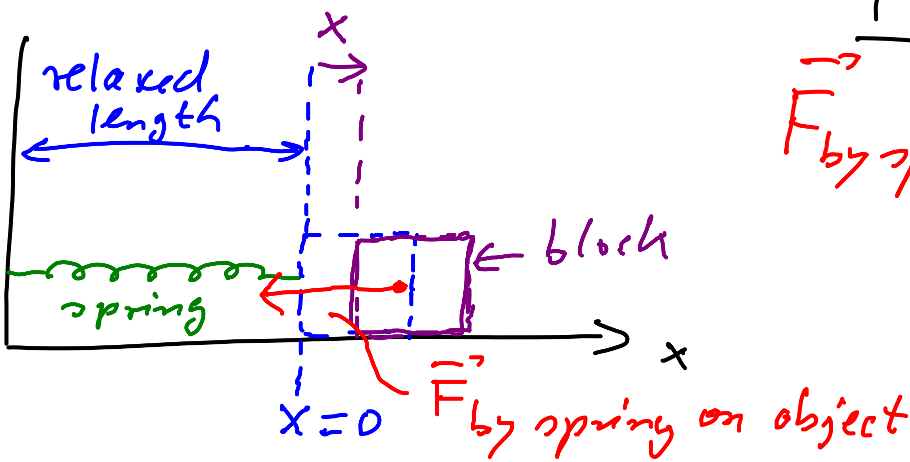
Recap: Force Problems:

- NI: If $\sum \vec{F}_{on\ object} = 0$, then $\vec{a} = 0$
- NII: $\sum \vec{F}_{on\ object} = m_{object}\, \vec{a}_{object}$
- NIII $\vec{F}_{A\ on\ B} = -\vec{F}_{B\ on\ A}$

- Weight: $\vec{W} = m\vec{g}$, always down
- Normal force: $\vec{N}$: always $\perp$ to surface, self-adjusts so that $\sum F_{\perp} = 0$
- Friction: always $\parallel$ to surface, opposes relative motion
- Tension $\vec{T}$: $|T_1| = |T_2|$ at rope ends, if $\vec{a}_{rope} = 0$ and/or $m_{rope} \approx 0$
- Spring force: $\vec{F}_{spring} = -k\vec{x}$

- **Spring Force:** $\vec{F}_{spring}$



For ideal spring:

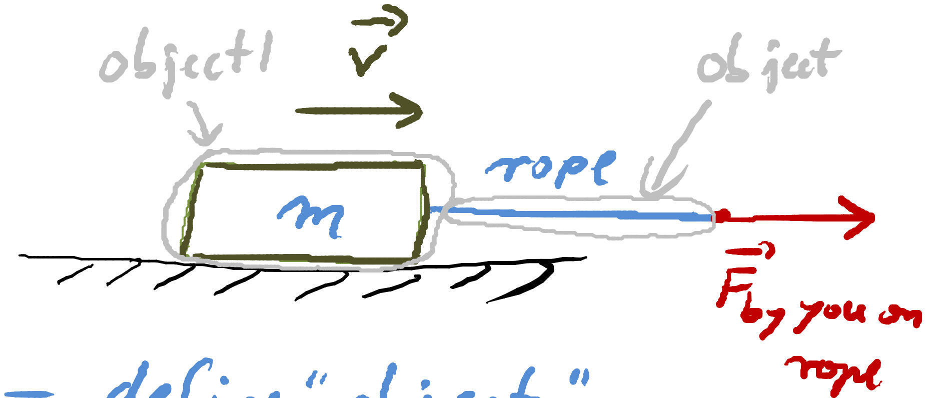
$$\vec{F}_{by\ spring\ on\ block} = -k\vec{x}$$

("−" : restoring force; k : "spring constant")

Today:

- **Forces**
  - **Solving force problems**
  - **Why do tennis nets sag?**

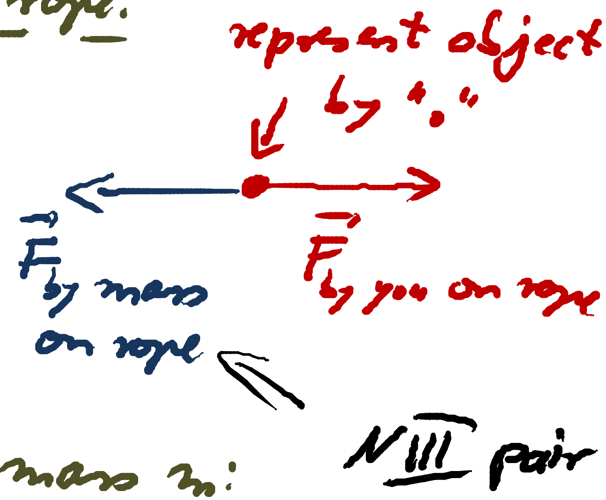
Example:



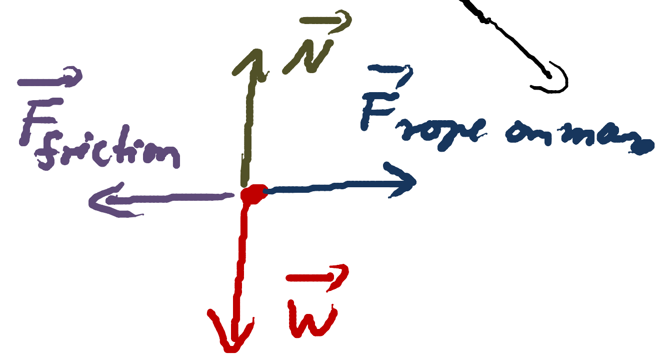
- define "objects"
- draw vectors representing each of the <u>external</u> forces acting on the object

"Free body diagram"

for rope:



for mass m:



Forces: General Methods for solving Force Problems

1. Draw a diagram/sketch of the problem, define object(s)
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 N II

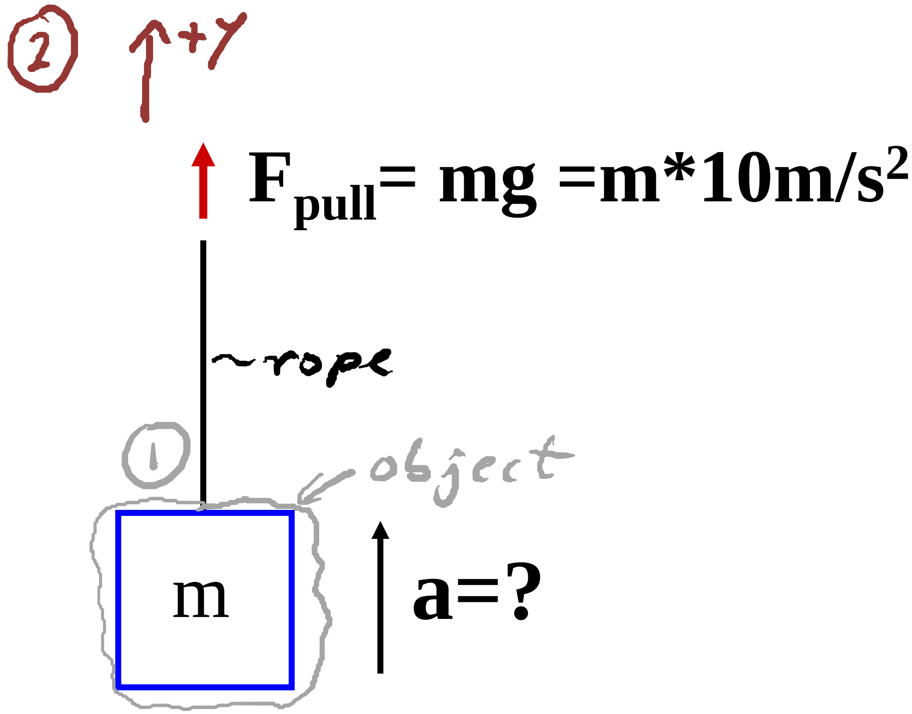
$$\sum F_x = m_{obj}\, a_{x,obj}$$

$$\sum F_y = m_{obj}\, a_{y,obj}$$

<u>Note:</u> - <u>never</u> draw $\vec{F}_{net} = m\vec{a}$ on a FBD!

$m\vec{a}$ is the net result of the external forces, <u>not</u> 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 <u>one</u> of the two forces in an N III force pair should appear on a given FBD!



a=?

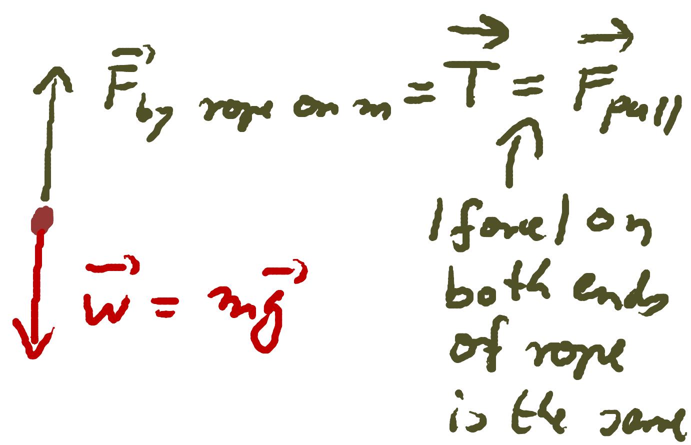
A. 0

B. g

C. >g

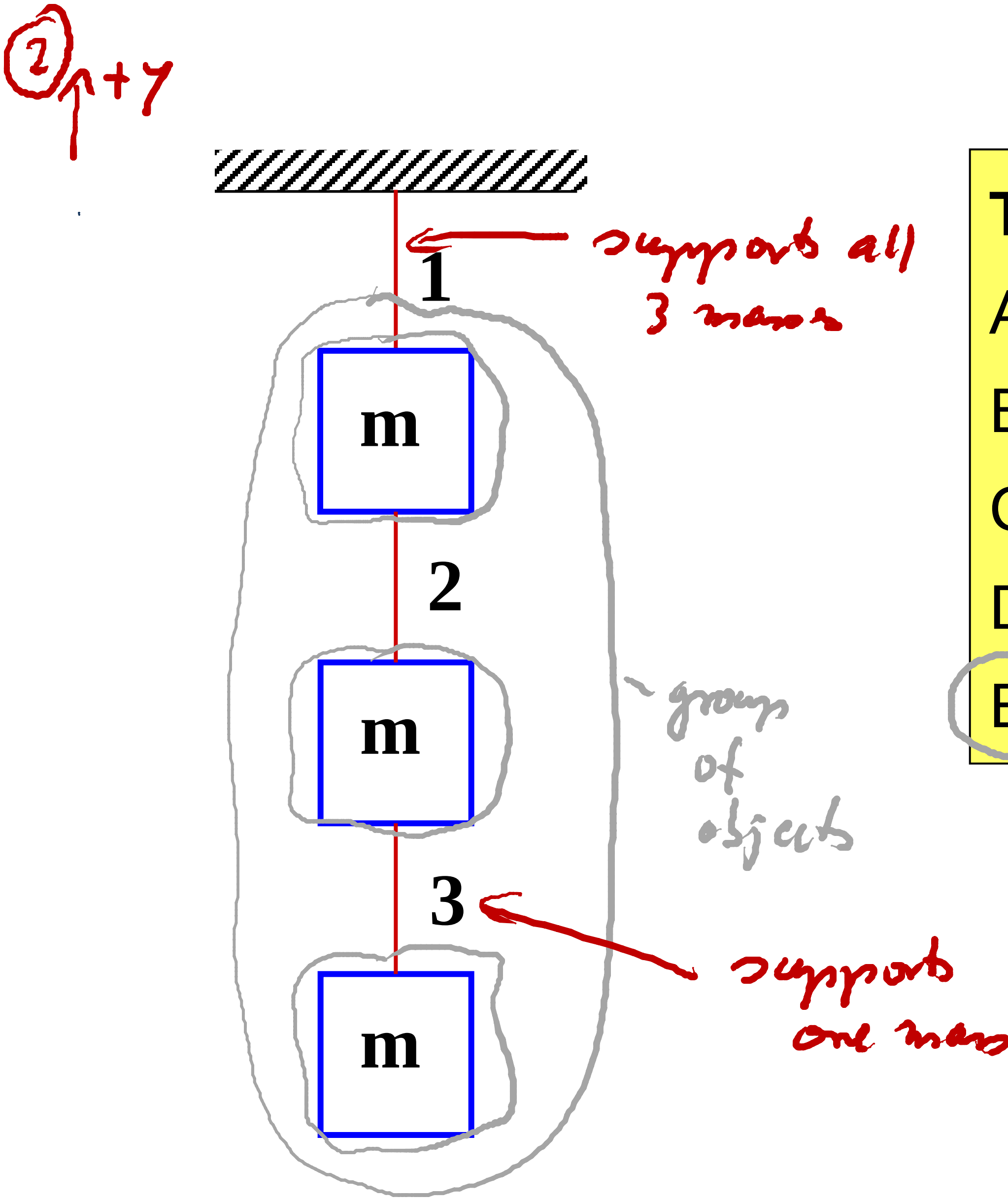
D. insufficient information

③ FBD of mass "m"



4/5 N II

$$\Sigma F_y = m a_y$$
$$= T - W$$
$$= m\,10\,m/s^2 - mg \quad (g = +10\,m/s^2)$$
$$= 0$$
$$\Rightarrow a_y = 0$$



T_1 / T_3 =?

A. 1/3

B. 1/2

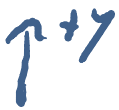
C. 1

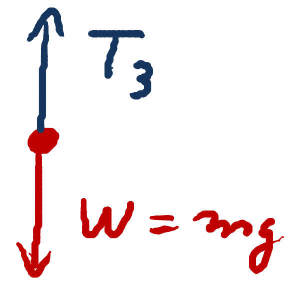
D. 2

E. 3

Methode I:

- FBD of 3rd mass (bottom mass)

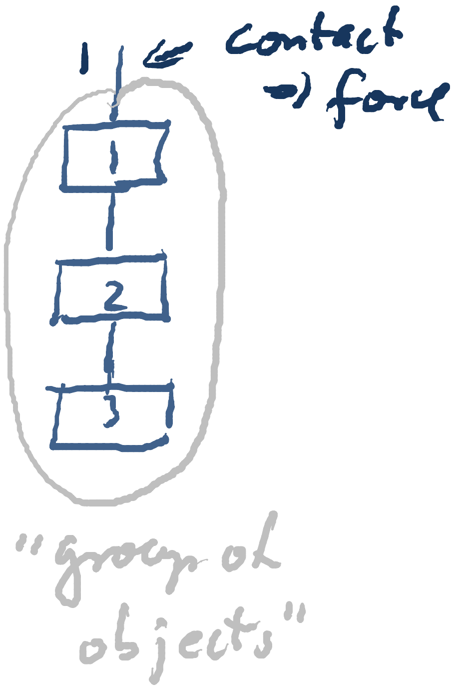


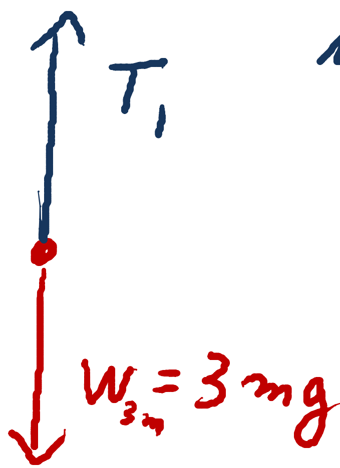


NII:

$$\Sigma F_y = m a_y = 0$$
$$= T_3 - W$$
$$\Rightarrow T_3 = W = mg$$

- FBD of all 3 mass = "object":



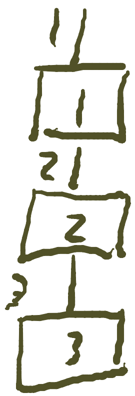


NII:

$$\Sigma F_y = m_{total}\, a_y = 0$$
$$= T_1 - W_{3m}$$
$$= T_1 - 3mg$$
$$\Rightarrow T_1 = 3mg$$

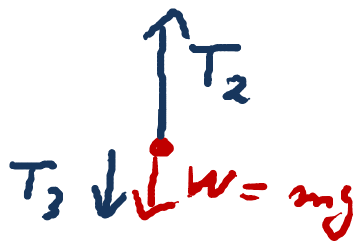
$$\Rightarrow T_1 / T_3 = \underline{\underline{3}}$$

Methode II:

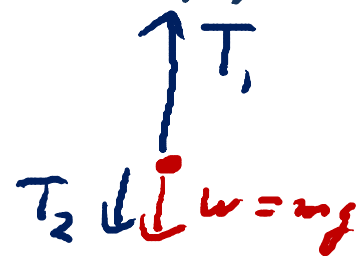


mass 3 (bottom)

mass 2 (middle)



mass 1 (top)



use N II: $\sum F_y = m a_y = 0$

Mass 3:

$\sum F_y = 0 = T_3 - W$

$\Rightarrow T_3 = W = mg$

Mass 2:

$\sum F_y = 0 = T_2 - T_3 - W$

$\Rightarrow T_2 = T_3 + W = T_3 + mg$

$\Rightarrow T_2 = mg + mg$
$= 2mg$

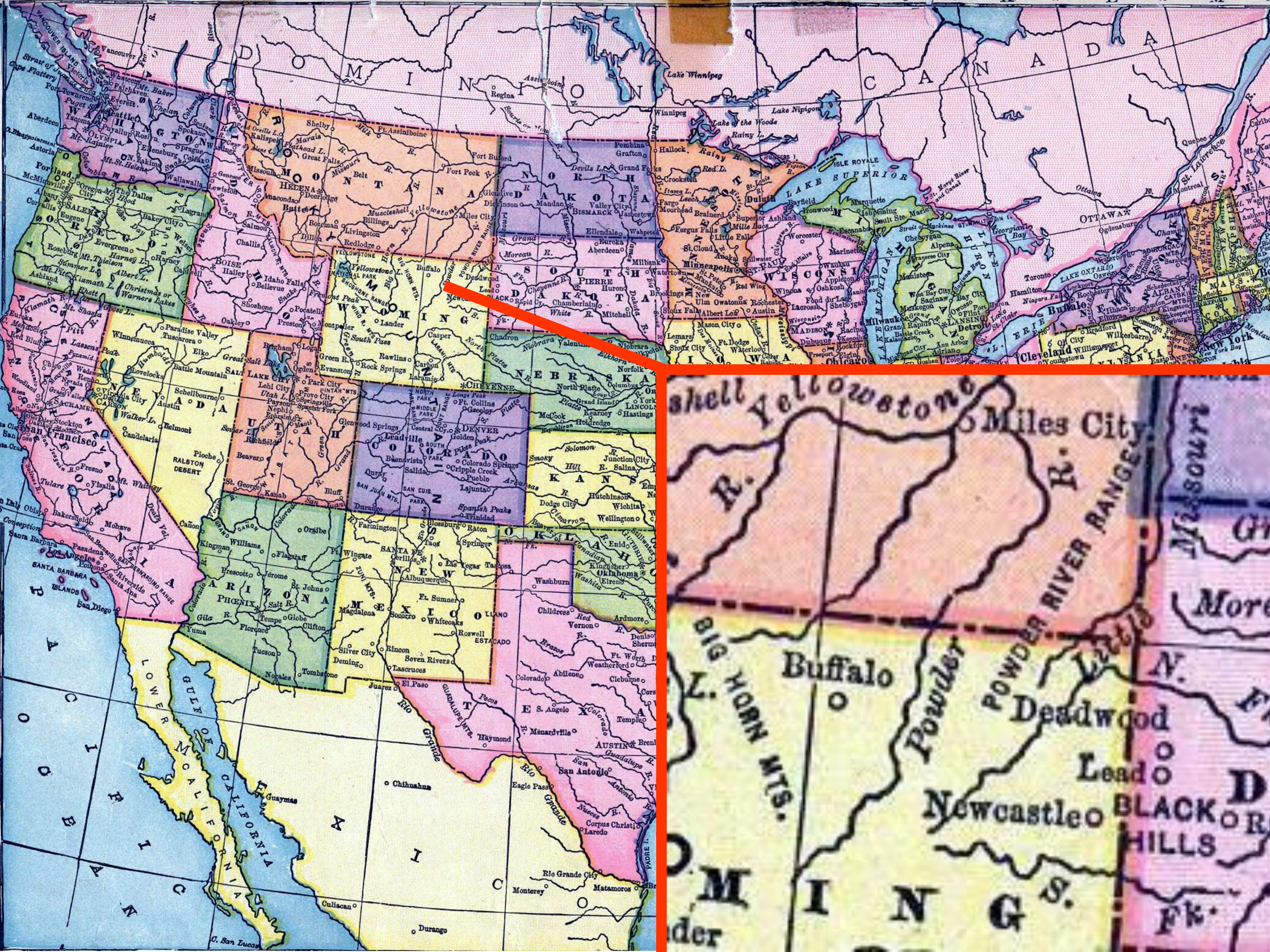
Mass 1:

$\sum F_y = 0$
$= T_1 - T_2 - W$

$\Rightarrow T_1 = T_2 + W$

$\Rightarrow T_1 = 2mg + mg$
$= \underline{3mg}$

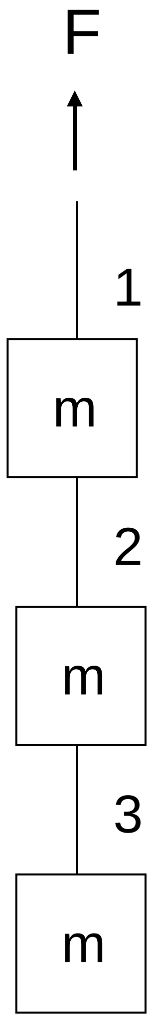
$\Rightarrow T_1 / T_3 = \underline{\underline{3}}$

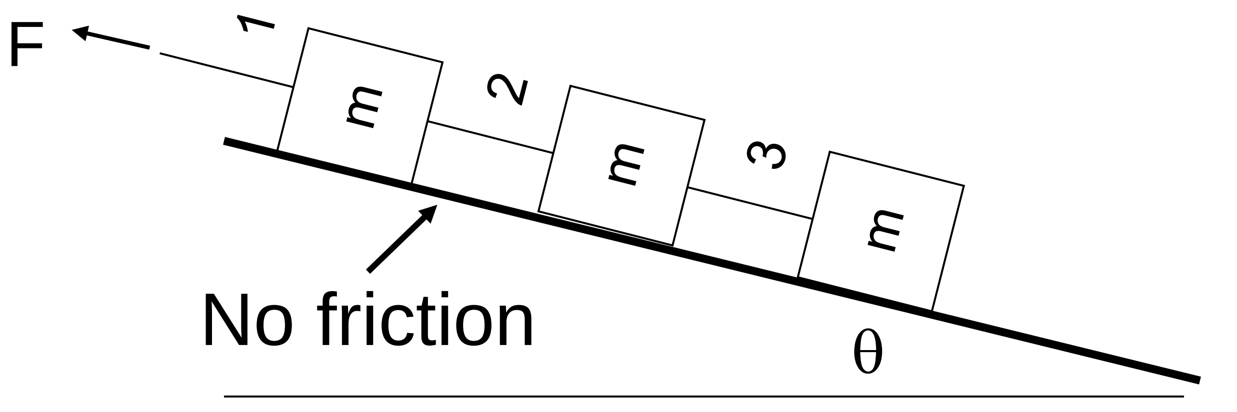


DOMINION OF CANADA
Lake Winnipeg
Winnipeg
Regina
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
Ottawa
Montreal
Quebec
Toronto
Buffalo
Cleveland
New York
Chicago
Milwaukee
Madison
Duluth
Minneapolis
St. Paul
Detroit
Lansing
WASHINGTON
Seattle
Olympia
Tacoma
Spokane
OREGON
Salem
Portland
The Dalles
Baker City
IDAHO
Boise
MONTANA
Helena
Butte
Great Falls
Billings
Miles City
NORTH DAKOTA
Bismarck
Fargo
SOUTH DAKOTA
Pierre
Deadwood
WYOMING
Cheyenne
Buffalo
Lander
NEBRASKA
Lincoln
NEVADA
Carson
UTAH
Salt Lake City
COLORADO
Denver
Leadville
Pueblo
Colorado Springs
Cripple Creek
KANSAS
Wichita
Dodge City
OKLAHOMA
CALIFORNIA
San Francisco
Sacramento
Los Angeles
San Diego
Fresno
Bakersfield
ARIZONA
Phoenix
Prescott
Tucson
Yuma
Flagstaff
NEW MEXICO
Santa Fe
Albuquerque
Las Vegas
El Paso
Roswell
TEXAS
San Antonio
Austin
Laredo
Corpus Christi
Abilene
Eagle Pass
MEXICO
Chihuahua
Monterey
Durango
Guaymas
Matamoros
LOWER CALIFORNIA
GULF OF CALIFORNIA
PACIFIC OCEAN
Rio Grande
shell
Yellowstone
Miles City
R.
Missouri
POWDER RIVER RANGE
BIG HORN MTS.
Buffalo
Powder
Deadwood
Lead
Newcastle
BLACK HILLS
N.
Fk.
S.
More
WYOMING
Little
ader

- 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.**

a=0





In both cases, **$T_1/T_3 = 3$**

If we add more masses, eventually rope 1 will break.

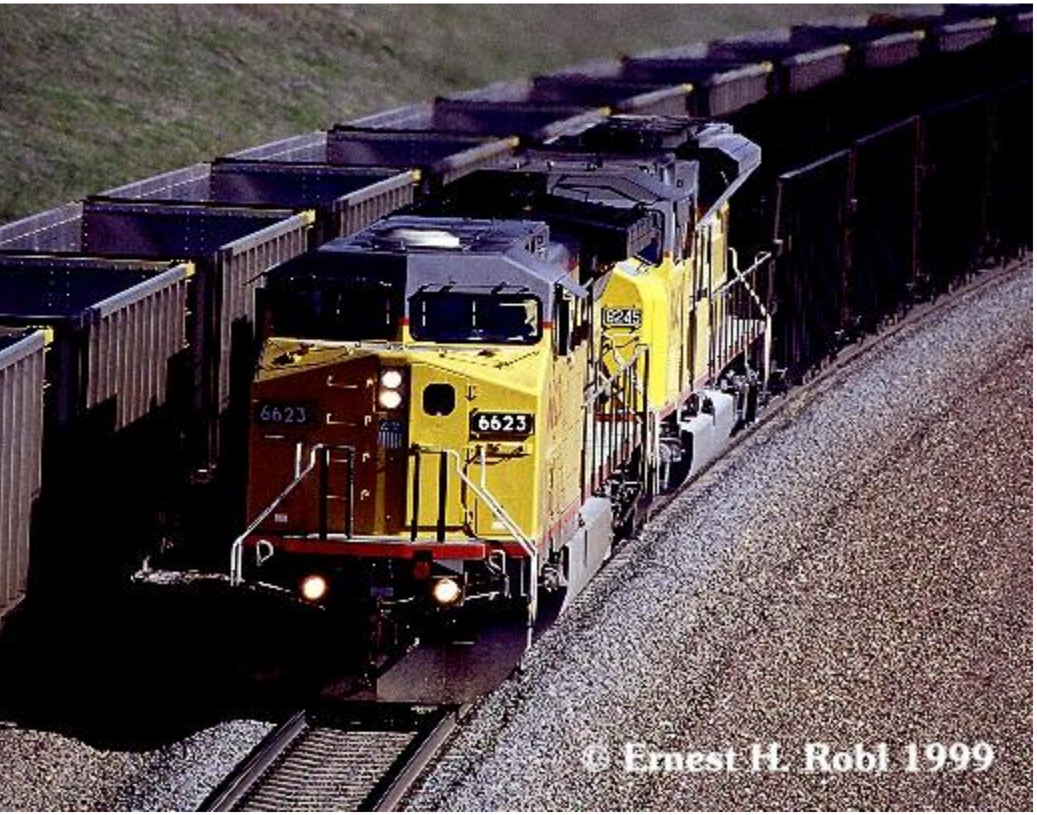
- A steep railroad grade is 1.5%
- (= 15 feet rise/1000 feet)
- The steepest mainline track in the U.S. has a 4% grade.

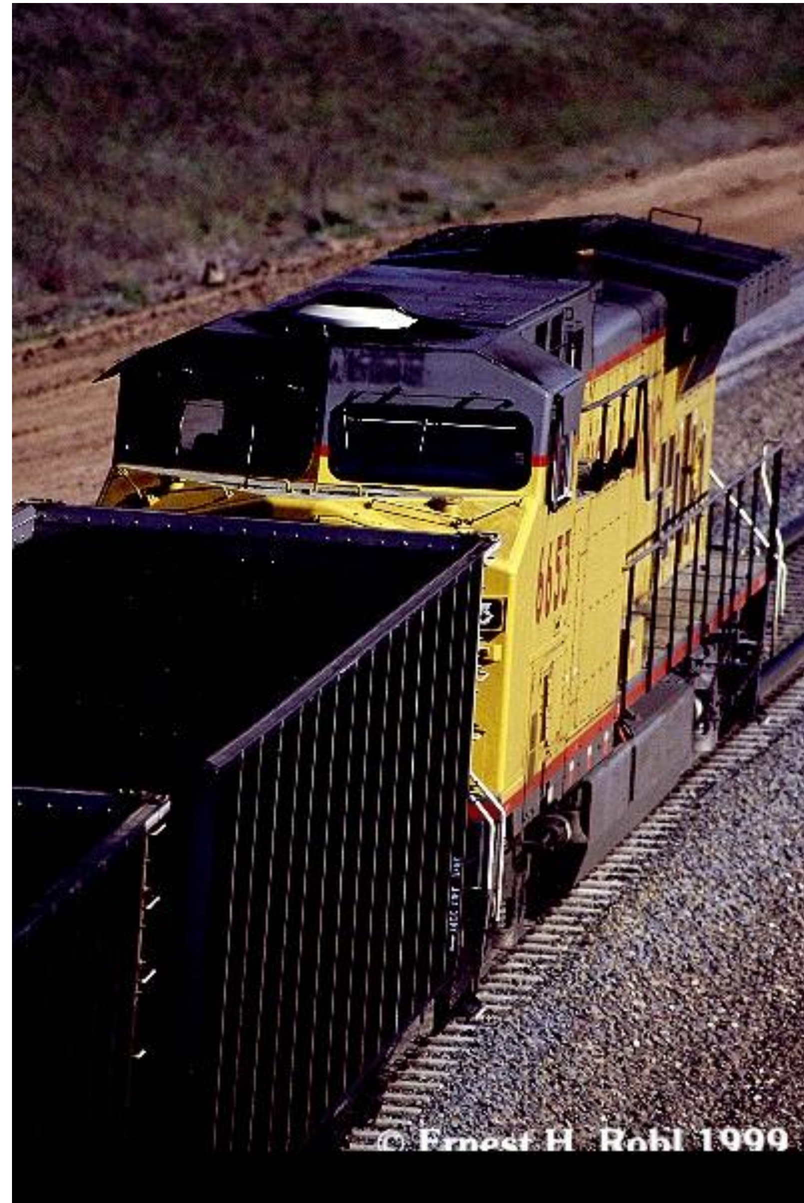
- **How can you keep the couplers between cars from breaking?**

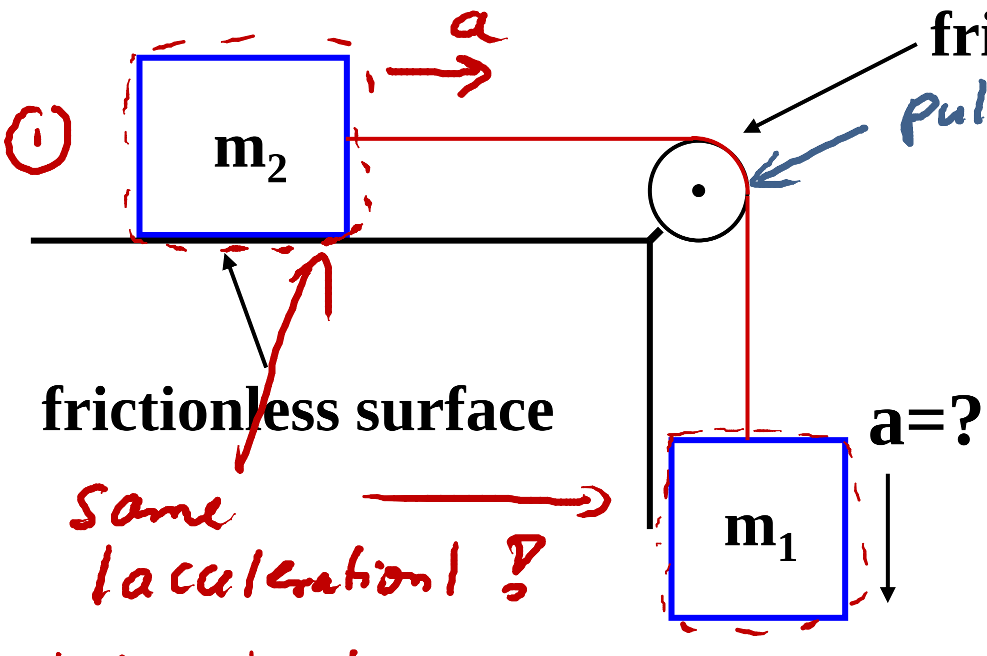
  (Couplers on coal trains break routinely.)

…end of train: locomotive in remote control mode

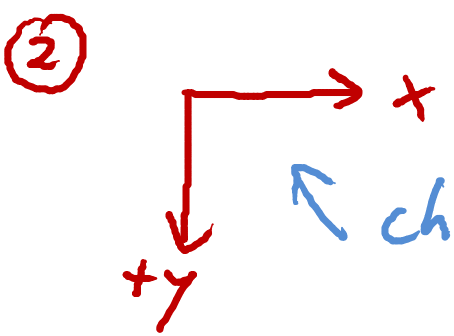
Front…







pulley: changes direction of rope and $\vec{T}$, but not $|\vec{T}|$



choose coordinate axis along direction of motion!

a=?

A. 0

B. g

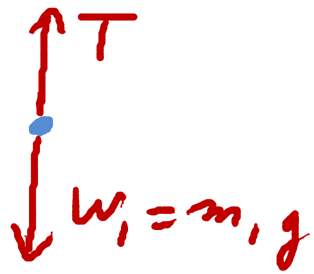
C. $m_1 g / (m_1 + m_2)$

D. $m_2 g / (m_1 + m_2)$

E. $(m_1 - m_2) g / (m_1 + m_2)$

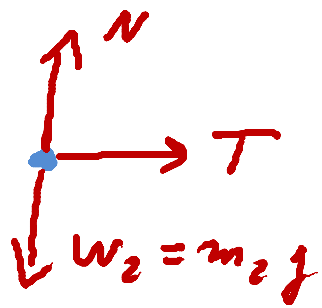
FBD of m_1 and m_2:

$\downarrow +y$ m_1:



$$\Sigma F_y = m_1 a_{y,1} = m_1 \overset{>0}{a}$$
$$= W_1 - T = m_1 g - T \quad (1)$$
↑ +y down!

+x, +y m_2:



$$\Sigma F_y = W_2 - N = m_2 a_{2,y} = 0$$
$$\Rightarrow N = W_2 = m_2 g$$
$$\Sigma F_x = m_2 a_{2,x} = m_2 a \quad (>0)$$
$$= T \Rightarrow T = m_2 a \quad (2)$$

⇒ insert (2) into (1)

$$m_1 a = m_1 g - T = m_1 g - m_2 a$$

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

check: $m_1 \to 0 \Rightarrow a \to 0$ ✓
$m_2 \to 0 \Rightarrow a \to g$ ✓