysis of this experiment is complex:
  - Information about the collisions will be available on the web (names, can deformations, etc.).
  - The two colliding students who look at the same collision need to compare their values for the velocities before and after the collision in order to determine the errors in their values (and catch any mistakes in the analysis of the video clips).
  - For each collision I expect you to submit a web form with all velocities and their errors for that collision.
  - I will convert the measured velocities to momenta and kinetic energies and publish the data on the web.
  - Each student will look at the entire data set and compare losses in kinetic energy with the deformation of the cans.
  - The lab report covering this experiment will receive the same weight as lab report # 4. You should know now what makes a lab report great!
  - Let's look at the various steps in a bit more detail.

Lab # 5.
Finding the collision time.

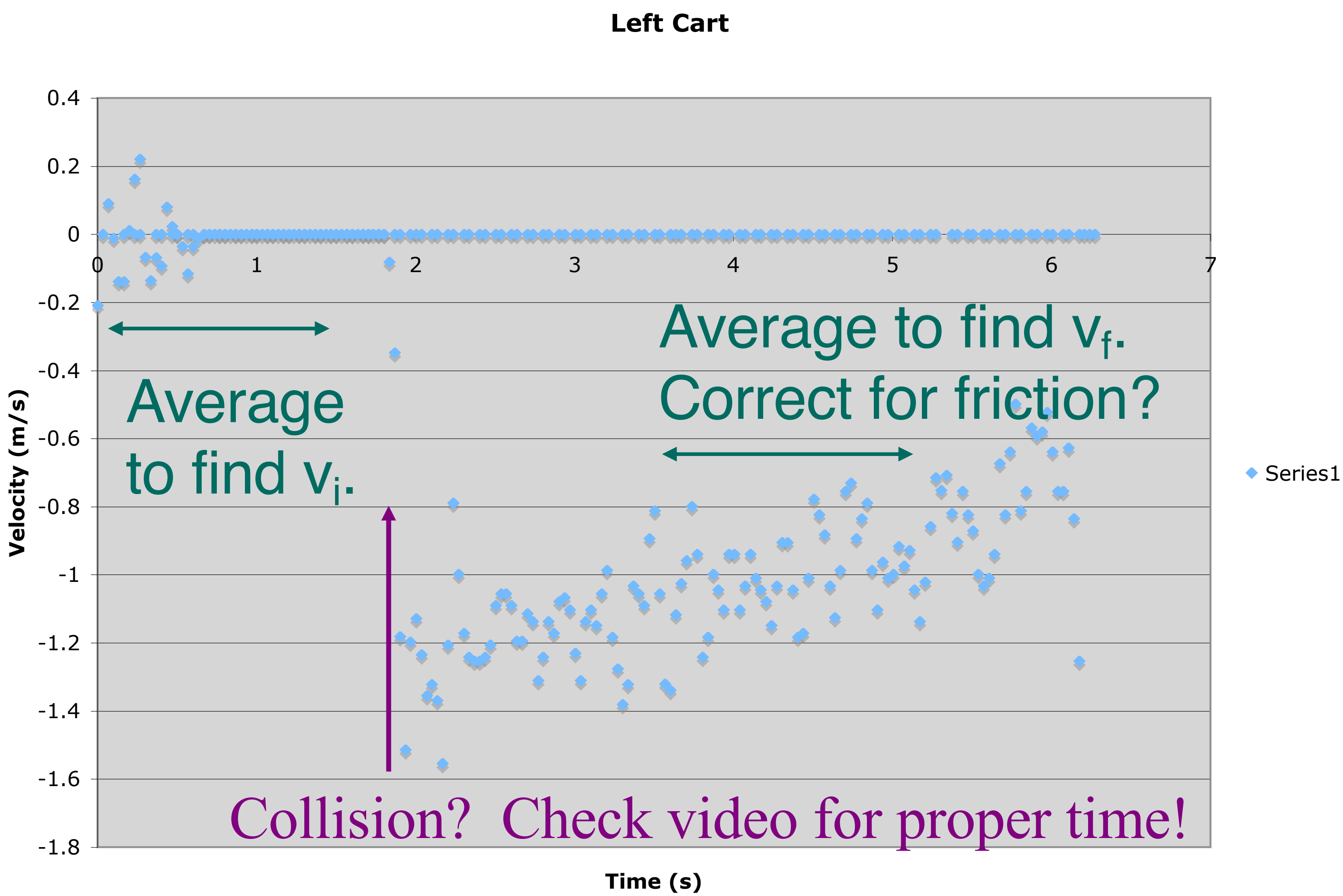
- The first step in interpreting the results of the video analysis is to determine the collision time.
- This can be done in LoggerPro or by looking at the results of the video analysis in Excel.
- Besides determining the collision time, it is also important to determine what time interval after the collision you should use to determine the final velocities (e.g. motion of the body will influence motion of the cart).

Calibration: wheel-to-wheel length of cart = 0.766 m.

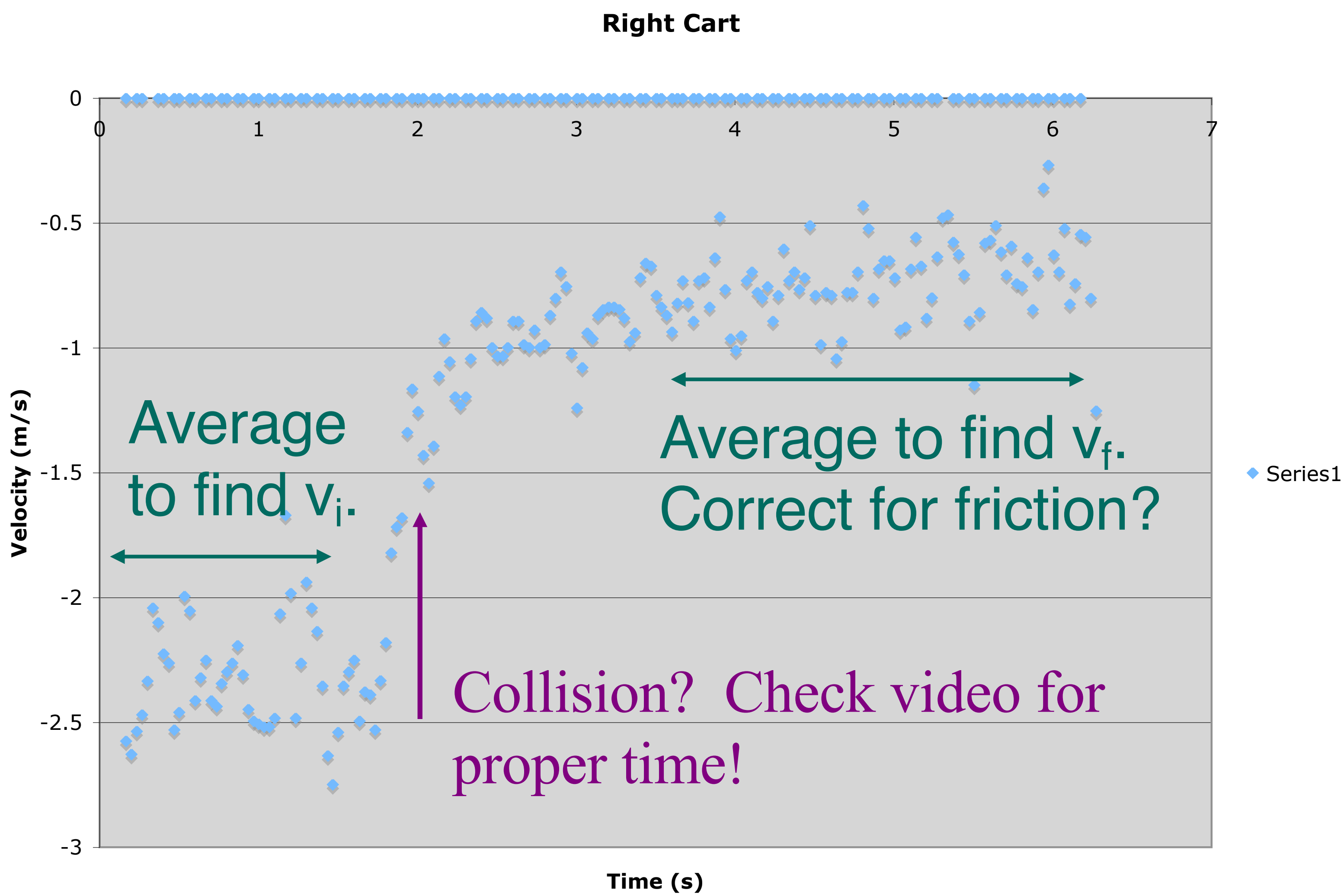
Lab # 5.
Position versus Time.

Lab # 5.
Finding velocities. Left Cart.

The initial velocity should be 0 m/s! What do you get? Provides info about the accuracy of the procedure.



Lab # 5.
Finding velocities. Right Cart.



Lab # 5.
How to determine the velocities?

- Any time you have a large number of data points, use tools to process them quickly (e.g. there is no learning involved in using your calculator to find the average of 100 numbers).

- **For professional graphs and curve fitting you should use Igor. This also will make it MUCH easier to determine the errors in the velocities!**

Lab # 5.
Combining two analyses.

- The results of two independent analyses need to be combined.
- The two results can also be used to catch mistakes in one of the analyses.
- Example 1:
  - $v_{left,f,1} = -5.2 \pm 0.4$ m/s
  - $v_{left,f,2} = -0.2 \pm 0.1$ m/s

  Calibration problems or reversal of cars?
- Example 2:
  - $v_{left,f,1} = -3.2 \pm 0.4$ m/s
  - $v_{left,f,2} = -2.2 \pm 0.4$ m/s

  These two results look consistent and can be combined to obtain the following estimate for the final velocity of the left cart:
  - $v_{left,f} = -2.7 \pm 0.3$ m/s

Lab # 5.
What do we learn?

- Based on the velocities determined, I will calculate the initial and final momenta and kinetic energies.
- The can deformations will be available on the WEB.
- We expect that the deformation of the cans is related to the loss of kinetic energy (since it takes energy to deform the cans).
- Models to consider:
  - Loss of kinetic energy is proportional to the deformation of the cans.
  - Loss of kinetic energy is proportional to the square of the deformation of the cans.
- Is linear momentum conserved?

Analysis of experiment # 5.
Models to be considered.

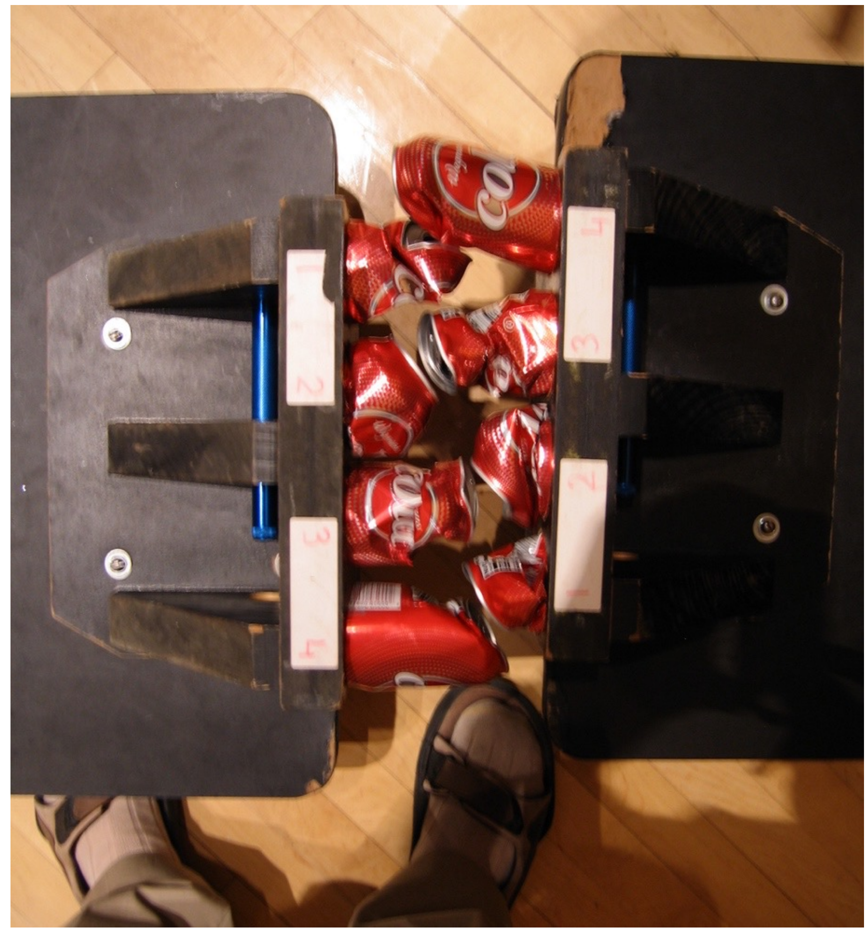
- Consider the following models:
  - Can force = F = const.
    Work done:

$$-\sum F x_i = \Delta K$$

  - Can force = kx.
    Work done:

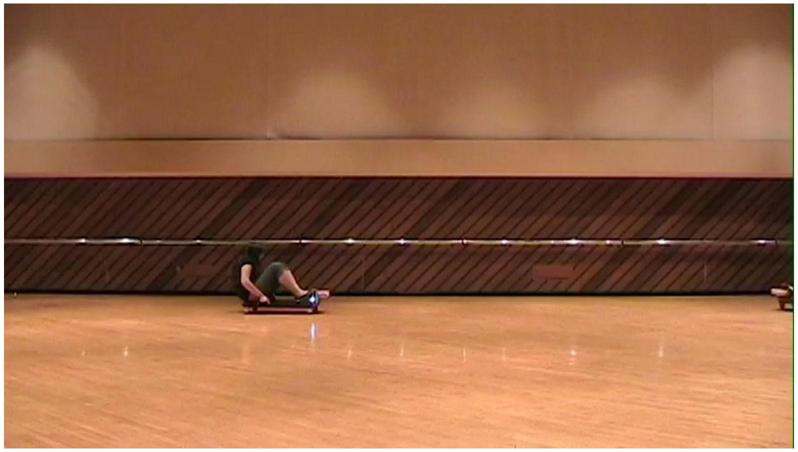
$$-\sum \frac{1}{2} k x_i^2 = \Delta K$$

  - A combination of these two forces:
    - Force = F if $x_i < x_0$
    - Force = kx if $x_i > x_0$



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

- ✓ 11/11: collisions in Spurrier Gym
- 11/18: analysis files available.
- 11/25: each student has determined his/her best estimate of the velocities before and after the collisions (analysis during regular lab periods).
- 11/25: complete discussion and comparison of results with colliding partners and submit the final results (velocities and errors).
- 11/27: we will compile the results, determine momenta and kinetic energies, and distribute the results.
- 12/2: office hours by lab TA/TIs to help with analysis and conclusions.
- 12/6: students submit lab report # 5.

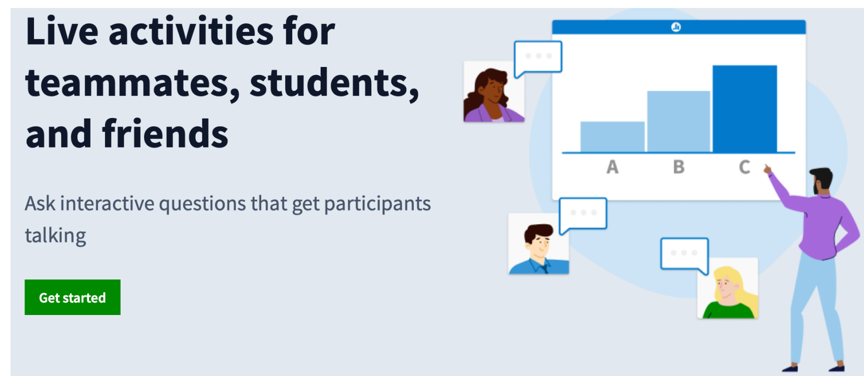


Physics 141.
Course information.

- Homework # 9 (WebWork only) is due on Friday November 15.
- Exam # 3, scheduled for November 19, covers Chapters 8, 9, 10, and 11.
  - A review of the material covered is scheduled for Thursday November 14.
  - There will be extra office hours on Monday November 18.

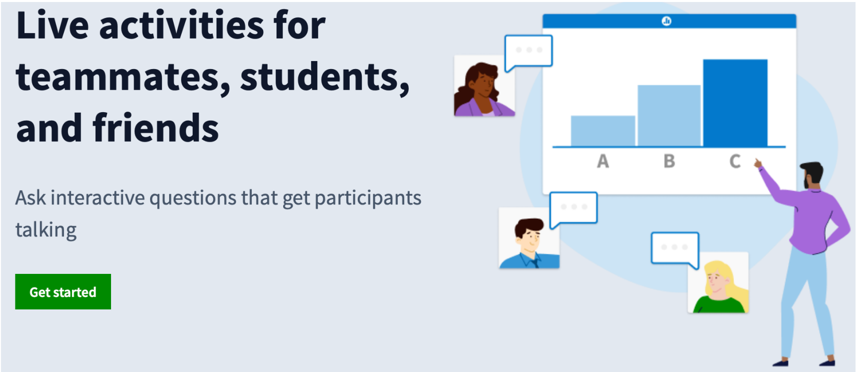
Quiz lecture 20.
PollEv.com/frankwolfs050

- The quiz today will have three questions.
- I will collect your answers electronically using the Poll Everywhere system.
- You have 60 seconds to answer each question.



Concept test lecture 20.
PollEv.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.



Equilibrium.

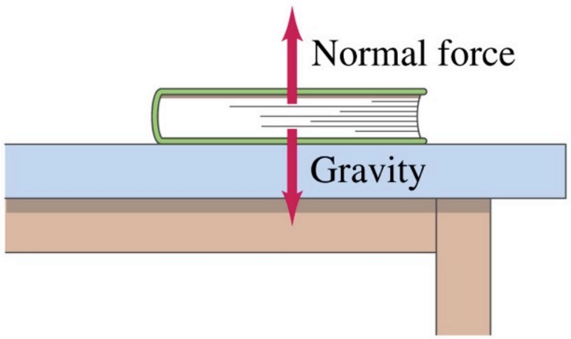
- An object is in equilibrium if the following conditions are met:

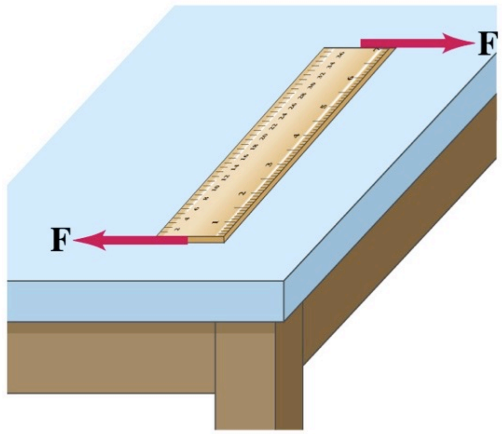
  Net force = 0 N (**first** condition for equilibrium)

  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.





Static equilibrium.

- What happens when the net force is equal to 0 N?
  - P = constant
- What happens when the net torque is equal to 0 Nm?
  - L = 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:
  - $P = 0$ kg m/s
  - $L = 0$ kg m^2/s

Using rotational motion to study equilibrium: equilibrium conditions.

- Equilibrium in 3D:

$$\sum F_x = 0 \quad \sum \tau_x = 0$$

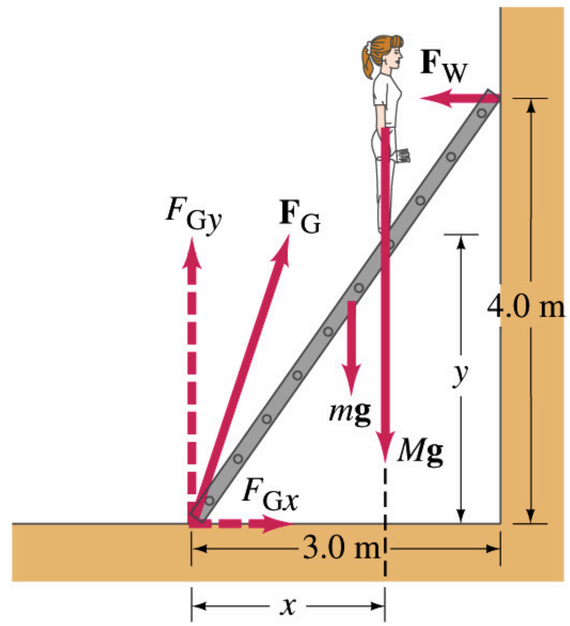
$$\sum F_y = 0 \quad \sum \tau_y = 0$$

$$\sum F_z = 0 \quad \sum \tau_z = 0$$

- Equilibrium in 2D:

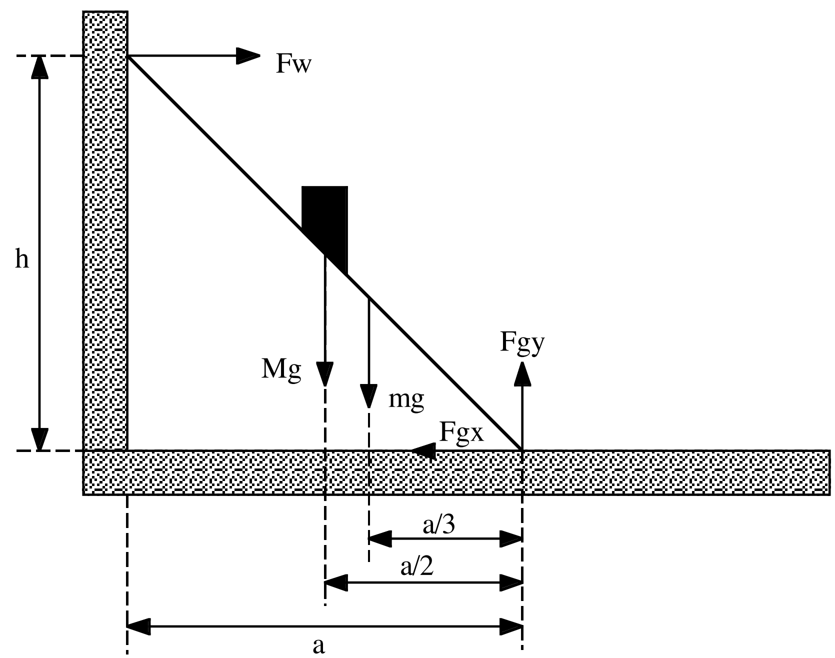
$$\sum F_x = 0$$

$$\sum F_y = 0 \quad \sum \tau_z = 0$$



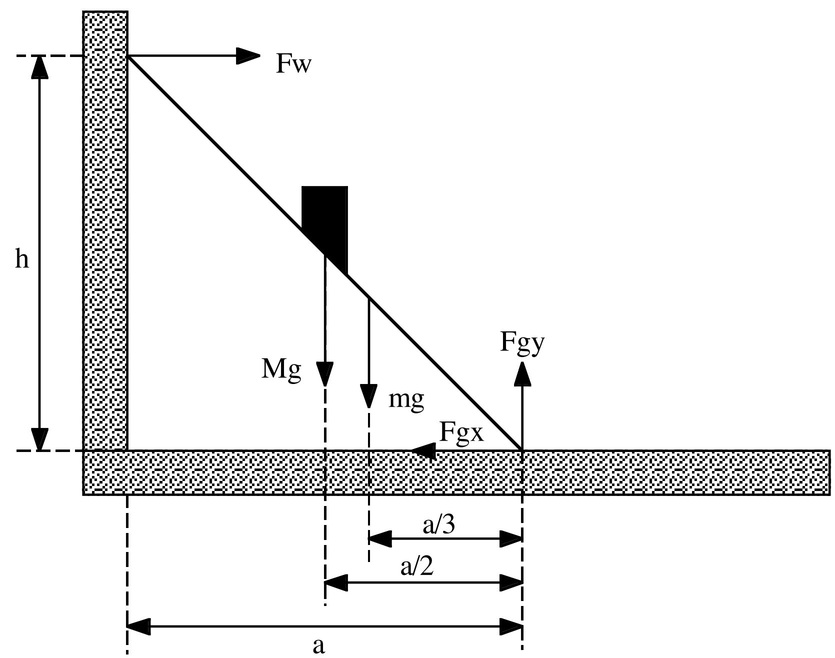
Using rotational motion to study equilibrium: equilibrium conditions.

- 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.

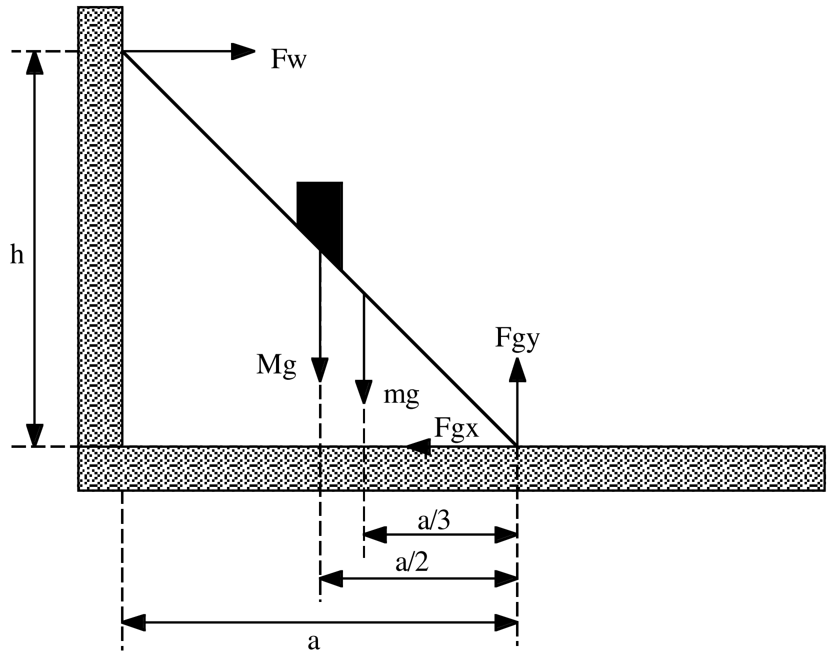
- The first condition for equilibrium requires that

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

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.



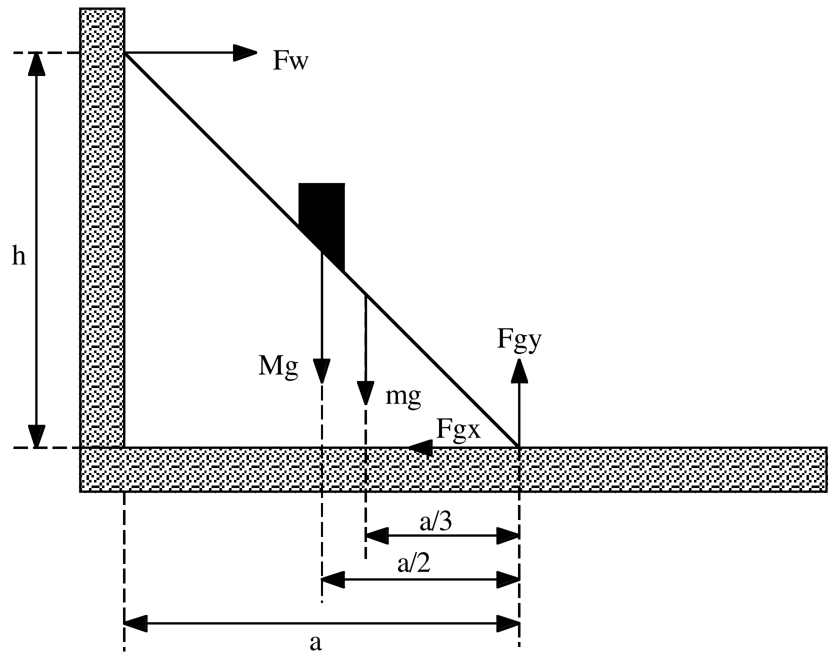
Using rotational motion to study equilibrium: equilibrium conditions.

- The second condition for equilibrium requires:

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

- Note: we have used 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:

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

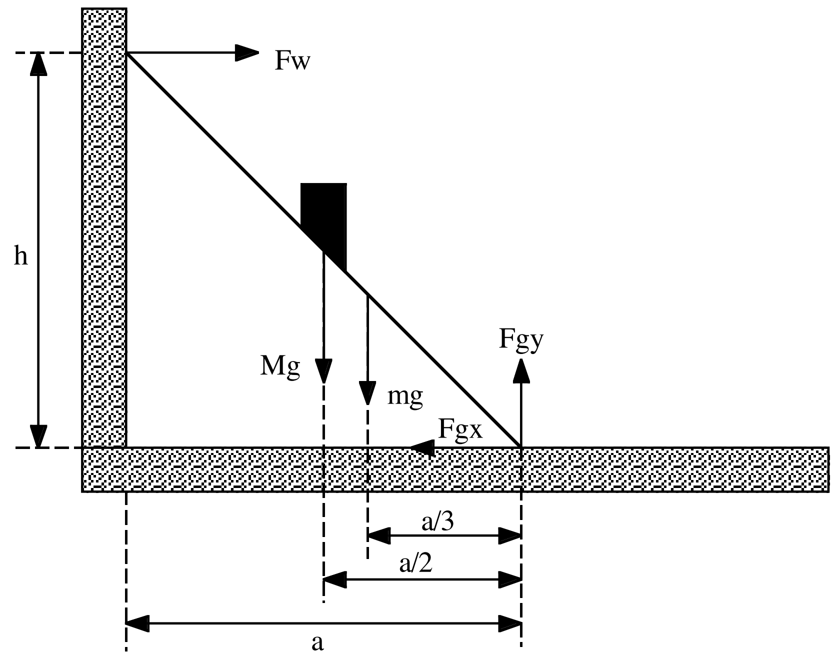


Using rotational motion to study equilibrium: equilibrium conditions.

- 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 fire fighter climbs the ladder.
- Since the frictional force must be less than $\mu_s F_{gy}$, there may be a maximum height that can be reaches by the fire fighter above which the ladder will slip.

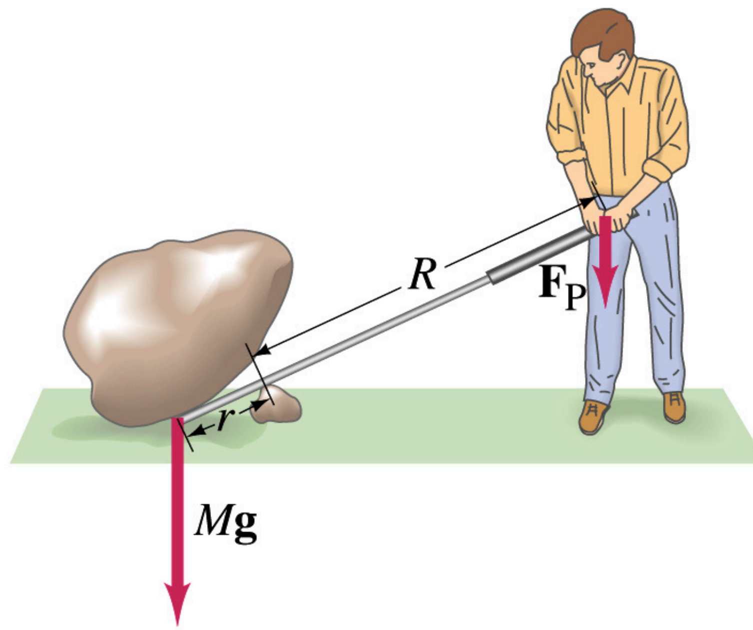


4 Minute 14 Second Intermission.

- 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.

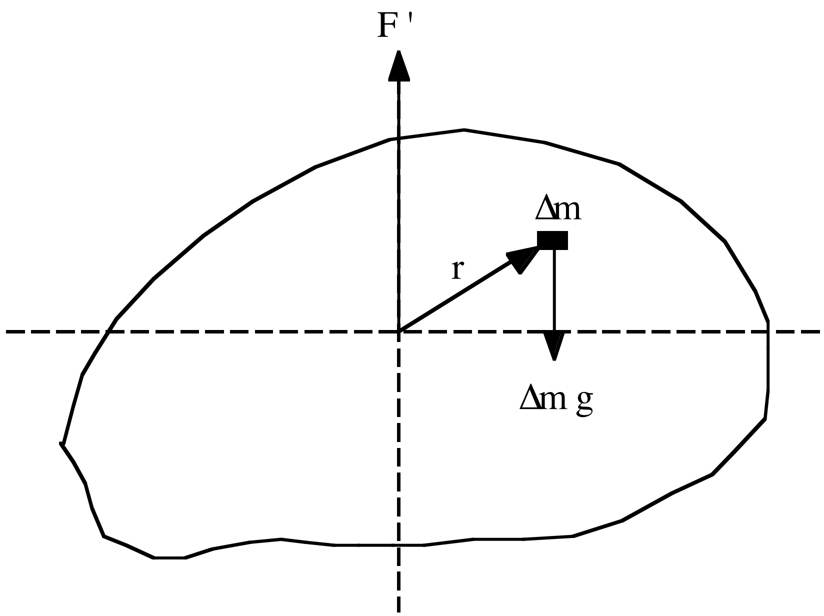
Equilibrium.
Be sure to include all forces!!!

- 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.



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.

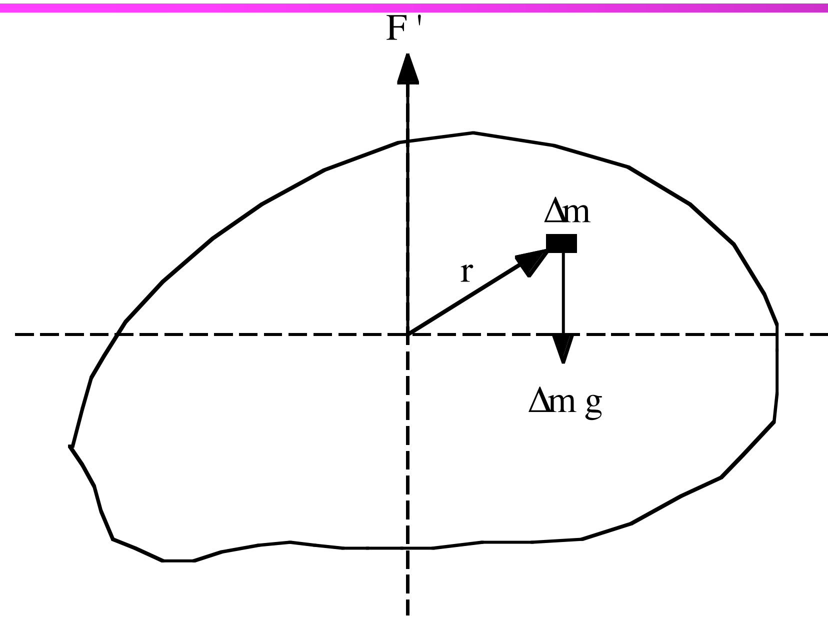
- If the object is in equilibrium, the net torque and the net force acting on it must be equal to 0.
- The net force acting on the object is equal to

$$\sum \vec{F} = \vec{F}' - \sum \Delta m \vec{g}$$

$$= (F' - Mg)\hat{y}$$

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

$$F' = Mg$$



Equilibrium.
The force of gravity.

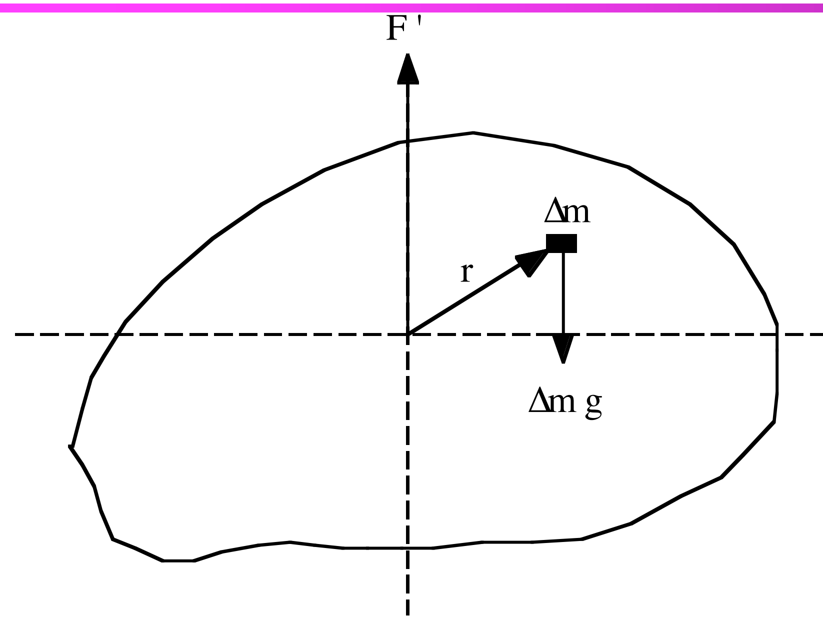
- The condition that $F' = Mg$ is not sufficient for static equilibrium. We must also require that the net torque is equal to 0 Nm.
- The net torque acting on the object is equal to

$$\sum \vec{\tau} = \sum \vec{r} \times \Delta m \vec{g}$$

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

- 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

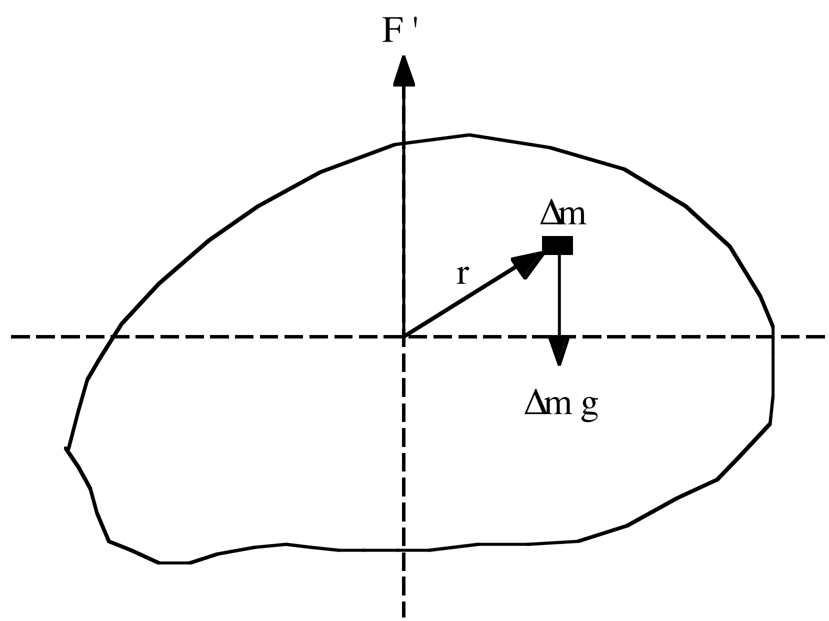
$$M\vec{r}_{cm}\times\vec{g} = 0$$

- The requires that

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

or

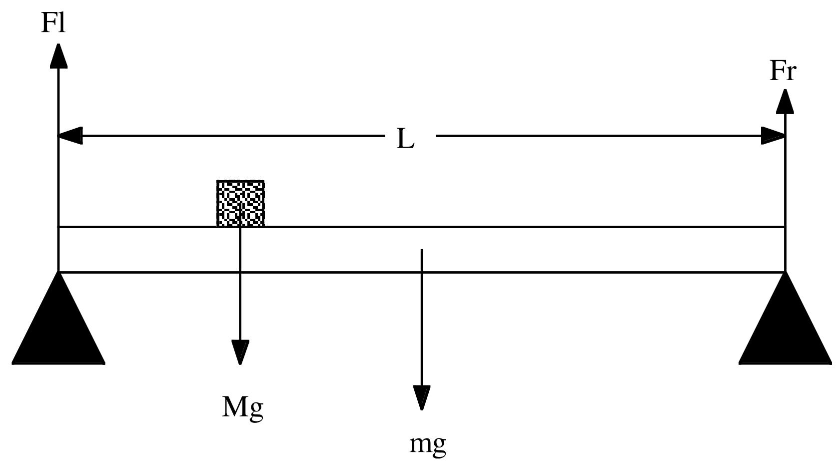
The center-of-gravity coincides with the rotation axis ($\vec{r}_{cm} = 0$)



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

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:

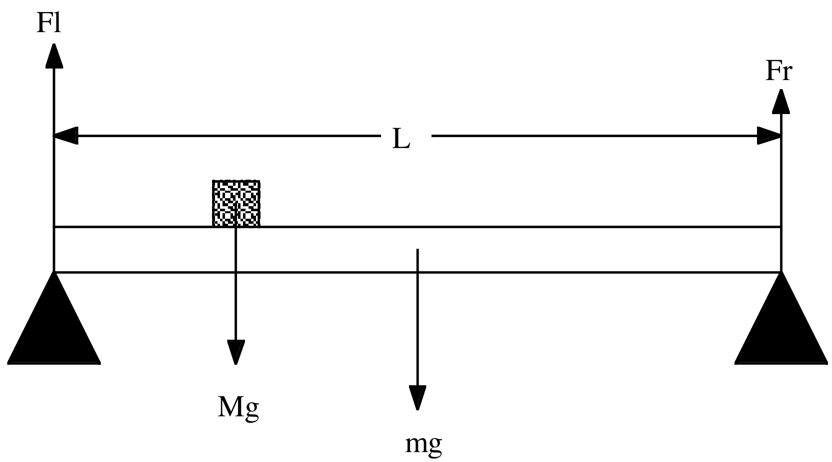
$$\sum F_y = F_l + F_r - Mg - mg = 0$$

Equilibrium. Sample problem.

- If the system is in equilibrium, the net torque must be 0 Nm.
- Note: the toque 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:

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

$$= 0$$



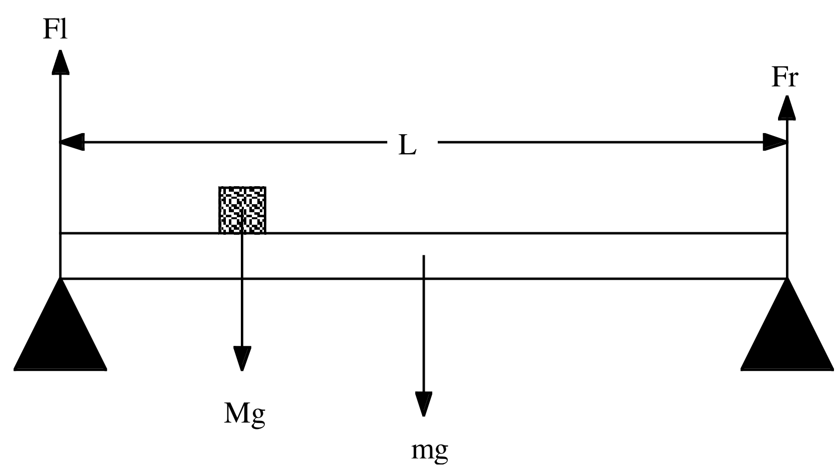
Equilibrium.
Sample problem.

- 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 week: thermodynamics.

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ED99-45243-01 Date: 1999 Photo by: NASA

X-43A Hypersonic Experimental Vehicle - Artist Concept in Flight