Recap: Force Problems:

1. \( \Sigma F_{\text{on object}} = 0 \), then \( \vec{a} = 0 \)
2. \( \Sigma \vec{F} \) on object \( = m \) object \( \vec{a} \) object
3. \( F_{A \text{ on } B} = -F_{B \text{ on } A} \)

- Weight: \( \vec{W} = mg \), always down
- Normal force: \( \vec{N} \) : always \( \perp \) to surface, self-adjust so that \( \Sigma F_{\perp} = 0 \)
- Friction: always \( \parallel \) to surface, opposes relative motion
- Tension \( \vec{T} \): \( |T_1| = |T_2| \) at rope ends, if \( \vec{a}_{\text{rope}} = 0 \) and/or \( m_{\text{rope}} \neq 0 \)
- Spring force: \( \vec{F}_{\text{spring}} = -k \vec{x} \)
Spring Force: $F_{\text{spring}}$

For ideal spring:

$F_{\text{by spring on block}} = -kx$

Restoring force

Spring constant

$x = 0$

For spring on object

relaxed length
Today:

- Forces
  - Solving force problems
  - Why do tennis nets sag?
Example:

- Define "objects".
- Draw vectors representing each of the external forces acting on the object.

"Free body diagram"

For rope:
- Represent object by "x".
- $F_y$ by you on rope.
- $F_y$ by mass on rope.

For mass m:
- Normal pair $N$.
- $F_r$ friction.
- $F_{rope on man}$.
- $W$.
**Forces: General Method for Solving Force Problems**

1. Draw a diagram/sketch of the problem, define objects.
2. Choose "good" coordinate system *important*
3. Draw a "free body diagram" (FBD) for each object (or group of objects)
   - indicate all external forces on that object
4. Resolve forces into components $F_x, F_y$ along chosen coordinate axes
5. Use $\sum$\hspace{1cm} $\sum F_x = m_{obj} a_x, obj$
   \hspace{1cm} $\sum F_y = m_{obj} a_y, obj$
Note: - never draw $F_{\text{net}} = m\ddot{a}$ on a FBD!

$m\ddot{a}$ is the net result of the external forces, not an additional force

- all forces are due either to direct physical contact between objects, or due to force which acts at a distance (e.g. gravity, EM forces)

- no mysterious forces

- only one of the two forces in an NICE force pair should appear on a given FBD!
\[ F_{\text{pull}} = mg = m \times 10 \text{m/s}^2 \]

**a = ?**

- A. 0
- B. \( g \)
- C. \( g \)
- D. insufficient information

**FBD of mass \( m \):**

- \( F_y \) (normal force on \( m \)) = \( T = F_{\text{pull}} \)
- \( \vec{F}_y \) (force on \( m \)) = \( \vec{T} \) (force on \( m \))
- Force on \( m \) at both ends of the rope is the same.

\[ 2F_y = ma_y \]

\[ = T - W \]

\[ = m(10 \text{m/s}^2) - mg \]

\[ = 0 \]

\[ \Rightarrow a_y = 0 \]
\[ \frac{T_1}{T_3} = ? \]

A. \( \frac{1}{3} \)
B. \( \frac{1}{2} \)
C. 1
D. 2
E. 3
Method II:

- FBD of 3rd mass (bottom mass)

\[ \sum F_y = m a_y = 0 \]

\[ W = m g \]

\[ T_3 = W = m g \]

- FBD of all 3 masses = "object":

\[ \sum F_y = m_{\text{total}} a_y = 0 \]

\[ = T_1 - W_{3,}\text{m} \]

\[ = T_1 - 3 m g \]

\[ \Rightarrow T_1 = 3 m g \]

\[ \Rightarrow \frac{T_1}{T_3} = \frac{3}{1} \]
**Method II:**

**Mass 3 (bottom):**

\[ T_3 \downarrow \quad \downarrow \quad w = mg \]

\[ \Rightarrow T_3 = w = mg \]

**Mass 2 (middle):**

\[ T_2 \downarrow \quad \downarrow \quad w = mg \]

\[ \Rightarrow T_2 = T_3 + w = mg + mg \]

\[ = T_1 - T_2 - w \]

\[ = T_1 - T_2 - mg \]

\[ = T_2 + w \]

\[ = mg + mg \]

\[ = 2mg \]

\[ \Rightarrow \frac{T_1}{T_3} = 3 \]

\[ = 3mg \]
• The Powder River Basin is one of the world’s largest coal producing region.

• **200 miles** of **coal trains** leave the Powder River Basin every day, 365 days a year, bound for electricity generating plants.

• Trains can be up to **2 miles long**, and weigh **23,000 tons**.

• **Air drag** from head winds can reduce an empty train’s speed on level ground from **50 to 20 mph**.
In both cases, $\frac{T_1}{T_3} = 3$

If we add more masses, eventually rope 1 will break.
• A steep railroad grade is 1.5%
• (= 15 feet rise/1000 feet)
• The steepest mainline track in the U.S. has a 4% grade.

• How can you keep the couplers between cars from breaking? 
(Couplers on coal trains break routinely.)
Front...

...end of train: locomotive in remote control mode
frictionless pulley

Pulley: change direction of rope and \( \neq \), but not \( \neq \)!

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

Choose coordinate axis along direction of motion!
FBD of $m_1$ and $m_2$:

$\sum F_y = m_1a_{x,1} = m_1a$

$= W_1 - T = m_1g - T$  \( \uparrow + \gamma \) down!

$\sum F_x = m_2a_{x,2} = m_2a_{x,2} > 0$

$\Rightarrow N = W_2 = m_2g$

$\Rightarrow \sum F_x = m_2a_{x,2} = m_2a_{x,2} > 0$

\( \Rightarrow \) in extortion 2 into 1

$\frac{m_1a = m_1g - T = m_1g - m_2a}{m_1 + m_2}$

$\Rightarrow a = \frac{m_1g}{m_1 + m_2}$

\( \text{check: } m_1 \to 0 \Rightarrow a \to 0 \)$

$m_2 \to 0 \Rightarrow a \to g$