Main points of last lecture:
- Newton’s 1st law:
- Newton’s 2nd law:

\[ \vec{F} = m\vec{a} \]
- \( \vec{F} \) is the net (total) force acting on the object. It is the vector sum of all forces acting on the object.

Main points of today’s lecture:
- Atwood’s machine.
- Normal force
- Newton’s 3rd Law:
  - “When a body exerts a force on another, the second body exerts an equal oppositely directed force on the first body.”
Atwood’s machine

- Consider the Atwood machine to the right. The massless string passes over a massless and frictionless pulley. It is under tension $T$, which we define to be the magnitude of the tension force. By this definition it is a positive number.

- Choosing up to be positive, what is the net force on mass 1?
  - a) $T - m_1g$
  - b) $T + m_1g$
  - c) $m_1g - T$
  - d) none of the above
Atwood’s machine: quiz

• Choosing up to be positive, what is the net force on mass 2?
  – a) \( m_2g - T \)
  – b) \( T + m_2g \)
  – c) \( T - m_2g \)
  – d) none of the above
Atwood’s machine

- From Newton’s 2\textsuperscript{nd} law:
  \[ T - m_1 g = m_1 a_1 \]
  \[ \Rightarrow T = m_1 a_1 + m_1 g \]

- Also
  \[ T - m_2 g = m_2 a_2 \]
  \[ \Rightarrow T = m_2 a_2 + m_2 g \]

- If \( m_2 \) exceeds \( m_1 \), \( m_2 \) goes down and \( m_1 \) goes up. If \( m_1 \) exceeds \( m_2 \), \( m_1 \) goes down and \( m_2 \) goes up. In either case
  \[ \Delta y_2 = -\Delta y_1 \]
  \[ v_2 = -v_1 \]
  \[ a_2 = -a_1 \]

- Putting it together:
  \[ m_1 a_1 + m_1 g = m_2 a_2 + m_2 g \]
  \[ = -m_2 a_1 + m_2 g \]
  \[ m_1 a_1 + m_2 a_1 = m_2 g - m_1 g \]
  \[ a_1 = \frac{(m_2 - m_1) g}{m_1 + m_2} \]
Static Equilibrium

- All objects are at rest and remain so. The net force on any object must vanish. I.e. on an object:

\[ \sum F_i = 0 \]

- Example: Three ropes are arranged so as to support a 4 kg mass as shown below. Determine the tension in each rope.

Solve by considering forces at point A

\[ \sum F_{i,x} = 0 = -T_1 + T_2 \cos(60^\circ) \]
\[ = -T_1 + T_2 / 2; \quad T_1 = T_2 / 2 \]
\[ \sum F_{i,y} = 0 = T_2 \sin(60^\circ) - T_3 \]
\[ T_2 = T_3 / \sin(60^\circ) = 1.16T_3 \]
\[ T_3 = mg = 39.1N; T_2 = 45.3N \]
\[ T_1 = 22.5N \]
Normal Force

- The Normal force acts perpendicular to the surface of the block on which the mass sits. It assumes whatever value is needed to prevent the block from penetrating the surface. In other words \( N=mg \) regardless of the mass of the block.
Example

- Two forces, \( \vec{F}_1 \) and \( \vec{F}_2 \), act on the 5.00 kg block shown in the drawing. The magnitudes of the forces are \( F_1 = 60 \) N and \( F_2 = 25 \) N. What is the horizontal acceleration (magnitude and direction) of the block?

<table>
<thead>
<tr>
<th>( F_1 )</th>
<th>60 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_2 )</td>
<td>25 N</td>
</tr>
<tr>
<td>( m )</td>
<td>5 kg</td>
</tr>
<tr>
<td>( \theta_1 )</td>
<td>60°</td>
</tr>
</tbody>
</table>

\[
F_{1,x} = 60 \cos(60°) \text{N} = 30 \text{N}
\]

\[
F_{net} = 30 \text{N} - 25 \text{N} = 5 \text{N}
\]

\[
a = \frac{F}{m} = \frac{5 \text{N}}{5 \text{kg}} = 1 \text{m/s}^2
\]

Block accelerates to the right.
Consider a person standing in an elevator that is accelerating upward. The upward normal force \( N \) exerted by the elevator floor on the person is
- a) larger than
- b) identical to
- c) smaller than
the downward weight \( W \) of the person.
Example: with balance scale marked in Newtons

- A 100 kg man stands on a bathroom scale in an elevator. Starting from rest, the elevator ascends, attaining its maximum speed of 1.2 m/s in 0.80 s. It travels with this constant speed for 5.0 s, undergoes a uniform negative acceleration for 1.5 s and comes to rest. What does the scale register (a) before the elevator starts to move? (b) during the first 0.8 s? (c) while the elevator is traveling at constant speed? (d) during the negative acceleration?

**Scale reading = Normal force**

a): \[ N = mg \] scale = N = 980 Newtons

b): \[ N - mg = ma \]
\[ a = (v - v_o) / \Delta t = (1.2 \text{ m/s}) / 0.8\text{s} = 1.5 \text{ m/s}^2 \]
\[ N = m(g + a); \text{scale} = m(g + a) = 1130 \text{ Newtons} \]

c): \[ N = mg \] scale = N = 980 Newtons

d): \[ a = (v - v_o) / \Delta t = -1.2 \text{ m/s} / (1.5\text{s}) = -0.8 \text{ m/s}^2 \]
\[ N = m(g + a); \text{scale} = m(g + a) = 830 \text{ Newtons} \]
A 100 kg man stands on a bathroom scale in an elevator. The cable supporting the elevator breaks and both man and elevator begin falling freely down the shaft. What does the scale read now?

- a) –100 kg
- b) 0 kg
- c) 100 kg
- d) none of the above

Einstein’s equivalence principle:

If all objects in the local environment are in free fall under the influence of the same uniform gravitation attraction, it appears to the observer that there is no gravitation force acting at all. I.e. for all practical purposes, the objects are “weightless”.
Newton’s Third Law

- When a body exerts a force on another, the second body exerts an equal oppositely directed force on the first body.
  - Note: the two forces act on different bodies

- Force on body 2 due to body 1: $\vec{F}_{21}$
- Force on body 1 due to body 2: $\vec{F}_{12}$
- $3^{rd}$ law: $\vec{F}_{21} = -\vec{F}_{12}$