PHYS 225
Fundamentals of Physics: Mechanics

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Fall 2024

Lecture 20: Force and motion II: Drag force and force in UCM

CALIFORNIA STATE UNIVERSITY FULLERTON

Learning goals for today

- Drag force
- Forces in uniform circular motion

Chapter 6.2: The drag force

Demo

- Air resistance.

Clicker question 1

- Which of the following is true **in air**?

A  lands first

B They land at the same time

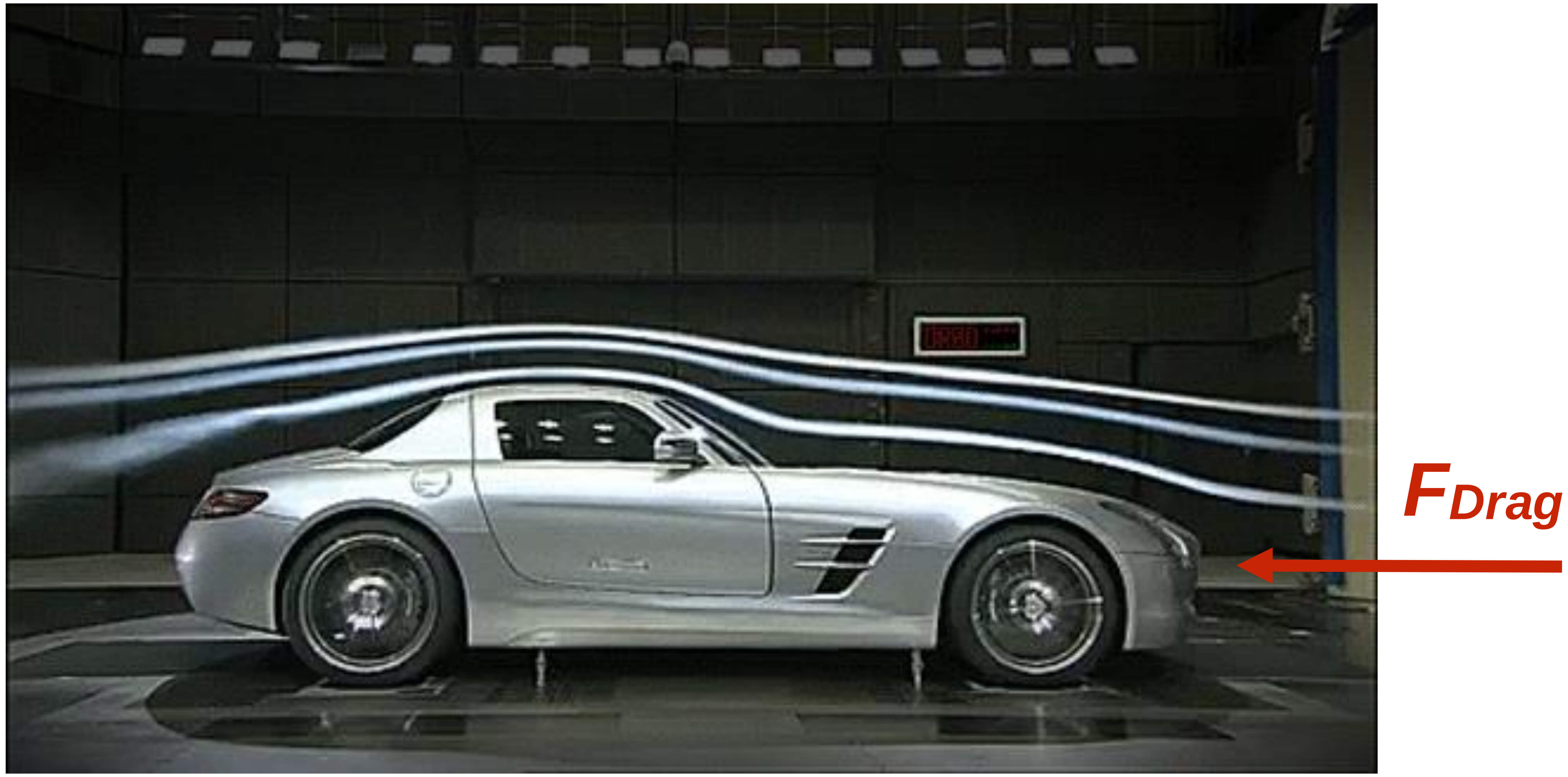
C 

lands first

less facing area

Drag Force

- Drag force, $\vec{F}_{drag}$: Air resistance due to a velocity difference between the object and the air



Magnitude

$$|F_{Drag}| = \frac{1}{2} C \rho A v^2 \quad = C' v^2$$

drag coefficient

air density

Facing area

Relative velocity w.r.t. air

Lumped coeff.

Direction: Opposing the relative motion of the object w.r.t. air.

Clicker question 2: Sky diving

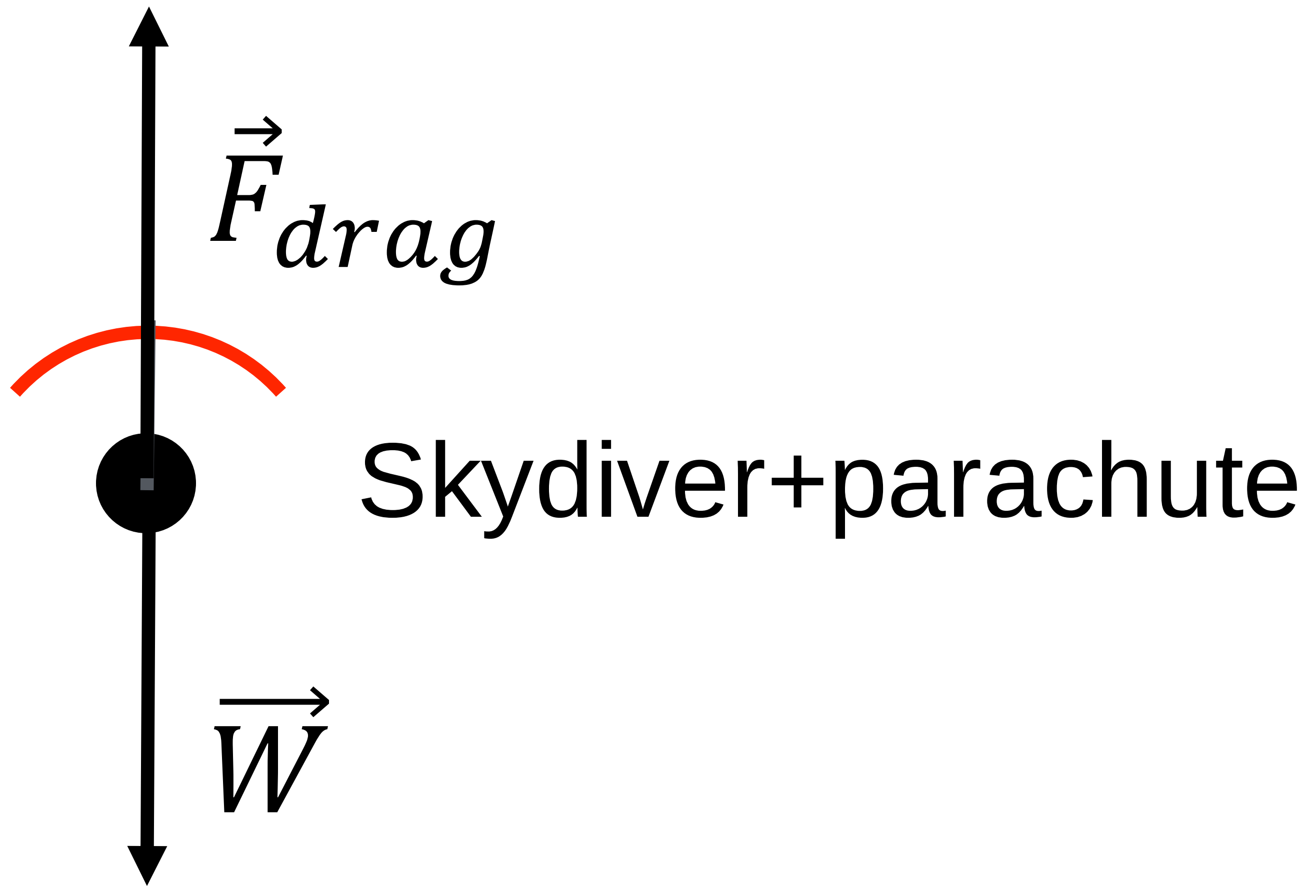
- A parachuter jump out of a plane very high off the ground and start falling towards the earth, what determines the drag force? *Hint:* $F_{Drag} = \frac{1}{2}C\rho A v^2$

A The drag coefficient and the air density

B The area facing the air

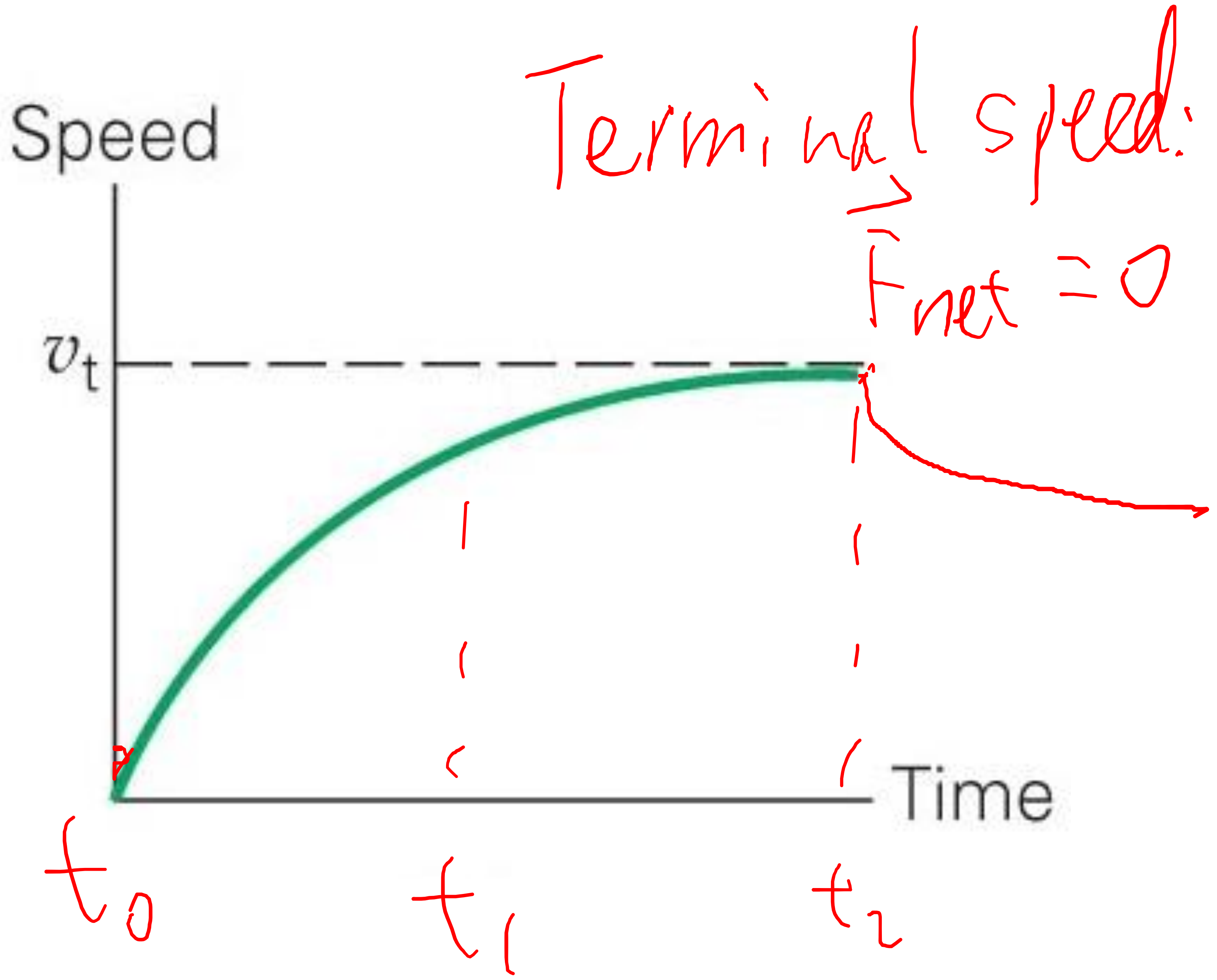
C The speed

D All above

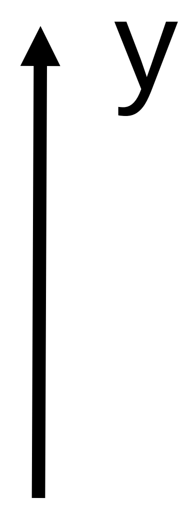


Example: Skydiving

t: $0 < t_1 < t_2$
Speed: $0 < v_1 < v_2$
F_{drag}: $0 < F_1 < F_2$

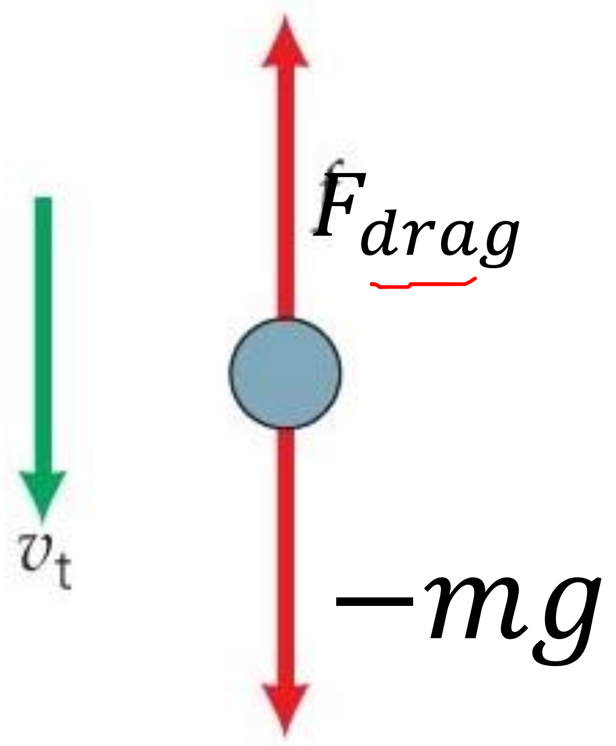


Air resistance and terminal velocity



- **At terminal velocity:** $\vec{v} = const$,
- At terminal velocity, $\vec{F}_{net} = \overrightarrow{F}_{drag} - mg\hat{j} = 0$

FBD



Typical terminal velocity for a skydiver before opening the parachute:

120 mph (200 km/h)

Example 1

Given: m, v_t, C, ρ

Goal: r

$\uparrow y$

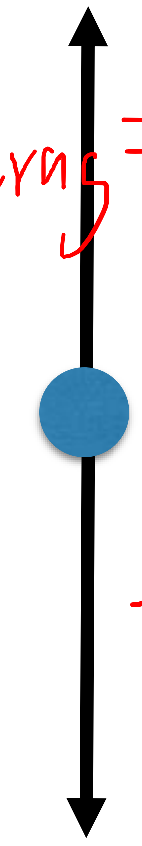
- The terminal speed of an m=7.00 kg spherical ball in air is 160 m/s. The drag coefficient is 1.48, the air density is 1.2 kg/m^3. What's the radius of the sphere?

Step 1: $v_t = \text{const}$, $\vec{F}_{net} = 0 = \vec{F}_{drag} + \vec{W}$ ...(1)

Step 2: $|\vec{F}_{drag}| = \frac{1}{2} C \rho A v^2$ ...(2)

FBD

$\vec{F}_{drag} = C'v^2 = \frac{1}{2} C \rho A v^2 \hat{j}$



Step 3: $\frac{1}{2} C \rho A v^2 - mg = 0$ ...(3)

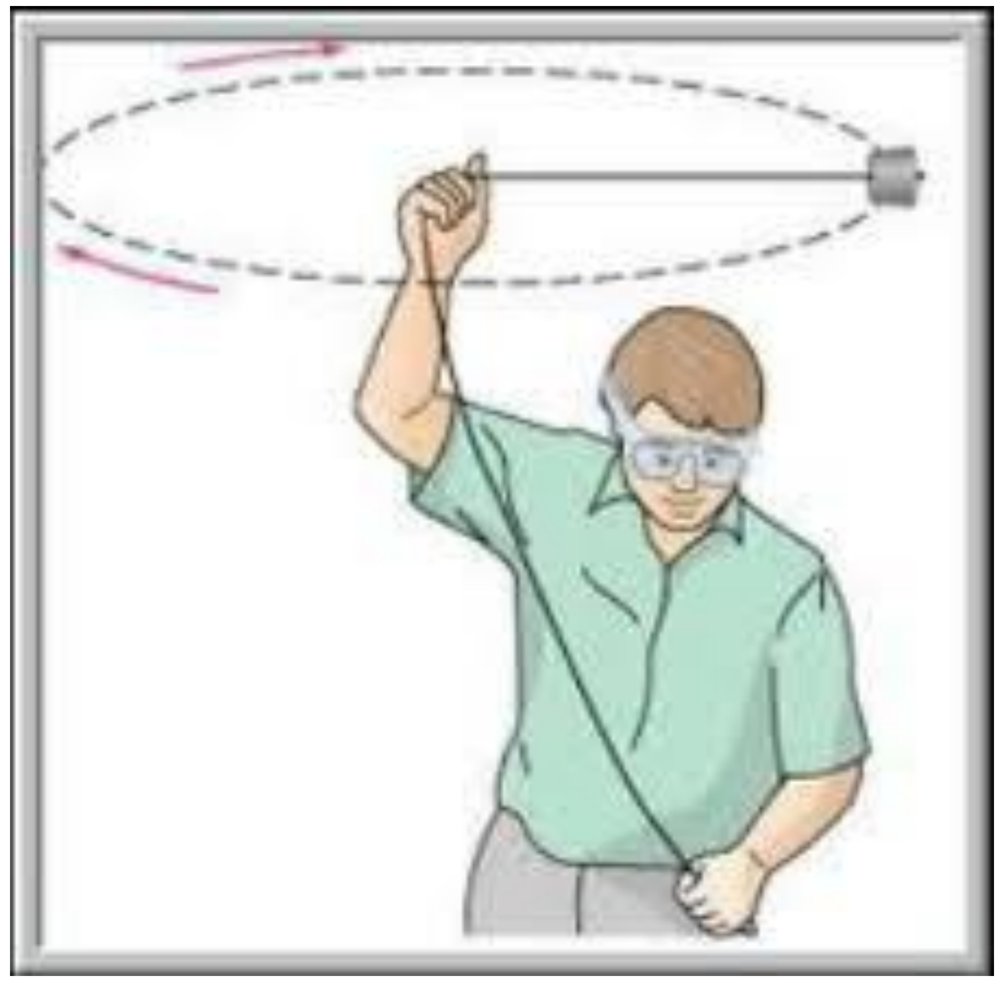
$A_{sp} = \pi r^2$

$\frac{1}{2} C \rho \pi r^2 v^2 = mg \rightarrow r = \sqrt{\frac{2mg}{C \rho \pi v^2}} \approx \sqrt{\frac{2 \times 7 kg \times 9.8 m s^{-2}}{1.48 \times 1.2 kg m^{-3} \times 3.14 \times (160 m s^{-1})^2}}$

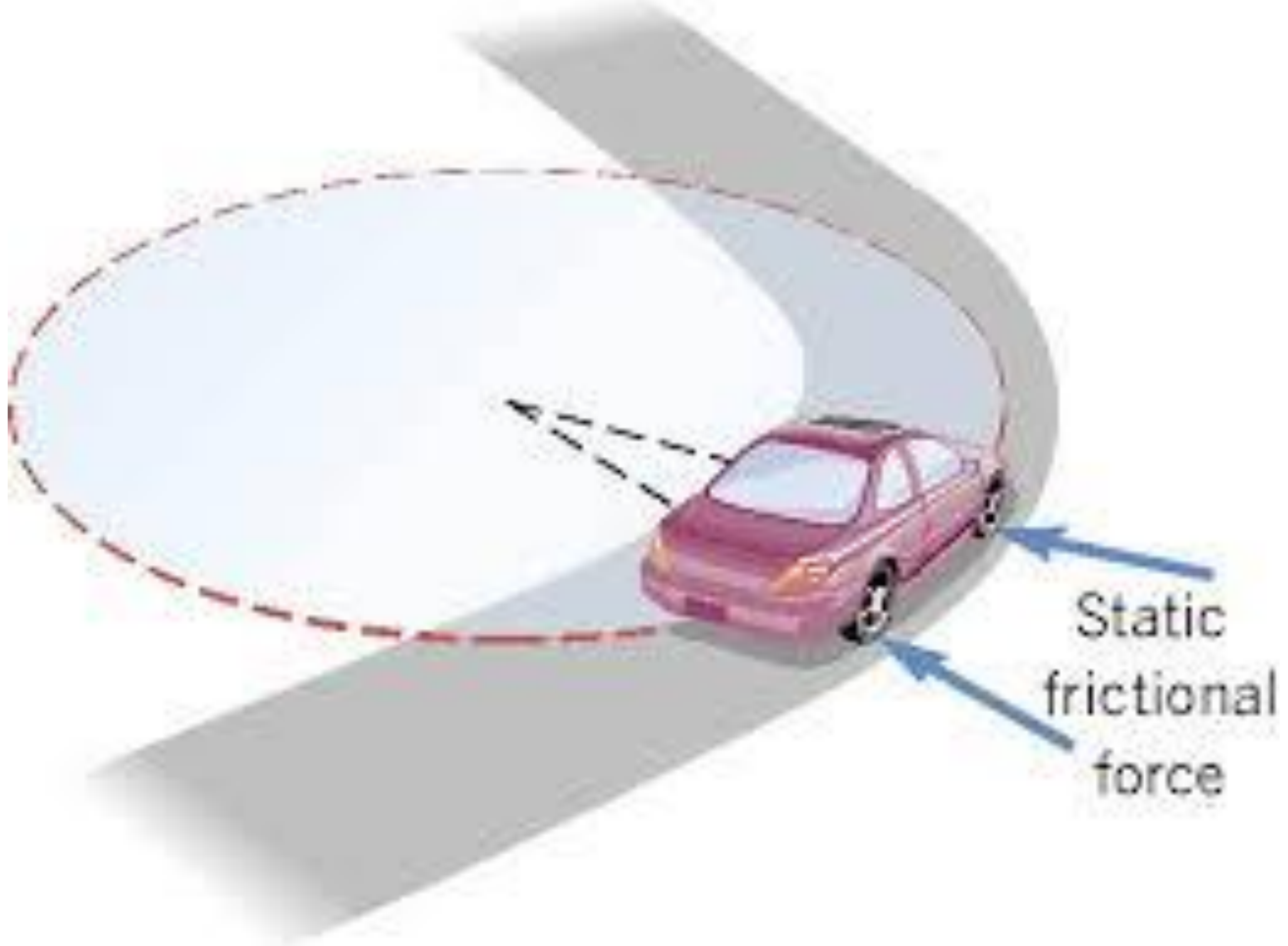
$\approx 0.031 m$

Chapter 6.3: Forces in uniform circular motion (UCM)

- Uniform circular motion = const angular velocity
  - Centripetal acceleration
    - ✓ Direction: points toward the center of the circle
    - ✓ Magnitude $a_c = \frac{v_t^2}{R} = \omega^2 R$
  - Centripetal force: The net force in UCM
    - ✓ Direction: points toward the center of the circle
    - ✓ Magnitude $F = \frac{mv^2}{R} = m\omega^2 R$
    - ✓ The centripetal force can be a tension, normal force, static friction, gravity, electrostatic force, etc., or the sum of different forces.



$\vec{F}_{net} = m\vec{a}$



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Clicker question 3: Netforce for a uniform circular motion

Tetherball

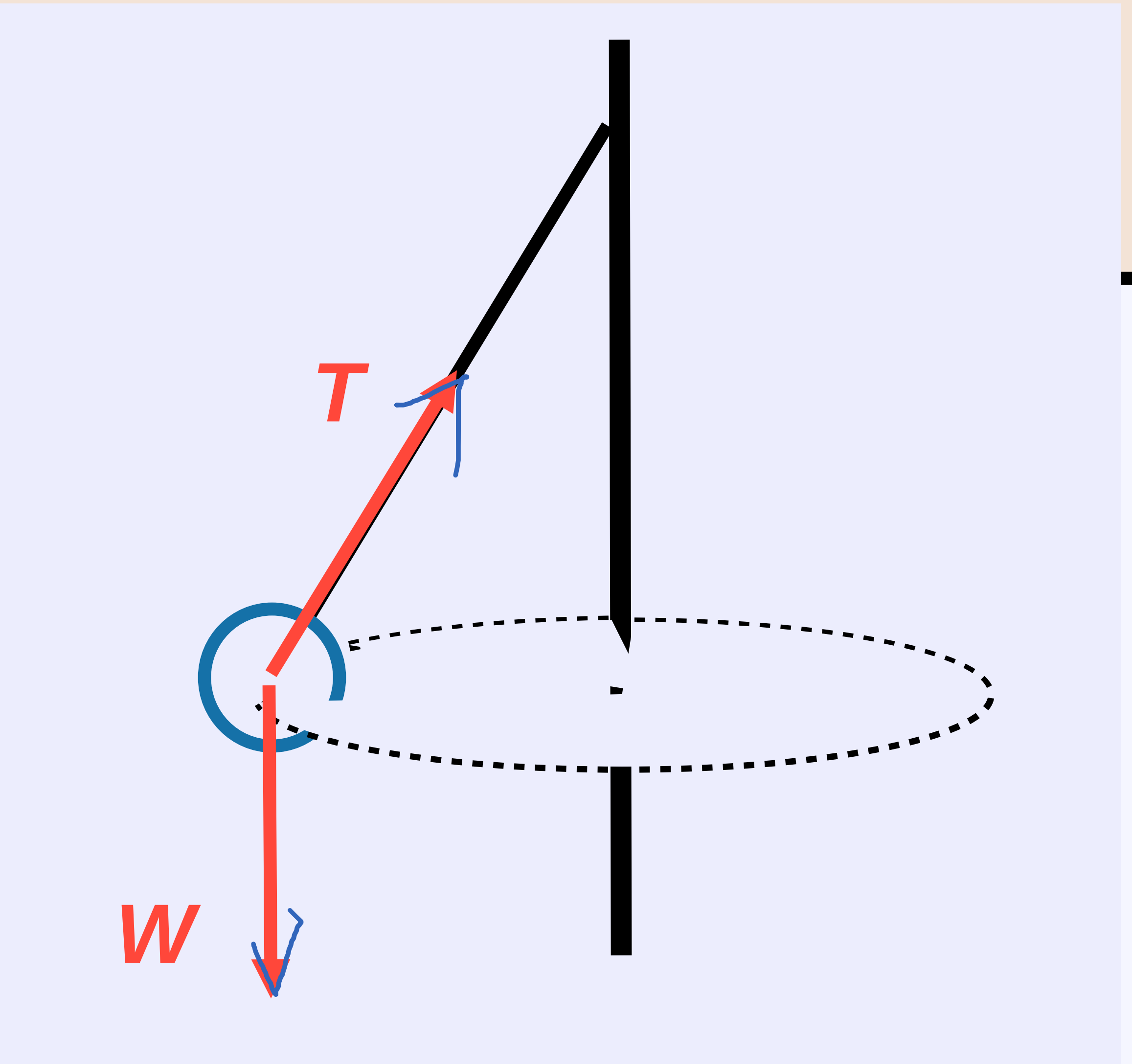
In the game of tetherball, the struck ball whirls around a pole, moving at a constant speed in a circle. In what direction is the net force on the ball point?

A toward top of pole along rope

B along the horizontal component of the tension force

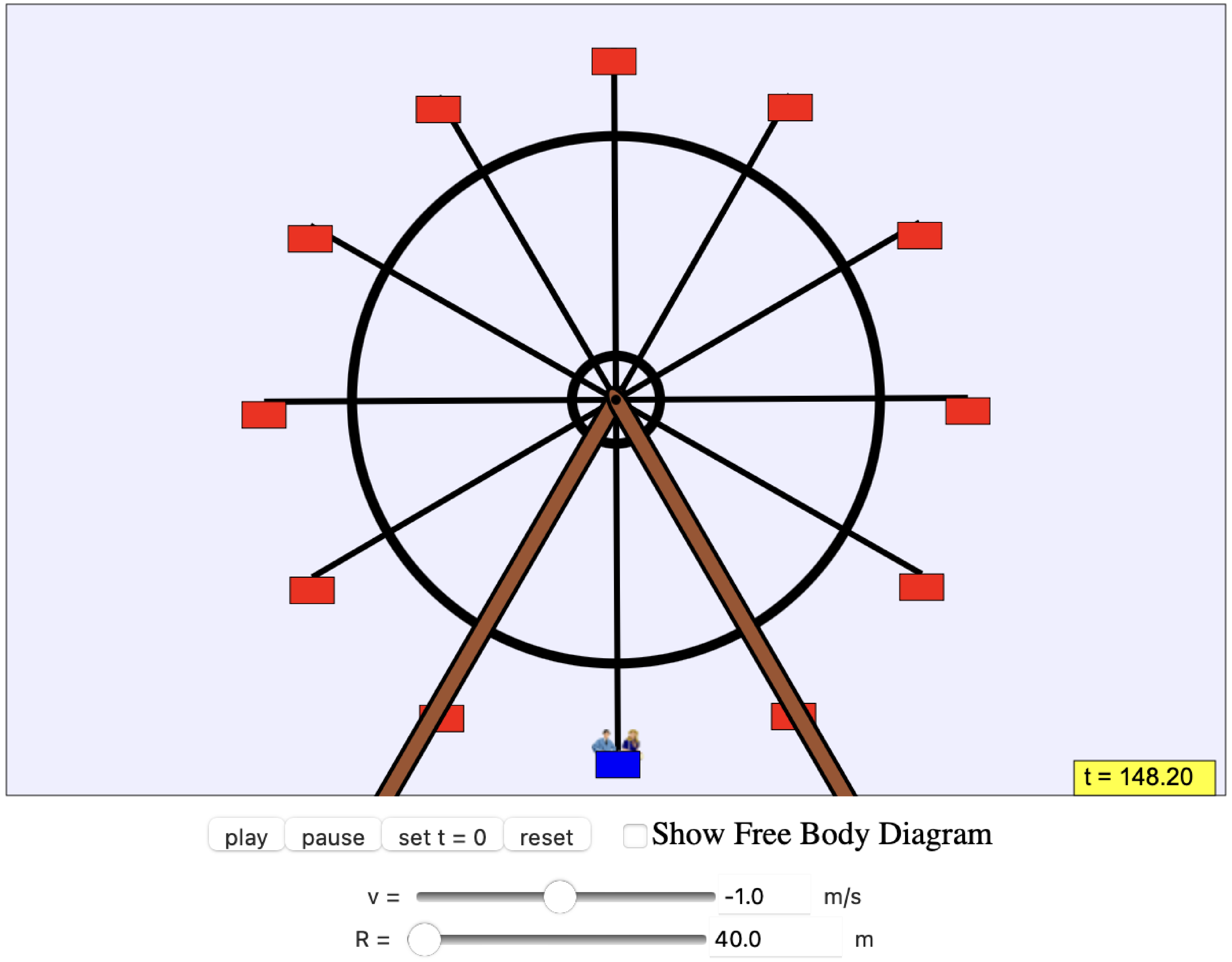
C along the vertical component of the tension force

D tangential to the circle



$$\vec{T}+\vec{W}=\vec{F}_c=m\vec{a}_c$$

Simulation demo

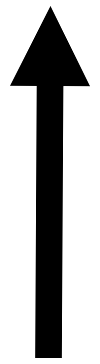


https://www.compadre.org/osp/EJSS/3569/8.htm

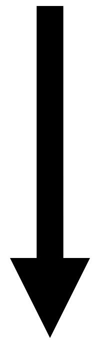
Clicker question 4

- A ferris wheel rotates with a constant angular velocity. What is the direction of the net force at the lowest point?

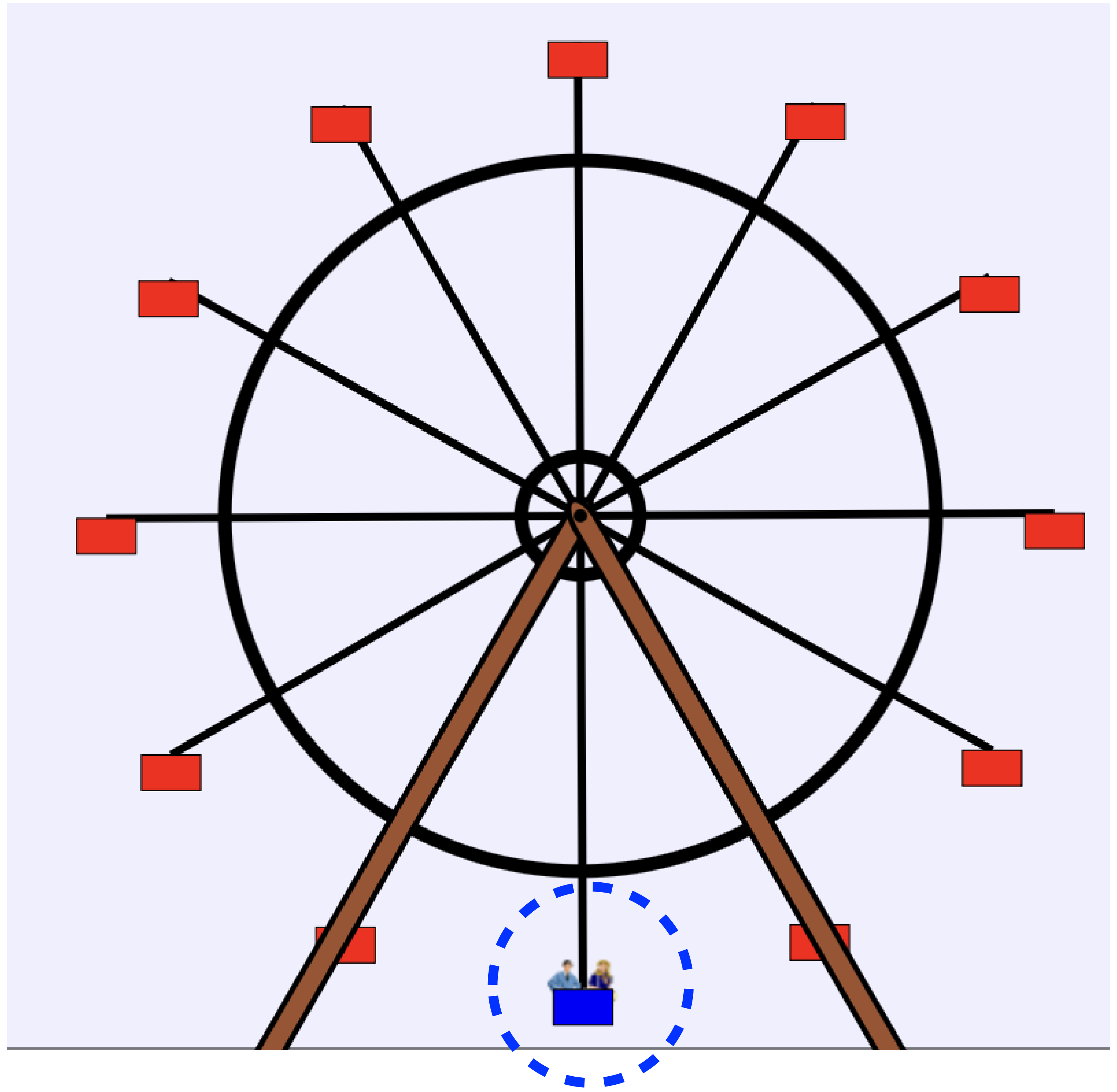
A



B



$\vec{F}_c = m\vec{a}_c$

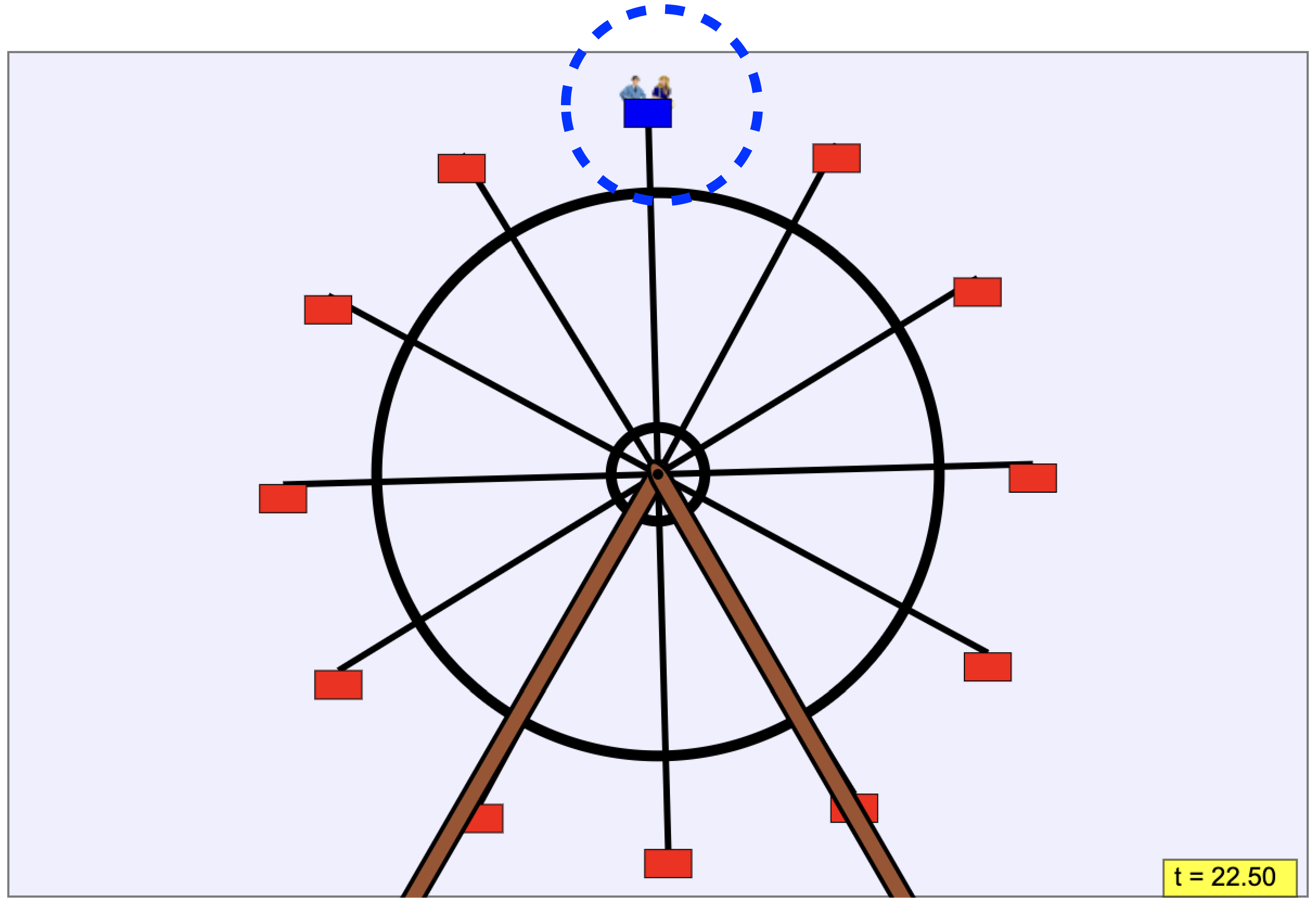


Clicker question 5

- A ferris wheel rotates with a constant angular velocity. What is the direction of the net force at the upmost point?

A ↑

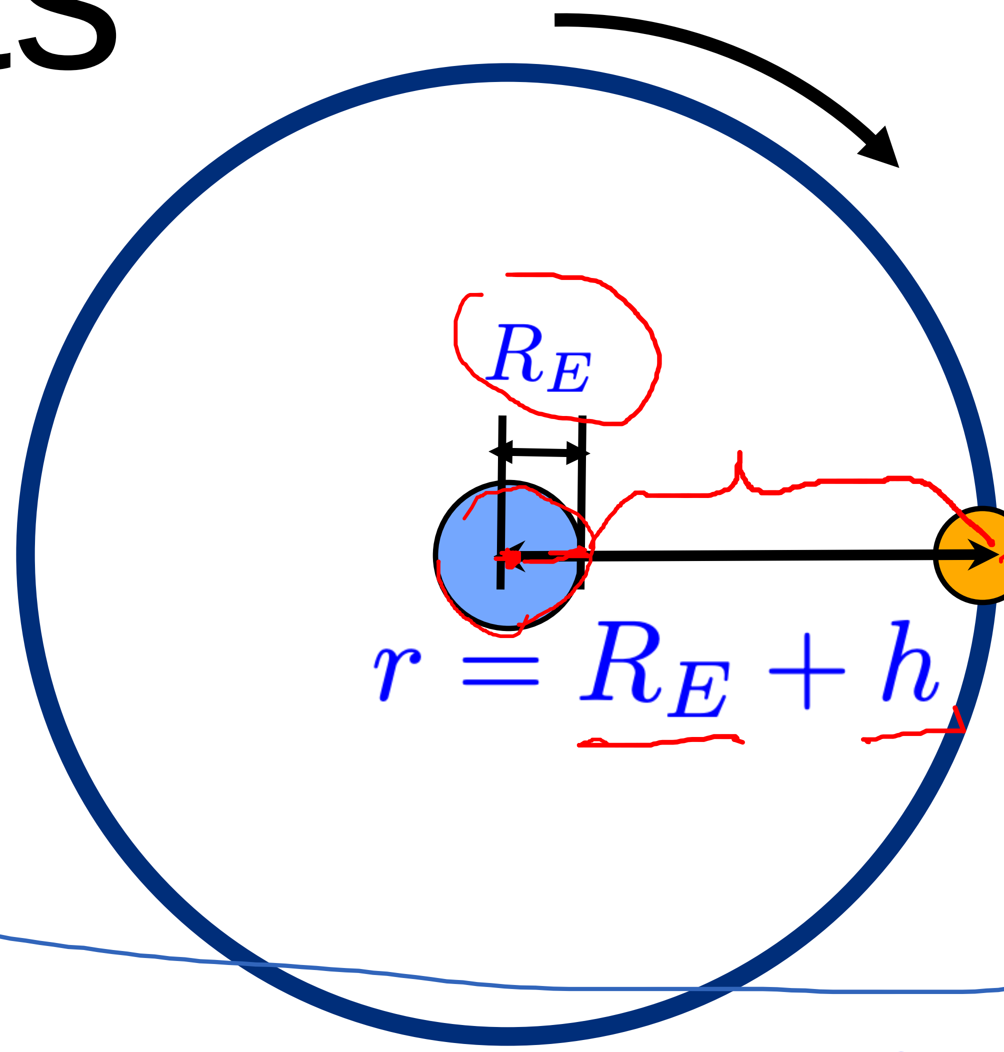
B ↓



Example: geosynchronous orbits

Satellite circles the orbit such that it hovers above one spot on earth. How high about the earth's surface is it?

UCM



Given: G, M_E, R_E **and** ω.

Goal: h

$$G = 6.7 \times 10^{-11}\ \mathrm{m^3\ kg^{-1}\ s^{-2}}$$
$$R_E = 6.4 \times 10^{6}\ \mathrm{m}$$
$$M_E = 6.0 \times 10^{24}\ \mathrm{kg}$$
$$\omega = \frac{2\pi\ \mathrm{rad}}{\mathrm{day}}$$

$3.6 \times 10^4\ \mathrm{km}$

Step 1: $\vec{F}_{net} = \vec{F}_c = m\vec{a}_c$

$|\vec{F}_c| = m|\vec{a}_c|$ ...... (1)

Step 2: $|\vec{F}_c| = |\vec{F}_G| = \frac{G M_E m}{r^2}$ ...... (2)

$|\vec{a}_c| = \omega^2 r$ ...... (3)

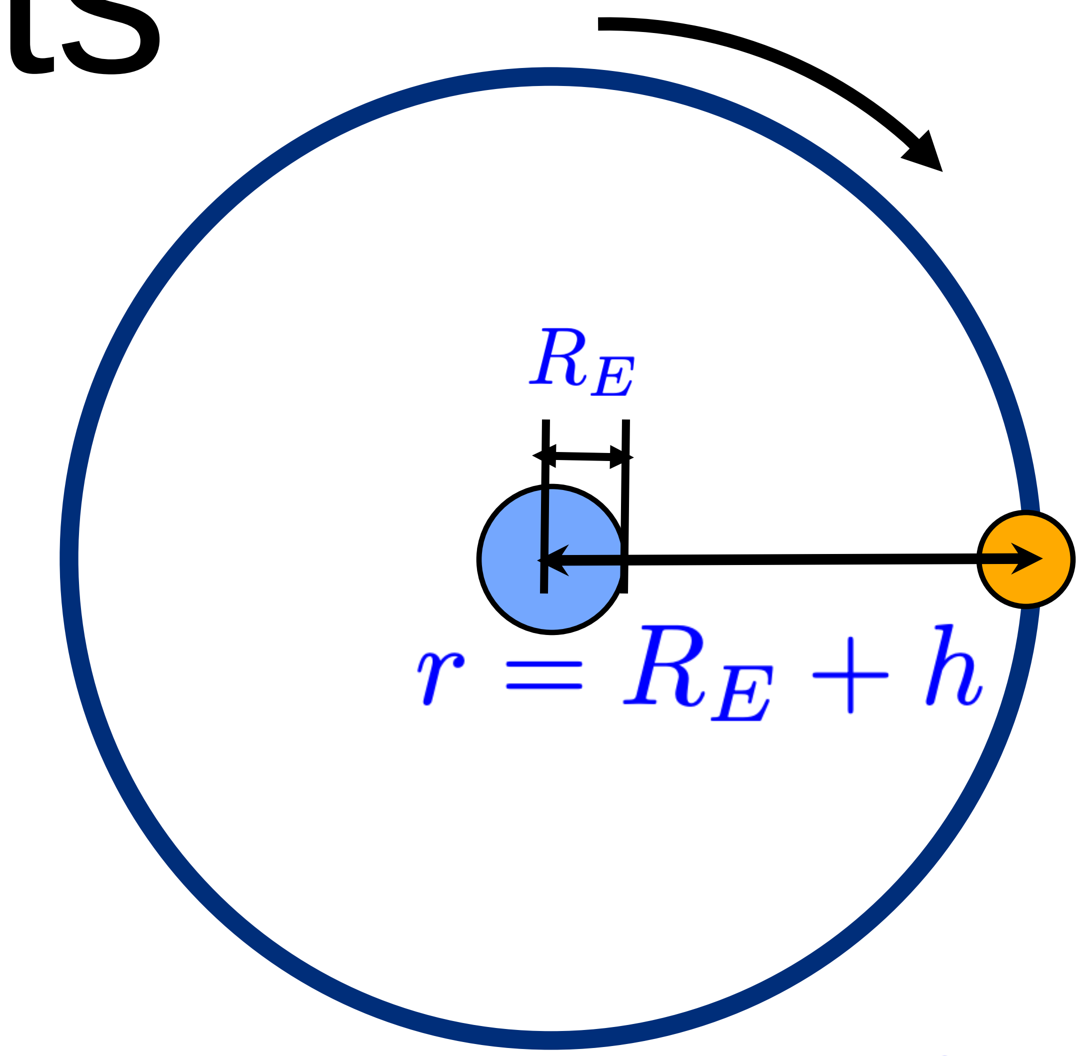
Step 3: sub. (2) & (3) to (1)

$$\frac{G M_E \cancel{m}}{r^2} = \cancel{m}\,\omega^2 r \rightarrow r = R_E + h = \left(\frac{G M_E}{\omega^2}\right)^{\frac{1}{3}}$$

$$h = \left(\frac{G M_E}{\omega^2}\right)^{\frac{1}{3}} - R_E = \left[\left(\frac{6.7\times10^{-11} \times 6.0\times10^{24}}{[2\pi/(24\times3600)]^2}\right)^{\frac{1}{3}} - 6.4\times10^{6}\right] \text{meters}$$

Example: geosynchronous orbits

Satellite orbits so that it hovers above one spot on earth.
How high about the earth's surface is it?



Given: G, M_E , R_E **and** ω.

Goal: h

Principles:
Newton's law of gravity, centripetal force

Newton's second law

$$G = 6.7 \times 10^{-11}\ \mathrm{m}^3\ \mathrm{kg}^{-1}\ \mathrm{s}^{-2}$$
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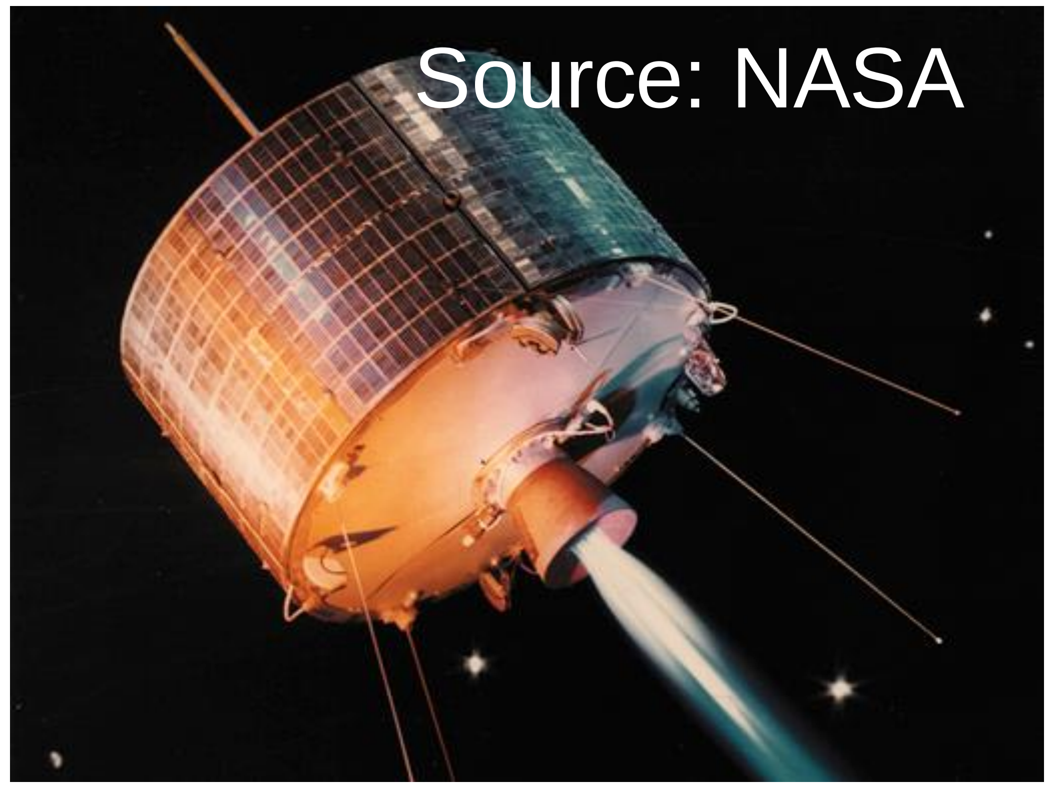


Summary of chapter 6

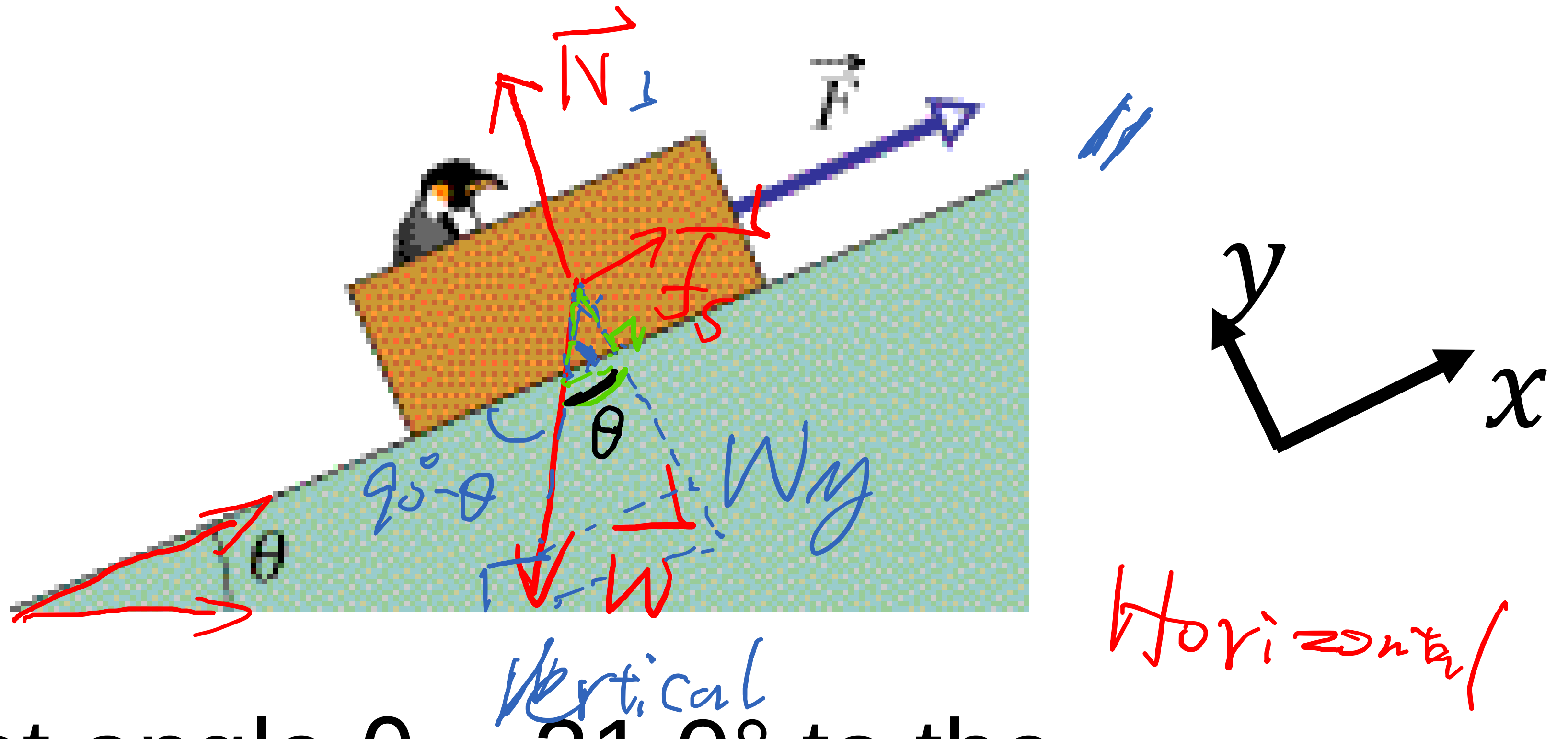
- Learning objectives
  - Friction force
    1. Static friction $|\vec{f}_s| \le \mu_s |\vec{N}|$, Newton's law
    2. Kinetic friction $|\vec{f}_k| = \mu_k |\vec{N}|$
  - Drag force $|\vec{F}_{drag}| \propto \vec{v}_{rel\ w.r.t.\ air}$
  - Forces in uniform circular motion

$$\vec{F}_c = m\vec{a}_c$$

Homework

- Homework assignment for chapter 6 in module 6.4: Assignment, due in a week.

Practice example: Friction on incline



- A loaded penguin sled weighing 70.0 N rests on a plane inclined at angle θ = 21.0° to the horizontal (see the figure). Between the sled and the plane, the coefficient of static friction is 0.290, and the coefficient of kinetic friction is 0.200. What is the minimum magnitude of the force, $\vec{F}$, parallel to the plane, that will prevent the sled from slipping down the plane? (x- and y- directions are shown above)

Step 1: Draw the free body diagram of the sled.

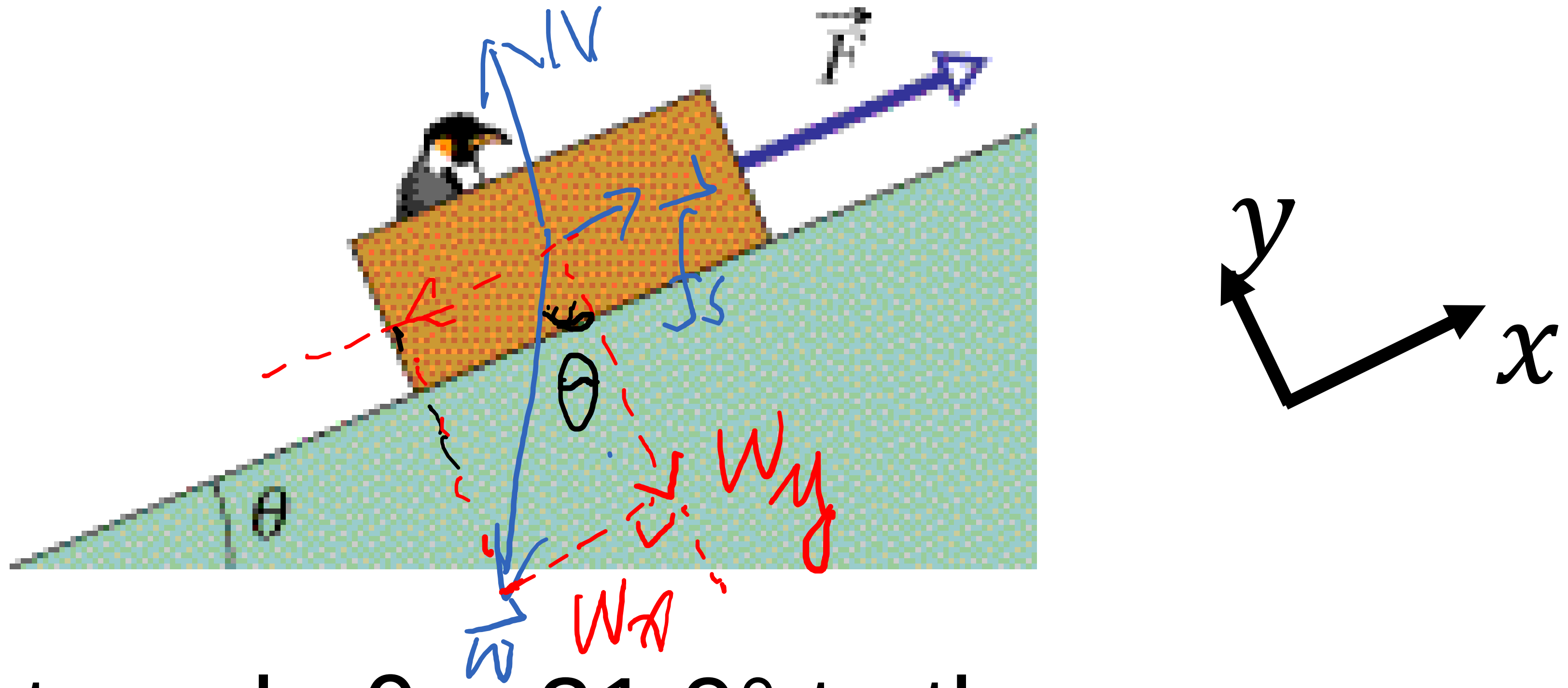
Step 2: x- and y- components of the Newton's 2nd law

Step 3: Find the magnitude of the normal force

Step 4: Find the magnitude of the maximum static friction

Step 5: Find the minimum $|\vec{F}|$

Practice example: Friction on incline



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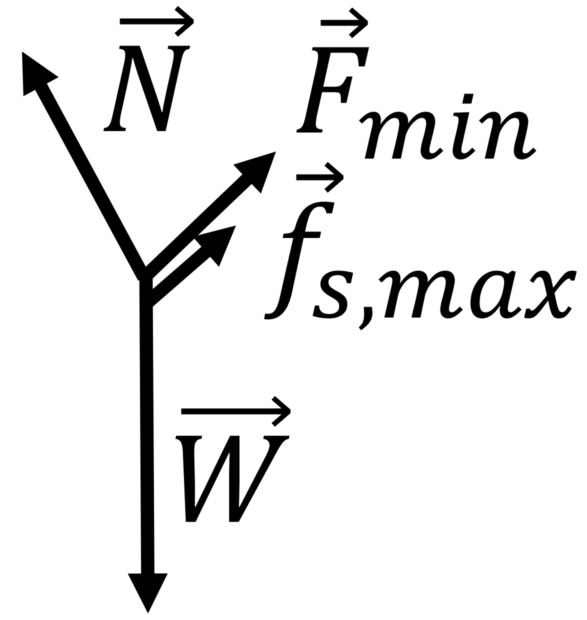

Pre-lecture for the next lecture

- Please complete Module 7.1: Pre-lecture survey before the next lecture

Midterm 2

- Date: Nov. 21, Thursday
- Location and format:
  - ➢In person, format is similar to Midterm 1.
- What to cover: Chapters 6-8, and part of Chapter 5 after Midterm 1.