Newton’s Laws

1. Bodies stay at constant velocity unless acted on by outside force!

2. \[ \sum \vec{F} = m\vec{a} \]  
   Defines mass, \( m \), as parameter reflecting body’s resistance to motion.

3. Action = Reaction! When force acts on body 2 by body 1, then equal and opposite force acts on body 1 by body 2.
Forces on the isolated pieces (sometimes called “free body diagrams")

No acceleration

Forces on all bodies balance

\[ \vec{F_g} = mg \]

\[ \vec{f}_1 + \vec{f}_2 \]

\[ kx\hat{j} \]
Sample Prob 5-6: Rope tensions?

- Illustrates force problem procedures
  1. Draw Picture and analyze the problem
  2. Isolate specific points or bodies and sketch forces acting on these
  3. Use $\Sigma F = ma$ at each point
     - If $a=0$, net force at the point is zero
The figure shows four penguins that are being playfully pulled along very slippery (frictionless) ice by a curator. The masses of three penguins and the tension in two of the cords are given. Find the penguin mass that is not given.
Sample Prob 5-8

- The “weight” recorded on the scale is $N$! **Not** $F_g$!
- If $a = 0$, then $N = F_g = mg$.
- But if $a$ is not zero, more complicated ... use Newton!
  (Note that scale feels a force equal to $N$.)

\[ N - F_g = ma \]

\[ N = m(g + a) \]

- Scale can read anything from 0 to $\infty$
- Note if $a \leq -g$, must rethink!
Sample Prob 5-7

\[ N = mg \cos \theta \]

\[ T = mg \sin \theta \]
Sample Prob 5-7 with string cut

\[ N = mg \cos \theta \quad \text{since} \quad a_y = 0 \]

\[ -mg \sin \theta = ma_x \quad \text{so} \quad a_x = -g \sin \theta \]

intuitive answer?
One Step Harder Problem

no friction

\[ T - m_1 g \sin \theta = m_1 a \]
\[ m_2 g - T = m_2 a \]

\[ m_2 g - (m_1 g \sin \theta + m_1 a) = m_2 a \]
\[ m_2 g - m_1 g \sin \theta = (m_1 + m_2) a \]

\[ a = g \frac{m_2 - m_1 \sin \theta}{m_1 + m_2} \]

Check get intuitive answers in limiting cases
Accelometer

Measure the acceleration of the car by measuring the angle of the string!
Try it in the subway!

\[ F_T \sin \theta = ma \]
\[ F_T \cos \theta = mg \]
\[ a = g \tan \theta \]
Problem 5 -43 (not assigned)

- 10 kg monkey (m)
- 15 kg package (M)
- How can monkey raise the package?
  - Monkey pulls on rope with force $T$ (uniform tension throughout rope)
  - Net force on monkey
  - Net force on package
- Find minimum acceleration of monkey in order to lift package!

Keep in mind when you do problem 5-50
Friction

\[ f_s^{\text{max}} = \mu_s N \]
\[ f_k = \mu_k N \]

<table>
<thead>
<tr>
<th>Surfaces</th>
<th>Coefficient of Static Friction, ( \mu_s )</th>
<th>Coefficient of Kinetic Friction, ( \mu_k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood on wood</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Ice on ice</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td>Metal on metal (lubricated)</td>
<td>0.15</td>
<td>0.07</td>
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<tr>
<td>Steel on steel (unlubricated)</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Rubber on dry concrete</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Rubber on wet concrete</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Rubber on other solid surfaces</td>
<td>1-4</td>
<td>1</td>
</tr>
<tr>
<td>Teflon® on Teflon in air</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Teflon on steel in air</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Lubricated ball bearings</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Synovial joints (in human limbs)</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

†Values are approximate and are intended only as a guide.
Details of friction

- **Static friction**:
  - No motion
  - Magnitude of frictional force: $f_s$ (maximum)

- **Kinetic friction**:
  - Acceleration
  - Constant velocity
  - $f_k$ is approximately constant

- **The tablecloth trick**: Breakaway
Example of finding coefficient of friction

Problem:
Raise the book until coin starts to fall
Measure the angle
Calculate the coefficient of static friction

\[ f_s = mg \sin \theta \]
\[ N = mg \cos \theta \]
\[ \mu_s = \frac{f_s}{N} = \tan \theta \]
Fluid Drag Forces

- Nonviscous flow (only thing considered ch 15) = no drag force
- Viscous but laminar
- Viscous and turbulent

\[ F_d = -Kv \]
\[ F_d \approx D \]
\[ D = \frac{1}{2} C \rho A v^2 \]
Drag Considered Ch 6

- Turbulent ...
- Cat falls and accelerates until \( D = F_g \)
- At that point, cat has reached **terminal velocity**
- See specific discussion in section 6-3.

\[ \vec{D} = \text{drag force, oppose motion} \]

\[ D = \frac{1}{2} C \rho A v^2 \]
Terminal Speed

- In either case, $D \propto -v^1$ or $2 \ldots$
  - Object will attain a terminal speed
  - Text does the turbulent flow case
  - Laminar flow case:
    
    \[ D = -K \eta v \]

    \[ D = mg \text{ when } v = v_{\text{term}} = \frac{mg}{K \eta} \]

In between:

\[ m \frac{dv}{dt} = mg - K \eta v \]

with solution for start at rest

\[ v = v_{\text{term}} \left(1 - e^{-\frac{K \eta t}{m}}\right) \text{ [culture]} \]
HW Problem 6-45 (assigned)

- Airplane in holding pattern flying in circle of radius, $r$, at constant speed, $v$
- Given $v$ and bank angle, what is $r$?

$$a = \frac{v^2}{r}$$

$40^\circ$

LIFT

WEIGHT
Centripetal Force

- Must **always** be a force to hold an object in circular motion
- This force supplies the centripetal acceleration!
- Hey! What happened to *centifugal* force?

\[ T = m \frac{v^2}{R} \]
Centrifugal Force is a Fiction!

Real life experiences that make clear ... objects without force travel in a straight line at the velocity with which they started!
Conclusion

- HW 2 due on Monday (problems ch 4, 5, 6)
- Read Chapter 7 before Monday lecture
- Sample Midterm 1 at website on Monday
  - Will include the solutions
  - Recommend strongly you try it before reading solutions
- Midterm exam in class following Monday 9/29
  - Will cover chapters 1 - 6