Recap:

Lecture 9

- **Relative motion:**

$\vec{v}$ B wrt R $= \vec{v}_{B \text{ wrt } A} + \vec{v}_{A \text{ wrt } R}$

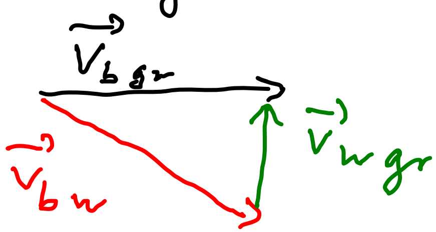
B wrt R
B relative to R
B as seen by R
B in reference frame R

"insert A"

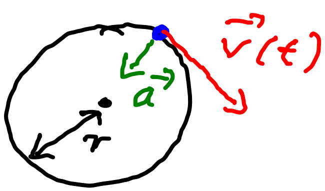
often: "R" = ground

e.g. $\vec{v}_{\text{rain wrt ground}} = \vec{v}_{\text{rain wrt car}} + \vec{v}_{\text{car wrt ground}}$

$\vec{v}_{\text{boat wrt ground}} = \vec{v}_{\text{boat wrt water}} + \vec{v}_{\text{water wrt ground}}$



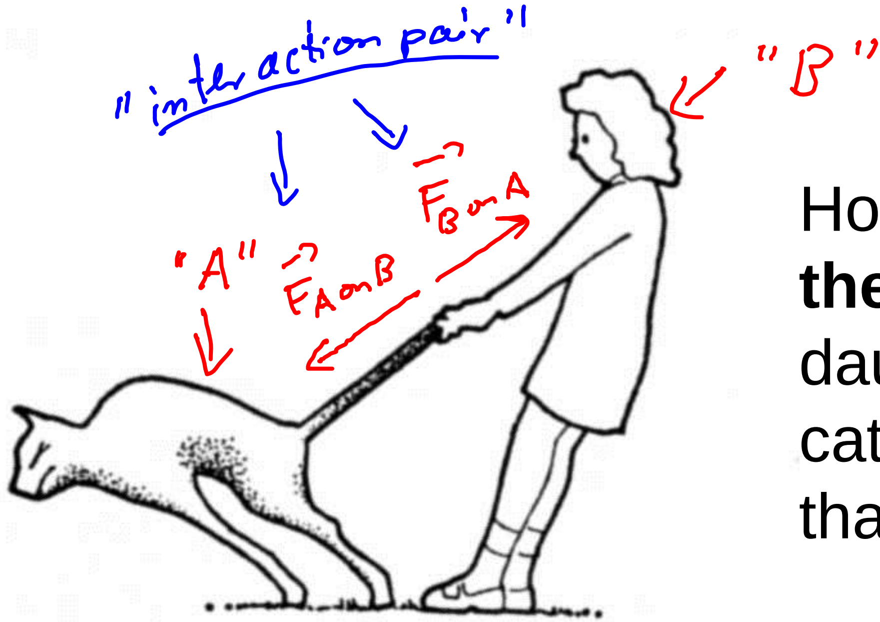
- **Uniform circular motion:**



$|\vec{v}| = \text{const} = \text{speed}$

$\vec{v}$ tangent to path

$|\vec{a}| = v^2/r$, points toward center



How does the **magnitude of the force** that Darling the daughter exerts on Kitty the cat compare with the force that Kitty exerts on Darling?

Do stop pulling the cat's tail, Darling.“

"I'm not pulling Mummy, Kitty's pulling!"

$$\vec{F}_{A\,on\,B} = -\vec{F}_{B\,on\,A} \quad \} \text{ N III}$$

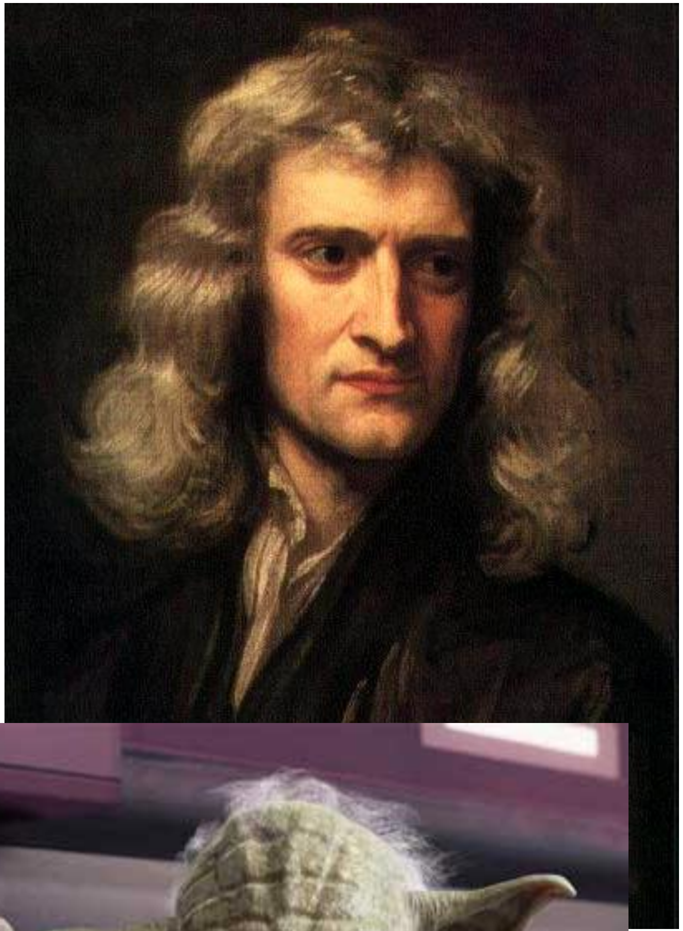
A. $|F_{\text{Darling on Kitty}}| > |F_{\text{Kitty on Darling}}|$

B. $|F_{\text{Darling on Kitty}}| = |F_{\text{Kitty on Darling}}|$

C. $|F_{\text{Darling on Kitty}}| < |F_{\text{Kitty on Darling}}|$

Today:

- Forces
  - Newton’s laws of motion
  - Gravitational force
  - Normal force
  - Friction
  - Tension
  - Spring force



have $\vec{a} \propto \vec{F}$, what else matters? ⇒ mass: $|\vec{a}| \propto \frac{1}{m}$

NII: Newton's second law of motion

$$\vec{a}_{\text{of object}} = \frac{\sum \vec{F}_{\text{on object}}}{m_{obj}} = \frac{\vec{F}_{\text{net on obj}}}{m_{obj}}$$

in component form:

$$a_x = \frac{\sum F_{x,\text{on obj}}}{m_{obj}} \qquad a_y = \frac{\sum F_{y,\text{on obj}}}{m_{obj}}$$

⇒ 2-D problem = 2 1-D problems

Note: External forces only! Internal forces don't affect the motion!

NI: Newton's first law of motion (special case of NII)

If $\sum \vec{F}_{on\ obj} = 0$, then $\vec{a} = 0$

$\Rightarrow$ if object is initially at rest, then $\vec{v}(t) = 0$ for all $t > 0$.

$\Rightarrow$ initially moving, then $\vec{v} = \overrightarrow{const}$ for all t.

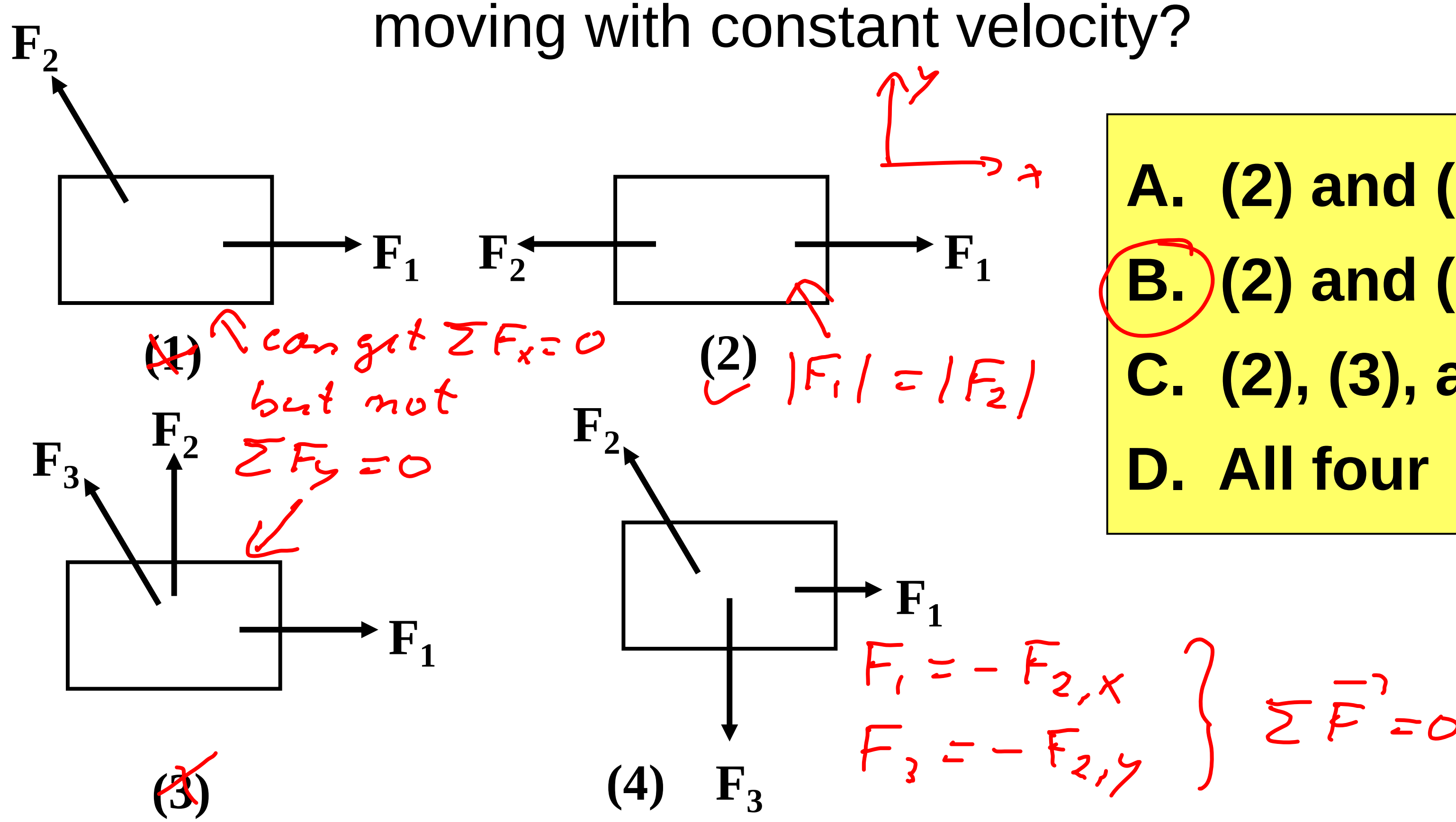
Units of force:

$$[F] = [m][a] = kg\ \frac{m}{s^2} =: N \text{ (Newton)}$$

Overhead views of a block that lies on a frictionless floor are shown below.

want $\vec{v} = \text{const} \Rightarrow \vec{a} = 0 \Rightarrow \Sigma \vec{F} = 0$

If the force magnitudes are chosen properly, in which situations is it possible that the block is either stationary or moving with constant velocity?



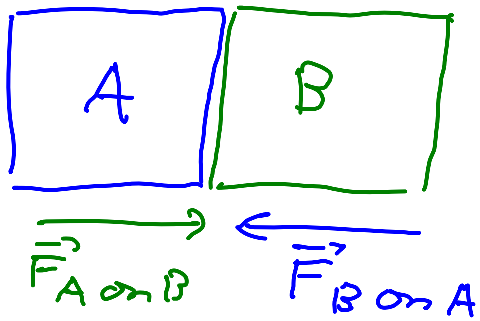
A. (2) and (3)

B. (2) and (4)

C. (2), (3), and (4)

D. All four

Newton's 3rd law of motion



} forces from object interaction

$$\vec{F}_{A\ on\ B} = -\vec{F}_{B\ on\ A}$$

"interaction pair" = forces involved in the interaction of two objects

= ~~action - reaction~~ pair

$N\overline{\underline{III}}$: - Forces in an interaction pair act on different objects (never on the same)!

e.g. $\vec{F}_{\text{apple on earth}}$ and $\vec{F}_{\text{earth on apple}}$

- $N\overline{\underline{III}}$ true even if object are moving or accelerating!

Newton's Third Law:

$\vec{F}_{\text{earth on apple}}$ → ← $\vec{F}_{\text{apple on earth}}$

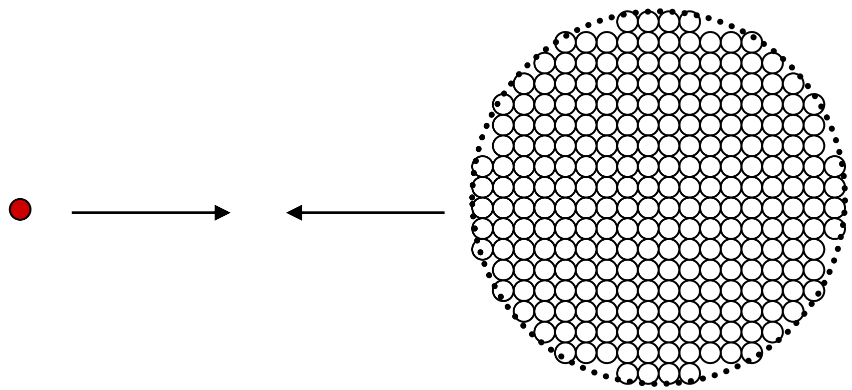
$$\vec{F}_{\text{earth on apple}} = - \vec{F}_{\text{apple on earth}}$$

"Proof": Break earth up into N apple-sized chunks:

Forces on apple:

$F_{\text{chunk 1 on apple}}$ +
$F_{\text{chunk 2 on apple}}$ +
$F_{\text{chunk 3 on apple}}$ +
.... +
$F_{\text{chunk N on apple}}$

$\mathbf{F}_{\textbf{earth on apple}}$



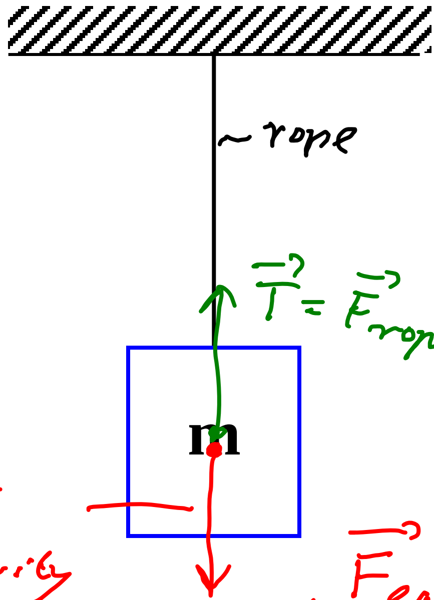
Forces on chunks of earth:

$F_{\text{apple on chunk 1}}$ +
$F_{\text{apple on chunk 2}}$ +
$F_{\text{apple on chunk 3}}$ +
.... +
$F_{\text{apple on chunk N}}$

$F_{\text{apple on earth}}$

It only seems reasonable that each term $F_{\text{chunk i on apple}}$ and $F_{\text{apple on chunk i}}$ on either side should be equal, so the sums must be equal.

Note: - |forces| can be equal, but don't have to be interaction pairs!
- 2 objects involved



Which of the following forces are 3rd-law interaction pairs?

A. Weight W of mass m and tension T of rope

B. W and gravitational force of mass m on earth

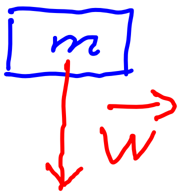
C. Tension T and force of mass m on rope

D. Two of the above

E. Three of the above

Some Forces:

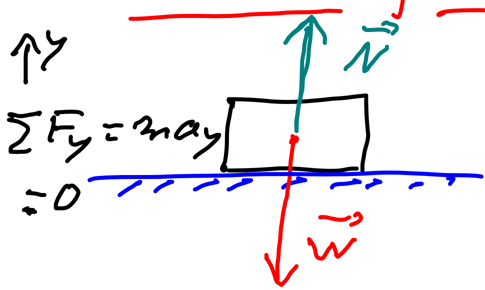
- **Weight** $\vec{W}$ = gravitational force = $\vec{F}_{by}$ earth on object
  = force on object due to Earth's gravity



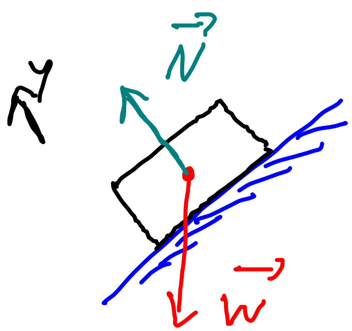
$$\vec{W} = m\vec{g}$$ pointing to center of Earth

[$g \approx 10\ m/s^2$ at earth's surface]

- **Normal force**: $\vec{N} = \vec{F}_{\perp}$ to surface by surface on object

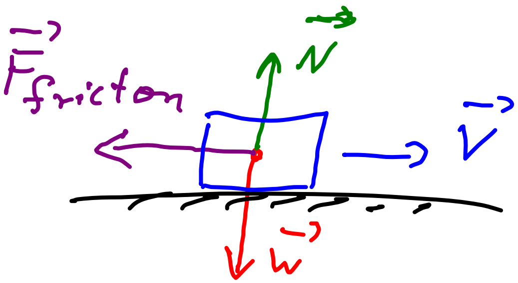


$\sum F_y = ma_y = 0$



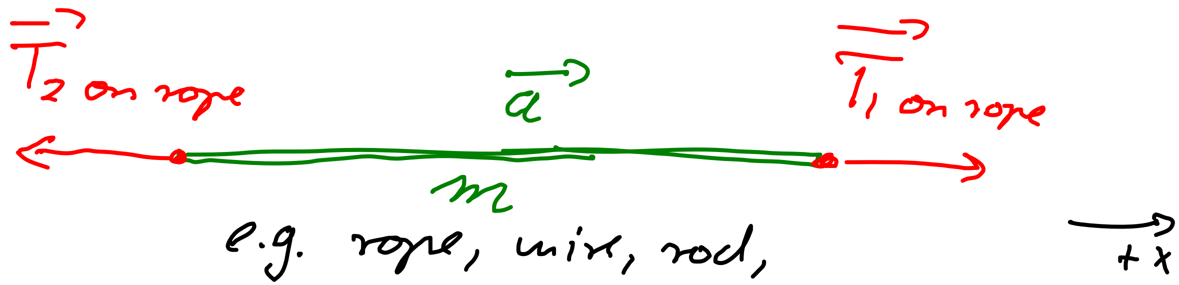
- $\vec{N}$ prevents motion $\perp$ to a surface (into surface)
- self-adjusting force, to prevent motion into surface $\Leftrightarrow a_{\perp} = 0$
- $\vec{N}$ always $\perp$ to surface (90° wrt surface)
- $\vec{N}$ is the $\perp$ component of the force by a surface on an object

- **Friction:**



- ∥ to surface
- oppose motion <u>relative</u> to surface
- ∥ component of the force by a surface on an object

- **Tension $\vec{T}$:**



e.g. rope, wire, rod, bone, muscle, ...

NII: $\sum F_x = m a_x = T_1 - T_2$

("−" for direction)

$\Rightarrow$ if $a_x = 0$, then $\boxed{T_1 = T_2}$

also : if $\underbrace{m_{rope} \approx 0}_{\text{valid when}}$ $\Rightarrow T_1 - T_2 = m a_x \approx 0 \; a_x = 0$

valid when $m_{rope} <<$ mass of other objects in problem

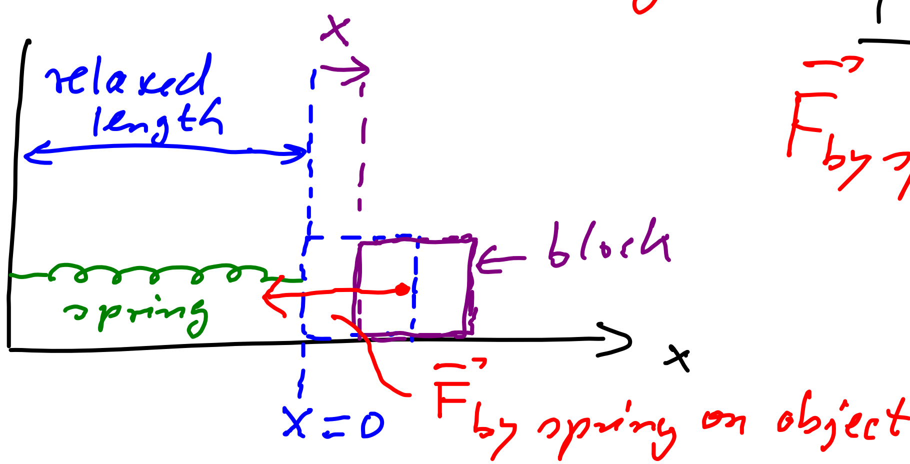
$\Rightarrow \boxed{T_1 = T_2}$ even if $a_x \neq 0$

$\Rightarrow$ use this in P2207 unless otherwise stated

$\vec{T}$: - equal in magnitude at either end of the rope (if $m_{rope} \approx 0$, or $\vec{a} = 0$)

- force each piece of rope exerts on the adjacent piece / section / object

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



For ideal spring:

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

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