

Outline for Day W5,D1

Quiz 2 review

Newton's 1st law

Relative velocity and motion

Types of Forces

Homework

Ch. 4 P. 1-5,7,12-14,28,33,42,45,47,48

MisQ 1-11 (odd), Read Sec 1-8.

Read 3.9 (rel motion) Due Wed->Fri

Notes: Hwk Ch. 3 graded #20. Avg=9.3,9.4

“NEW STUFF” has new PPT,YouTube (FOR), exam-like problems for Ch. 4-5, relative motion problems.

Exam I follows Chapter 5 material.

Week 5-6 Topics

Chapter 3. Relative velocity

Chapter 4. Newton's laws of motion

Types of forces

Free body diagrams

Chapter 5. Friction and centripetal force

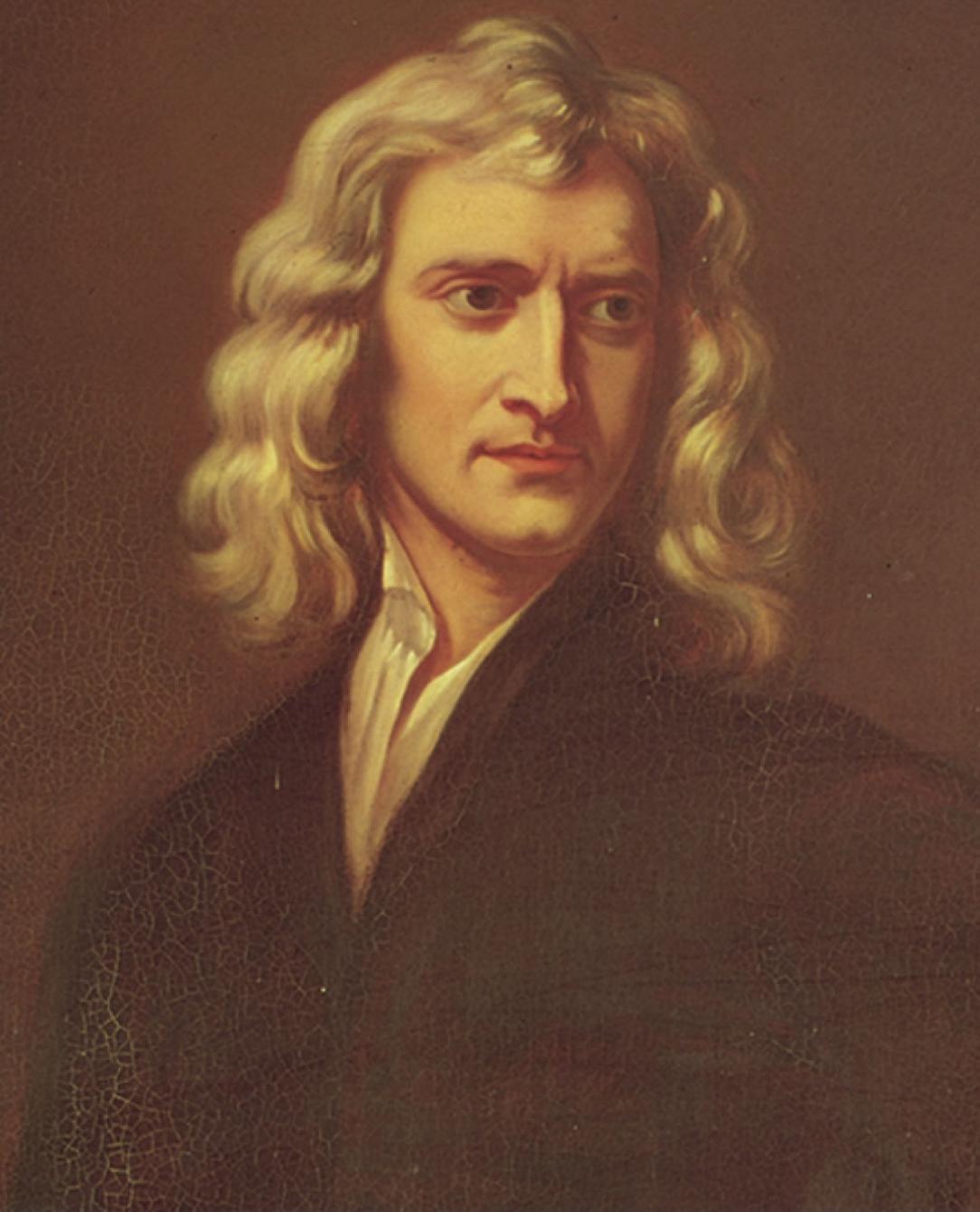
Exam I follows Chapter 5.

Isaac Newton
(1642 - 1727)

3 laws of motion

1 law of Universal
Gravitation

Co-invented calculus



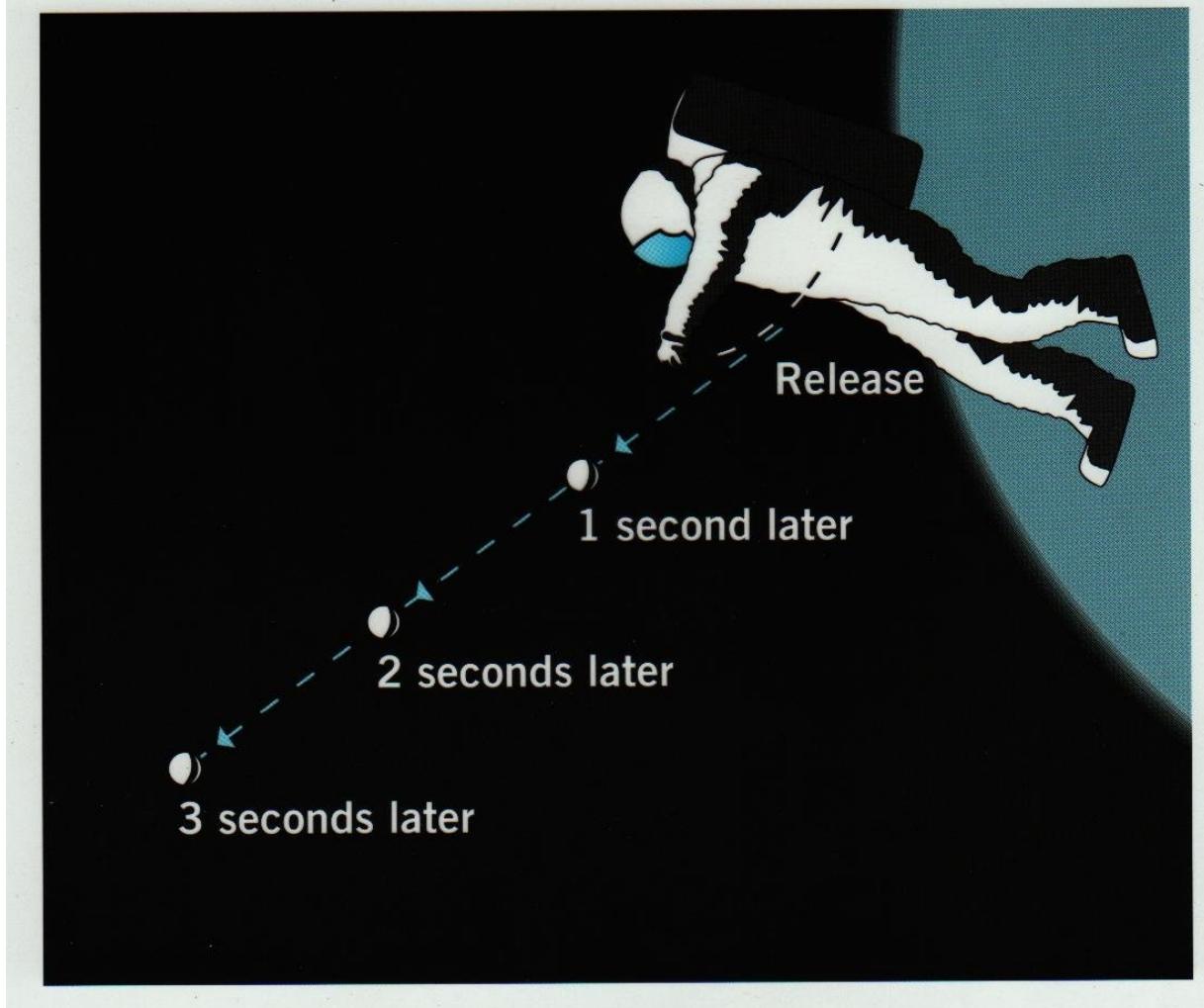
Newton's 1st law = inertial frames of reference exist such that an object will move with a constant velocity if no forces act upon it.

$$v = \text{const} \text{ if } F_{\text{net}} = 0$$

Overthrows Aristotle and medieval ideas:

“natural state” is at rest

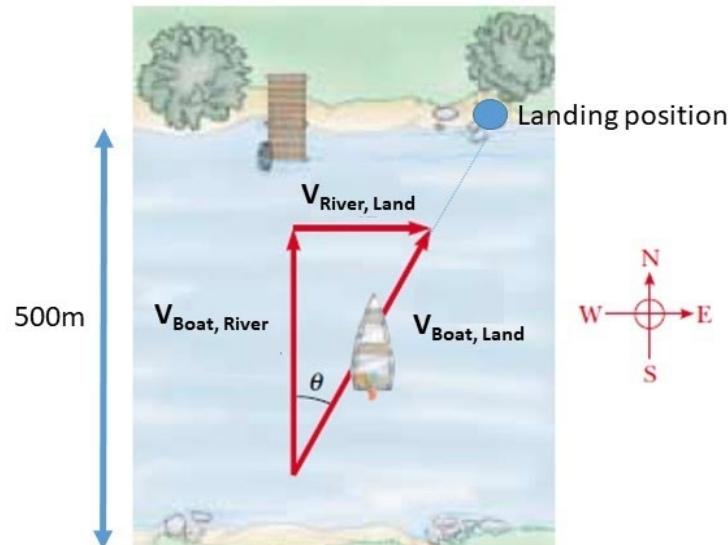
“impetus” pushes an arrow along



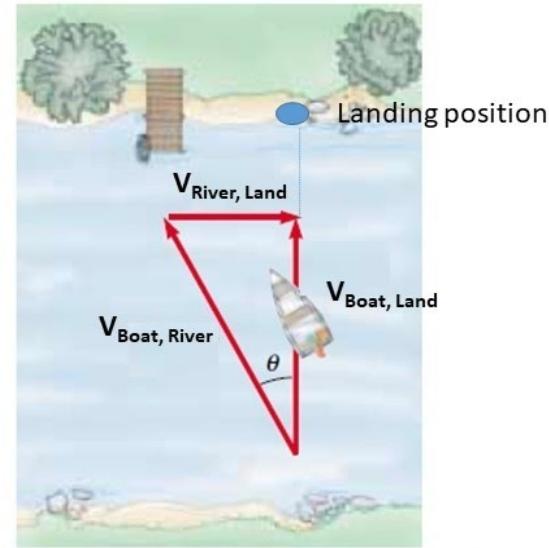
Frames of reference and relative motion

The assumption of inertial frames of reference was implicit in Ch. 3's "relative velocity" examples.

Problem 1



Problem 2



3 frames of ref: the boat (B), the land (L) and the river (R).

Given $v_{RL} = 3 \text{ m/s E}$, $v_{BR} = 8 \text{ m/s N}$.

P1) If the boat moves N relative to the river, find v_{BL} .

Find v_{BL} . $v_{BL} = v_{BR} + v_{RL} = 8\hat{j} + 3\hat{i}$, $|v_{BL}| = 8.54 \text{ m/s}$, $\theta = 20.6^\circ$

How far East does it drift? $X/500 = \tan \theta$. $X = 188 \text{ m}$.

Outline for Day W5,D2

Relative velocity and motion (cont.)

Types of Forces

Newton's 2nd law

Mass vs weight

Homework

Ch. 4 P. 1-5,7,12-14,28,33,42,45,47,48

MisQ 1-11 (odd), Read Sec 1-8.

Read 3.9 (rel motion) Due Wed->Fri

Notes: Hwk Ch. 3 graded #20. Avg=9.3,9.4

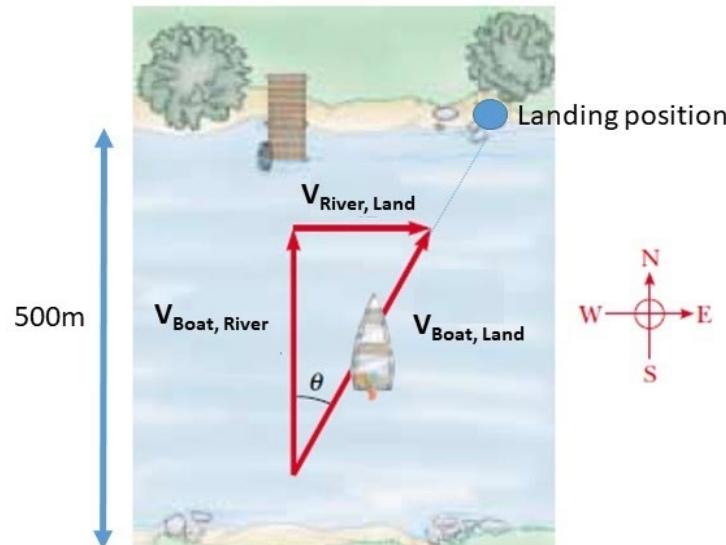
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Exam I follows Chapter 5 material.

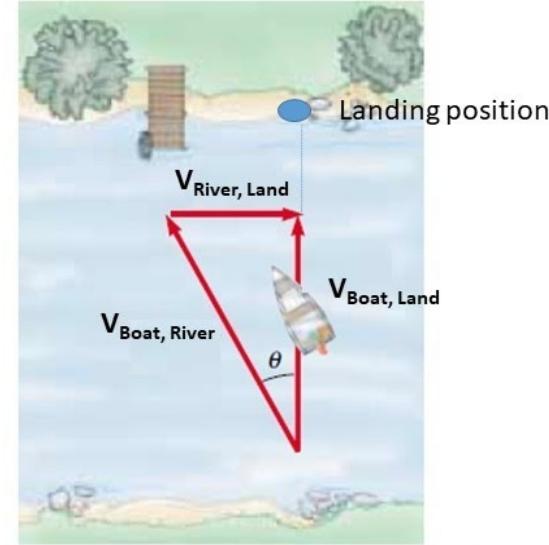
Frames of reference and relative motion

The assumption of inertial frames of reference was implicit in Ch. 3's "relative velocity" examples.

Problem 1



Problem 2



3 frames of ref: the boat (B), the land (L) and the river (R).

Given $v_{RL} = 3 \text{ m/s E}$, $|v_{BR}| = 8 \text{ m/s}$.

P2) What θ is needed so that the boat goes straight N?

$$\text{Ans: } \sin \theta = v_{RL} / |v_{BR}| = 3/8. \quad \theta = 22.0^\circ$$

Also, what is v_{BL} ? $v_{BL}/v_{BR} = \cos 22$, $v_{BL} = 8 \cos 22 = 7.4 \text{ m/s}$

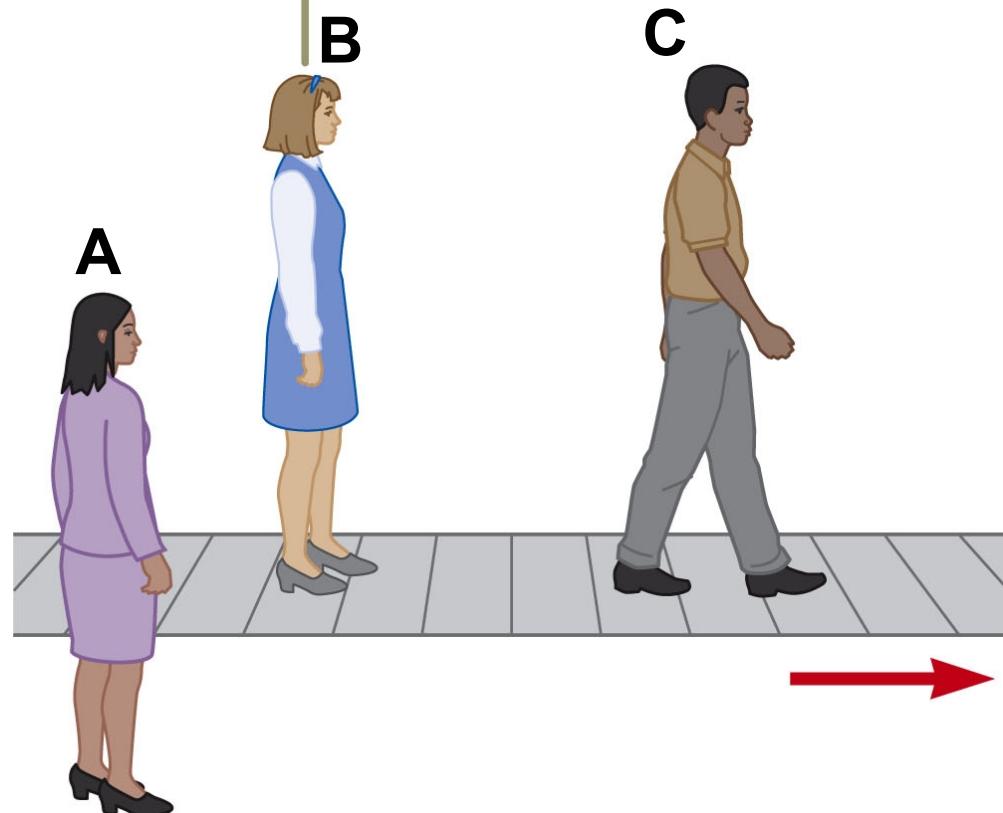
Relative Motion Problem

The woman standing on the beltway sees the man moving with a slower speed than does the woman observing the man from the stationary floor.

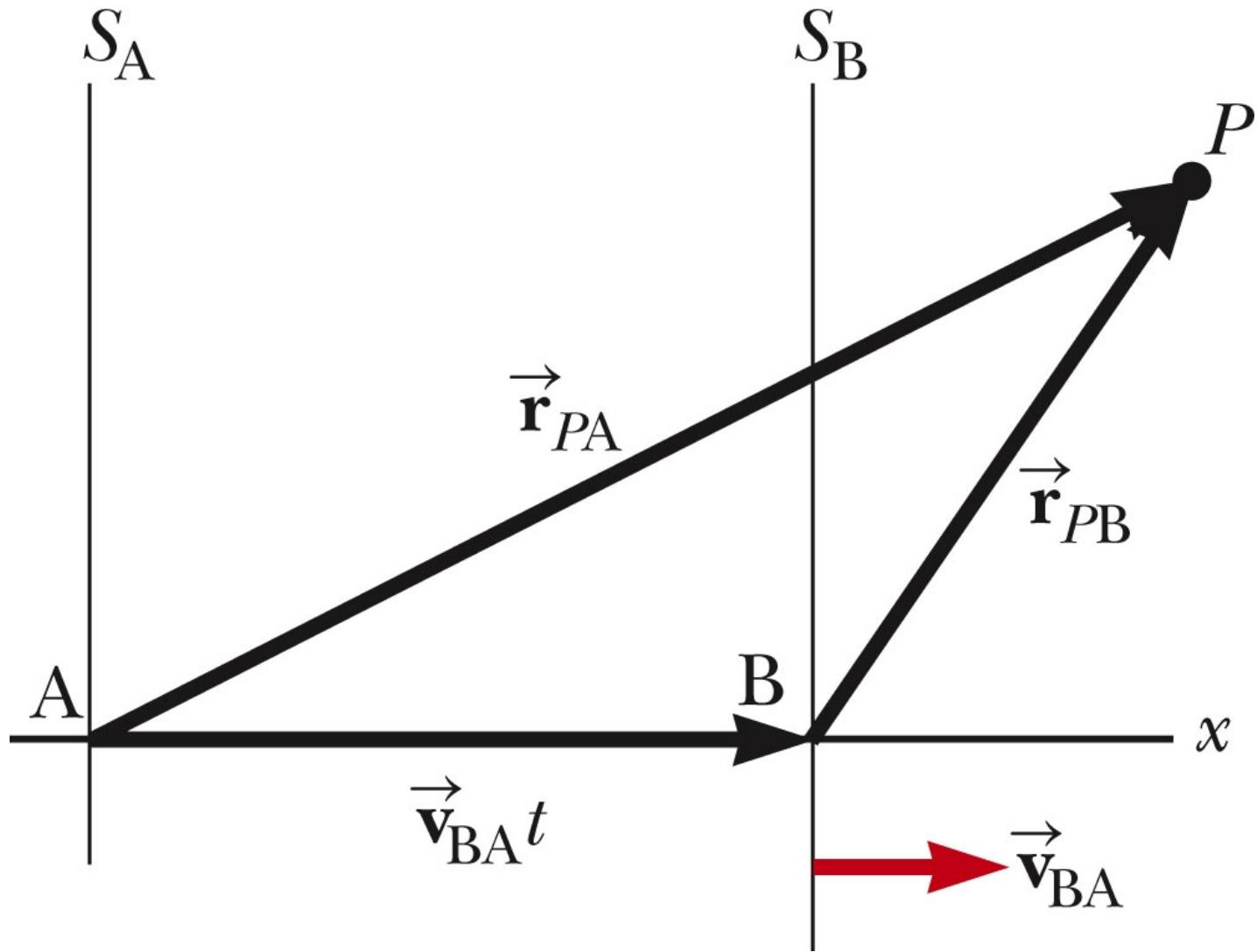
Each person is in a different inertial frame-of-reference!

So we can say

$$v_{CA} = v_{CB} + v_{BA}$$



Transforming between two frames of reference, A and B.



$$\mathbf{r}_{PA} = \mathbf{r}_{PB} + \mathbf{r}_{BA} \rightarrow \mathbf{v}_{PA} = \mathbf{v}_{PB} + \mathbf{v}_{BA} \rightarrow \mathbf{a}_{PA} = \mathbf{a}_{PB} + 0_{11}$$

Examples of non-inertial frames of reference

- 1) Inside of a truck that is accelerating in a line.
(See movie “Frames of Reference” 13:27- 17:04)
- 2) Inside of a car that is turning (even if moving at a constant speed).
- 3) Sitting on a rotating platform. (See movie
“Frames of Reference” 17:05-22:00)
- 4) The Earth’s surface! (See movie “Frames of Reference” and the Foucault pendulum 24:20-26:00.)

Try “Relative motion airplane example” under NEW STUFF. 12

Inertial Frames of reference (cont.)

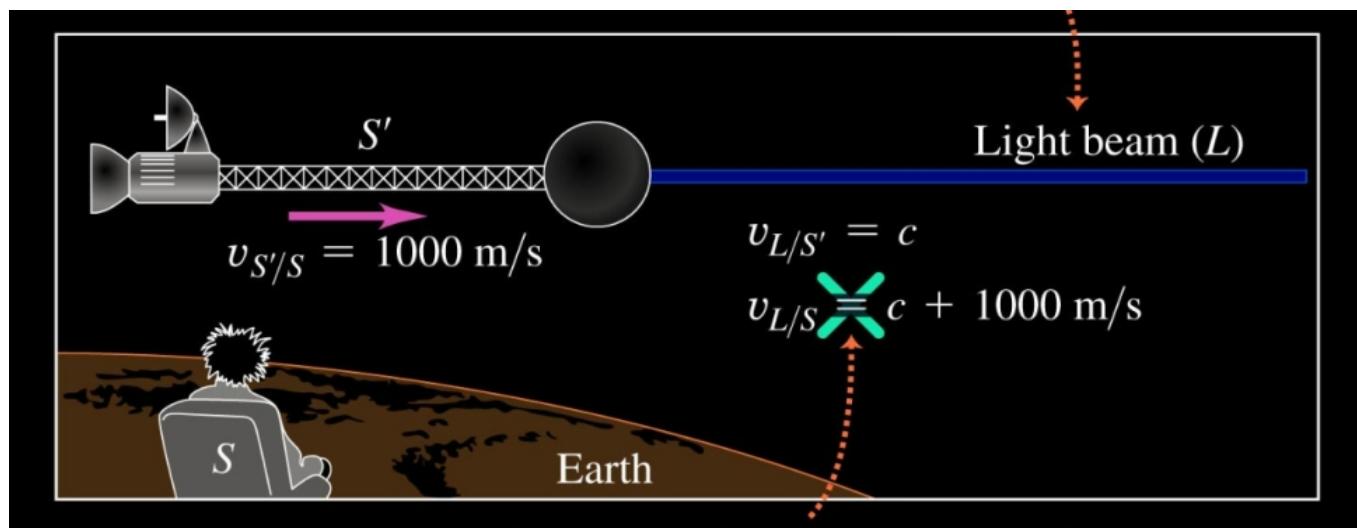
Velocity transformation (from Galilean relativity):

$$v_{PA} = v_{PB} - v_{BA}$$

Velocity transformation (from Special Relativity):

$$v_{PA} = \frac{v_{PB} - v_{BA}}{1 - \frac{v_{PB} v_{BA}}{c^2}}$$

(Applies to just x-components
with v_{BA} in the x direction.)

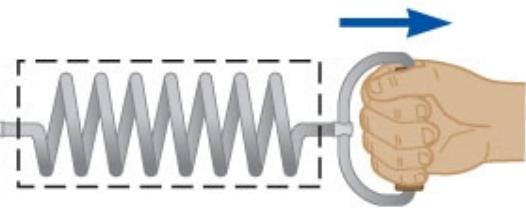


Forces – the cause of acceleration

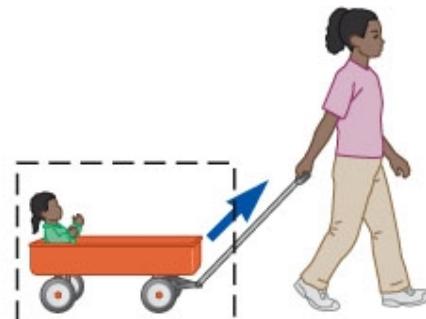
Forces are vectors

Forces act between *systems* (the dashed boxes)

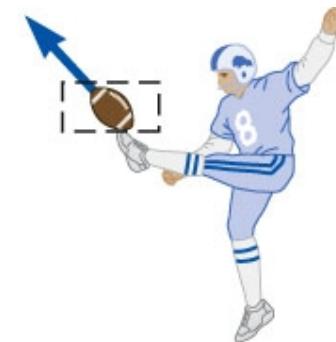
Contact forces



a

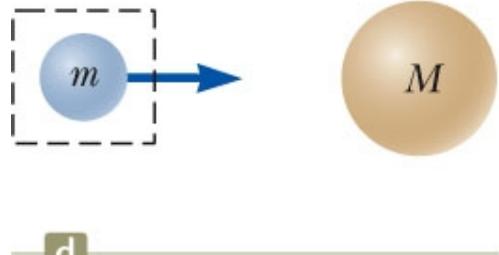


b

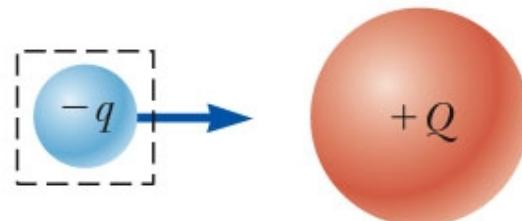


c

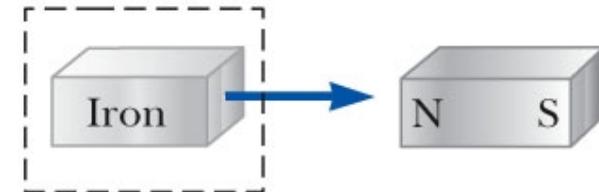
Field forces



d



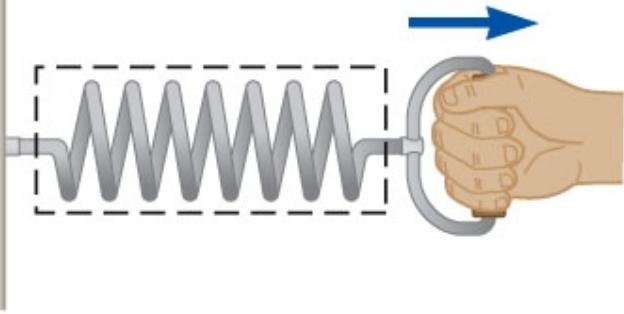
e



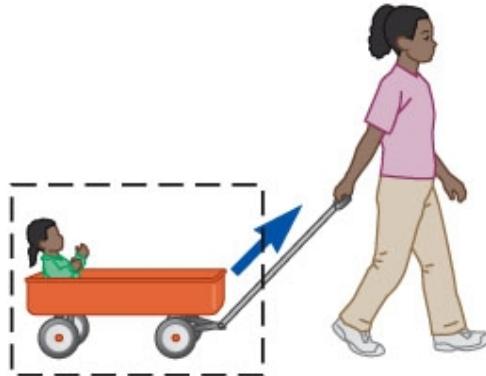
f

Types of forces

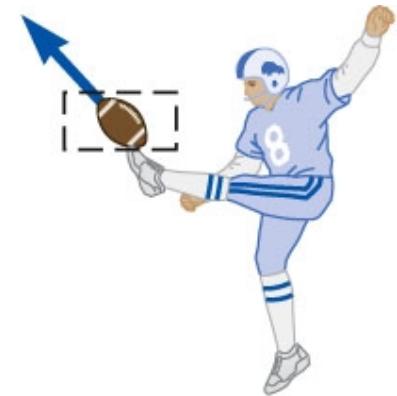
Contact forces



a



b



c

contact forces

tension – pulling apart

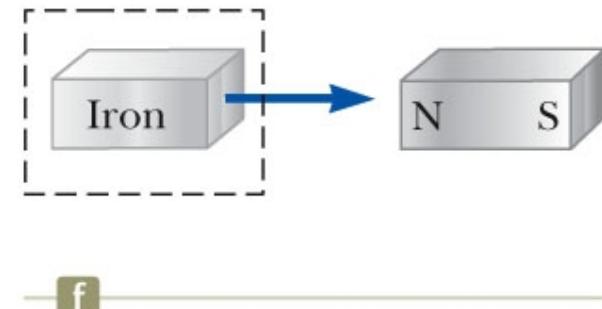
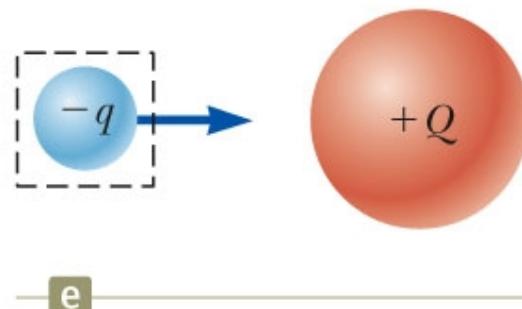
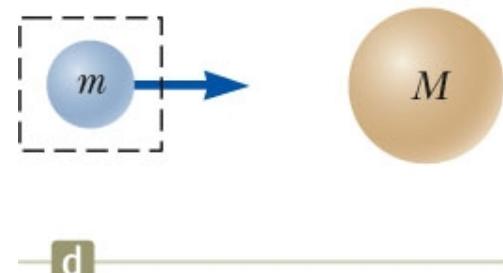
compression – pushing together

shear – pushing tangentially

torsion - twisting

Types of forces

Field forces



Field forces

gravitational

electric

magnetic

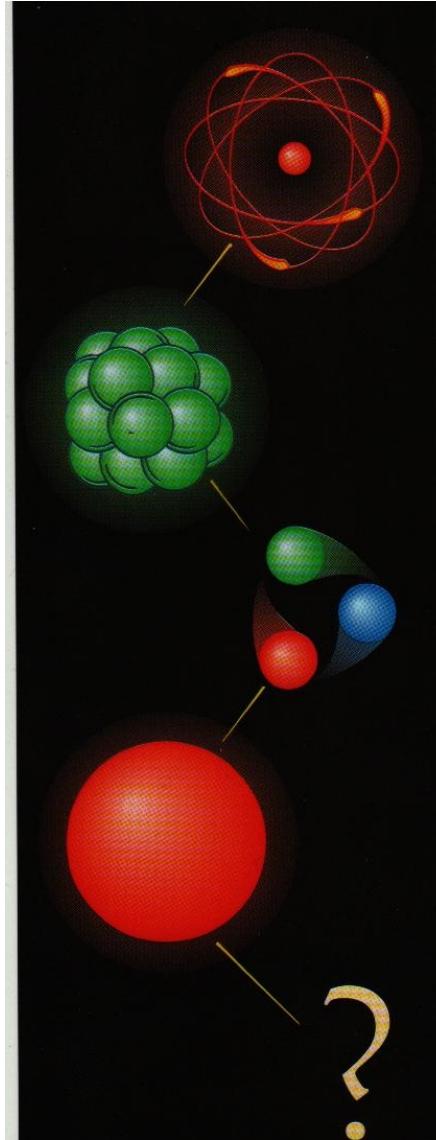
The 4 Fundamental forces

Gravity

Electromagnetic Force

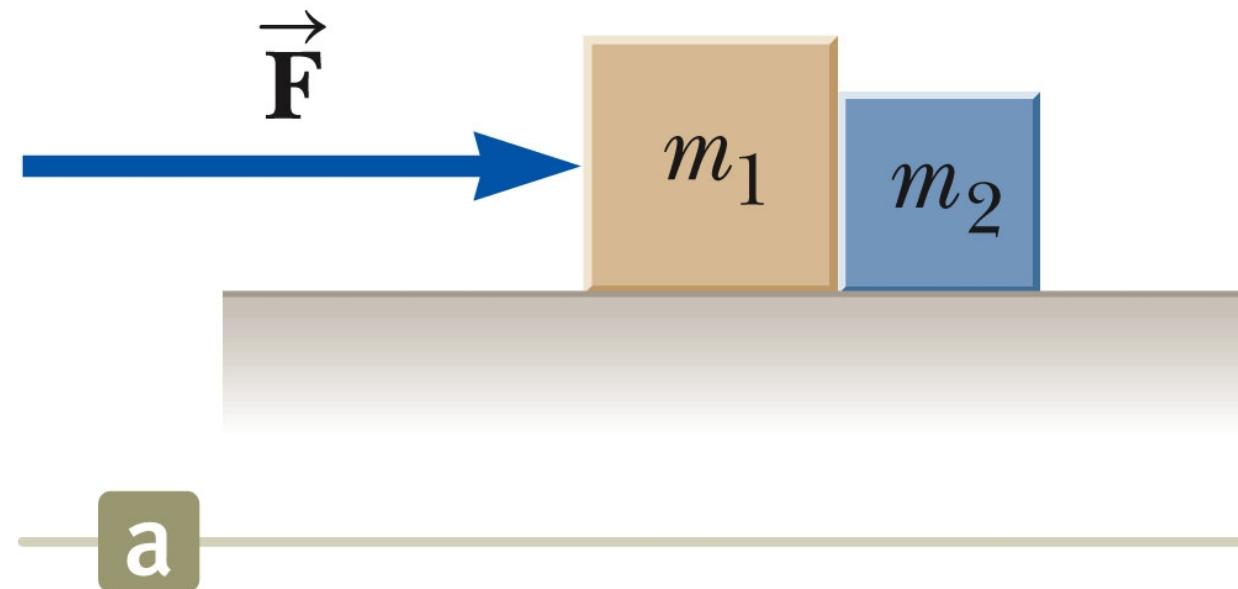
Nuclear Strong Force – holds nuclei together

Nuclear Weak force – decay of n and p



Distances at the frontier of nuclear physics are astonishingly short. An atom is so small that 250,000 fit into the thickness of aluminum foil. The nucleus at the atom's center is a cluster of nucleons, each 100,000 times smaller than the atom itself. The three quarks inside each nucleon are smaller still.

Newton's 2nd law = the acceleration of an object is proportional to the net force and inversely proportional to the mass.



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

If same force acts on m_1 , m_2 , and m_1+m_2 , the accelerations are different.

Outline for Day W5,D3

Newton's 2nd law

Newton's 3rd law

Weight and apparent weight

Examples of applying Newton's Laws

Homework

Ch. 4 P. 1-5,7,12-14,28,33,42,45,47,48

MisQ 1-11 (odd) Due today by 2:30

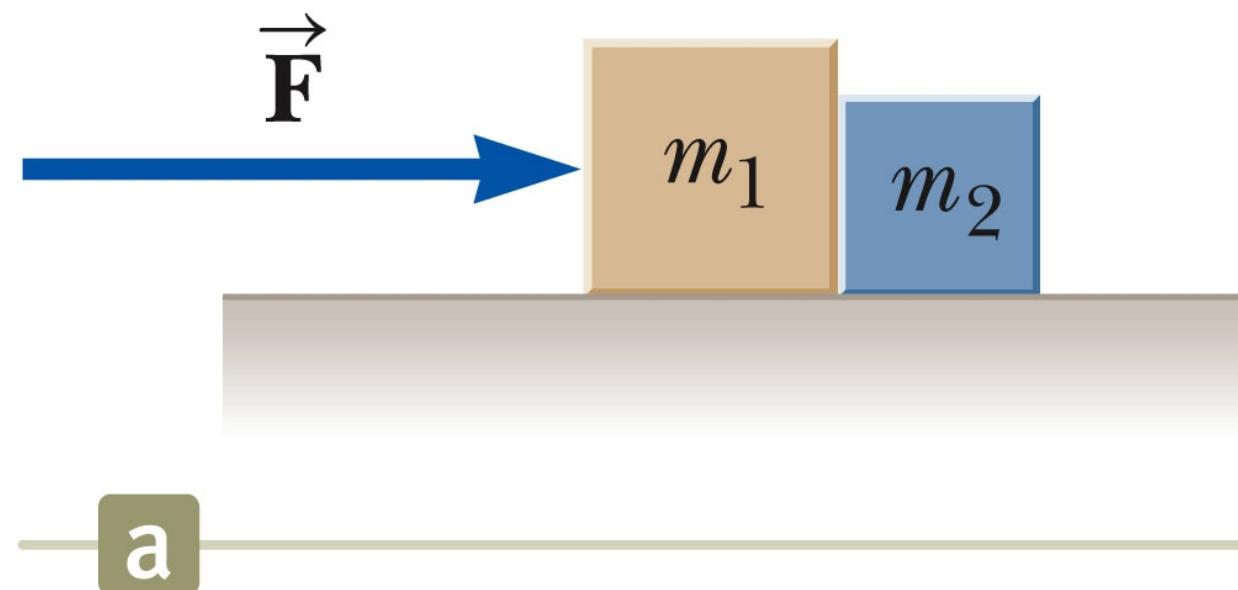
Ch. 5 Read 5.1-5.5, P. 1,2,3,6,7,19,23,35,36,38,45,50 Next Fri

Notes:

“NEW STUFF” has new PPT, YouTube (FOR), exam-like problems for Ch. 4-5, relative motion problems.

Exam I follows Chapter 5 material.

Newton's 2nd law = the acceleration of an object is proportional to the net force and inversely proportional to the mass.



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

Let $m_1=5$ kg, $m_2=2$ kg, and $\vec{F} = 10$ N \hat{i} .

- 1) Find \vec{a}_1 if \vec{F} acts only on m_1 .
- 2) Find \vec{a}_2 if \vec{F} acts only on m_2 .
- 3) Find \vec{a}_{1+2} if \vec{F} acts on both m_1 and m_2 .
- 4) In #3, what is the force on m_1 by m_2 , \vec{F}_{12} ?

Newton's 2nd law (cont.)

Does free fall due to gravity obey Newton's 2nd law?

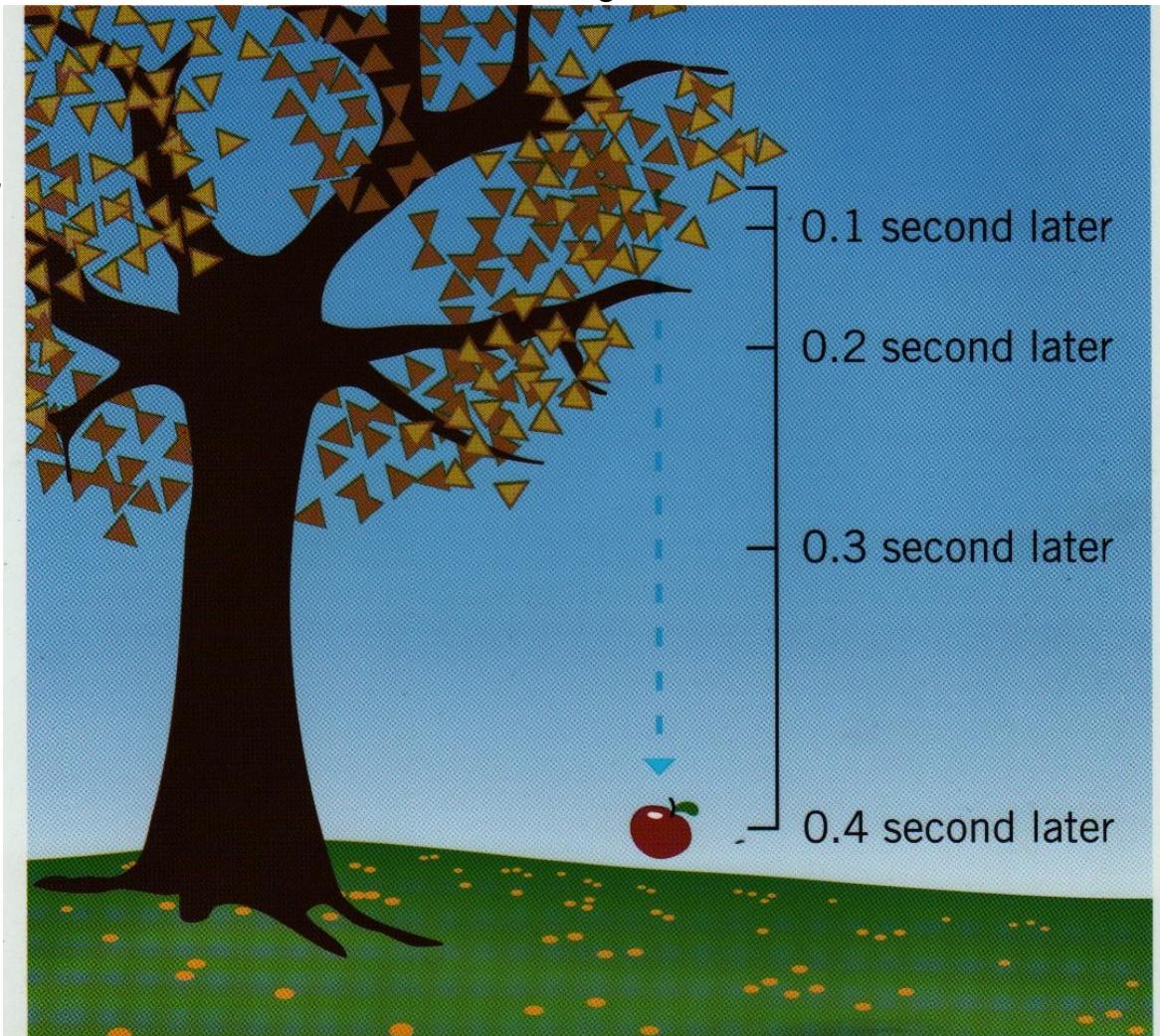
Yes: $F_{\text{net}} = F_g$ if only gravity acts. Then $a = F_g/m = mg/m = g$

Ex) Compare the F_g and the free fall acceleration of a 0.2 kg apple and a 20 kg anvil.

Weight = the force of gravity on an object

$$W=F_g=mg$$

Mass = the amount of matter in an object



Newton's 2nd law (cont.)

Ex) P. 4.5. What average force is required to stop a 950 kg Car in 8.0 sec if the car is traveling at 95 km/hr?

Set up: "average force" = net force. $F_{\text{net}} = m a$

First must find $a_{\text{avg}} = \Delta v / \Delta t = (0 - 95 \text{ km/hr}) / 8.0 \text{ sec}$

Convert to m/s: $-95 \text{ km/hr} (1\text{hr}/3600\text{s})(1000 \text{ m/km}) = -26.4 \text{ m/s}$

Then $a_{\text{avg}} = -26.4 / 8.0 = -3.30 \text{ m/s}^2$

And so $F_{\text{avg}} = ma_{\text{avg}} = -3134 \text{ N}$

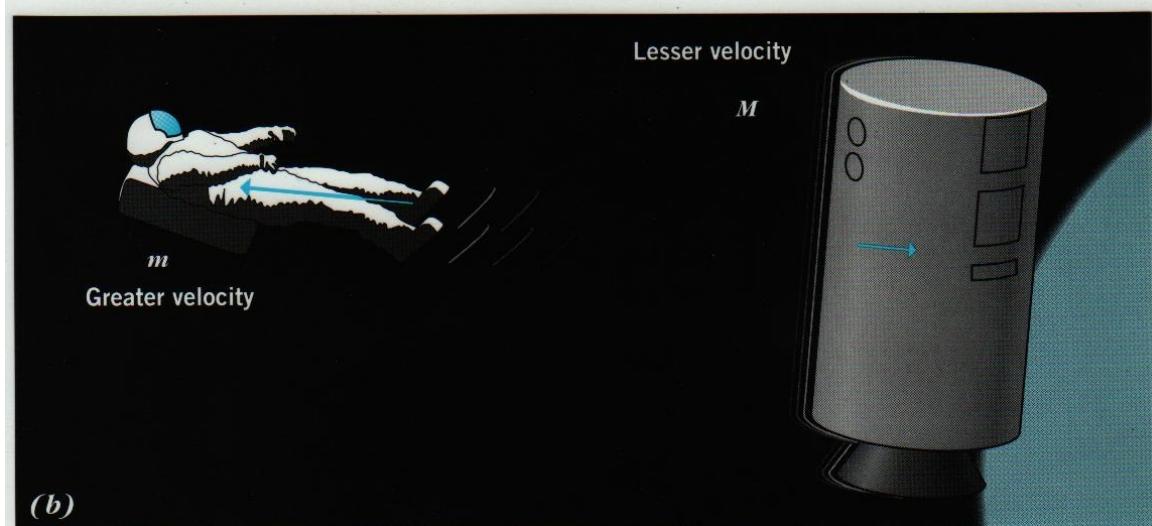
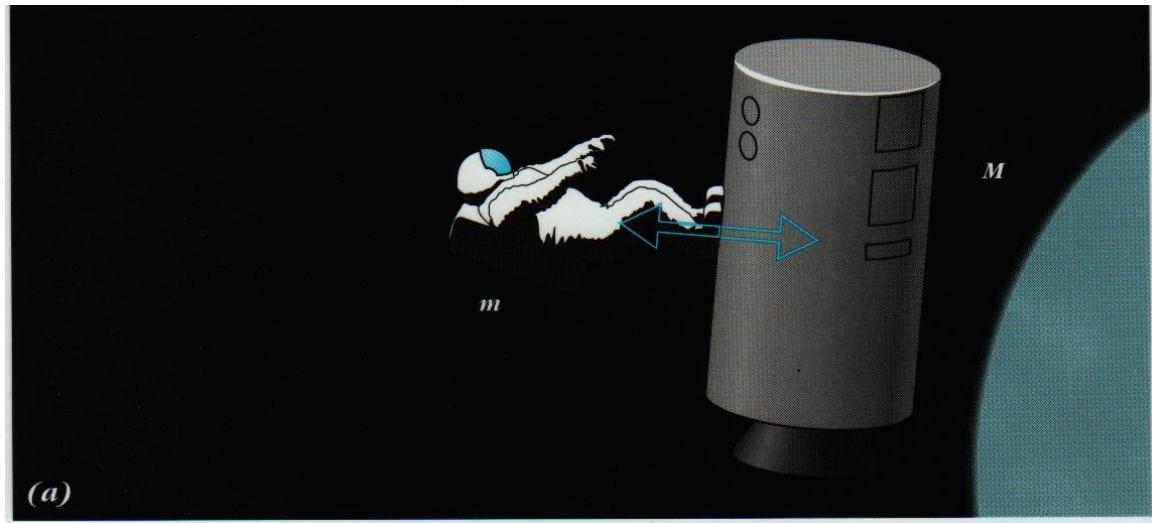
(The – sign means F is in opposite direction of the velocity.)

Newton's 3rd law (cont.)

“For every action there is an equal but opposite reaction.”
“Forces come in equal but opposite pairs.”

$$\mathbf{F}_{12} = -\mathbf{F}_{21}$$

The “12” subscript means
“on 1 by 2”.



Newton's 3rd law ($\mathbf{F}_{12} = -\mathbf{F}_{21}$)

Example)

Let $m_1 = 70 \text{ kg}$ (astronaut) and $M_2 = 700 \text{ kg}$ (satellite)

a) If $\mathbf{F}_{21} = 1000 \text{ N} \hat{i}$, what is \mathbf{F}_{12} on astronaut?

b) What is \mathbf{a}_2 ?

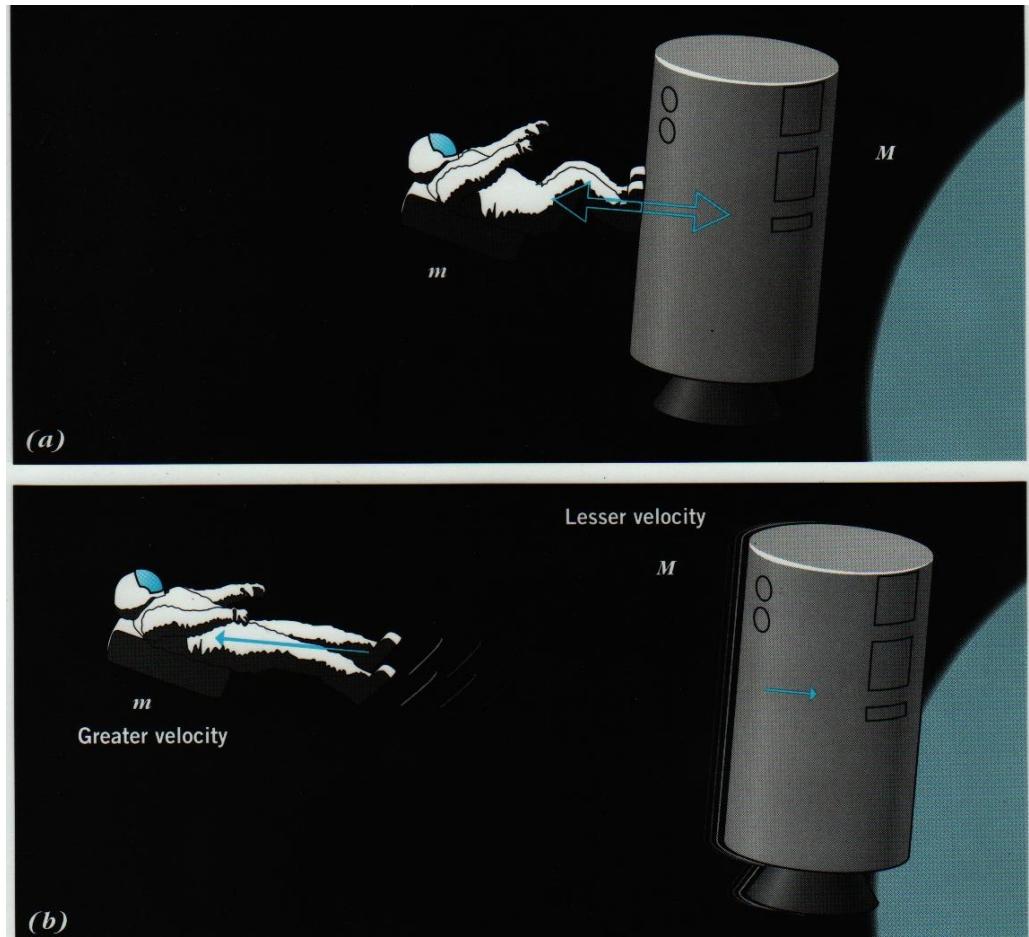
$$\mathbf{a}_2 = \mathbf{F}_{21} / m_2$$

$$\mathbf{a}_2 = 1000/700 = 1.43 \text{ m/s}^2 \hat{i}$$

c) What is \mathbf{a}_1 ?

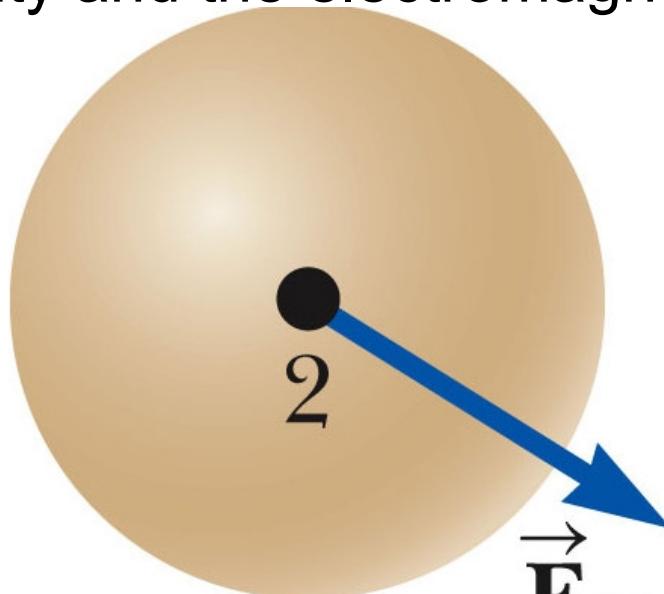
$$\mathbf{a}_1 = -1000 \hat{i} / 70 = -14.3 \text{ m/s}^2 \hat{i}$$

d) What are $|a_1/a_2|$ and $|\Delta v_1/\Delta v_2|$ in terms of m_1/M_2 ?

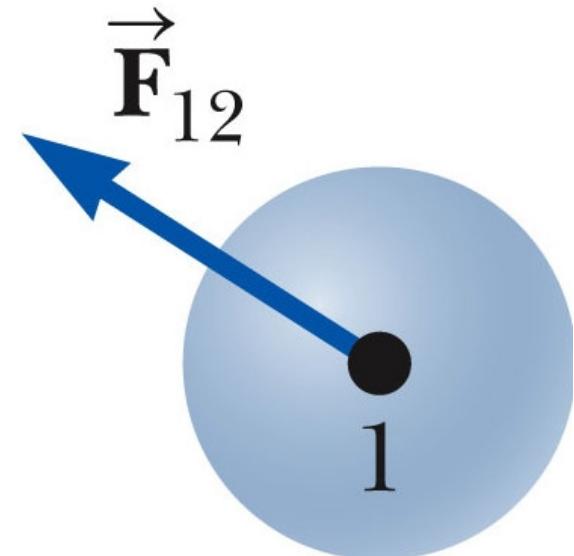


Newton's 3rd law (cont.)

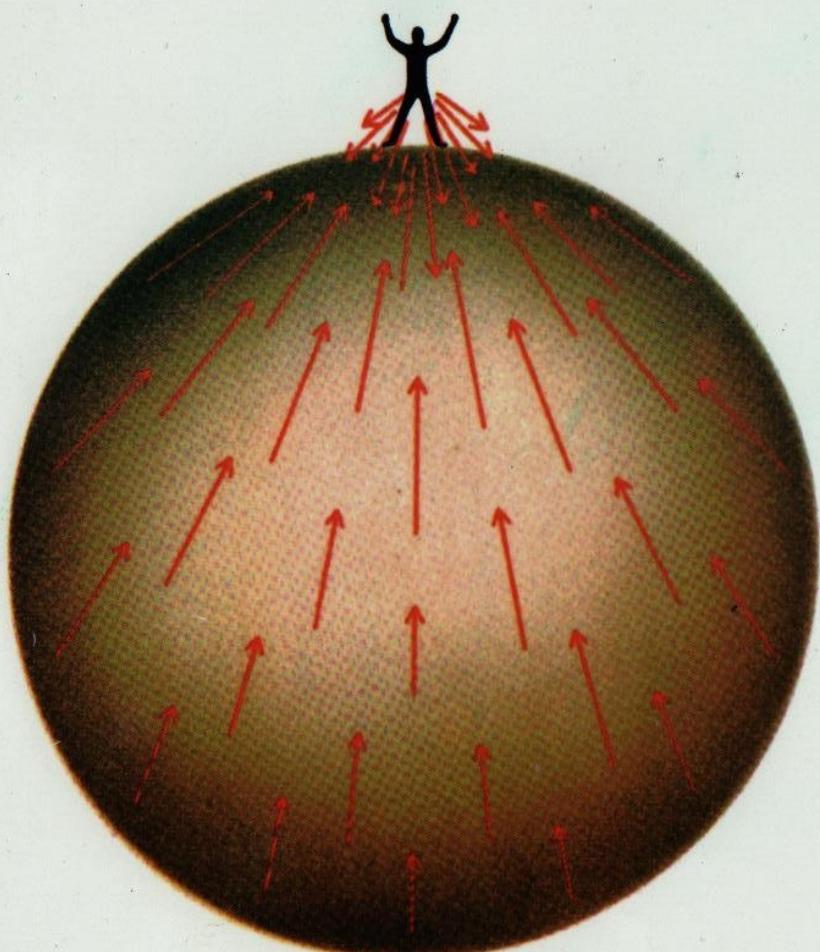
Gravity and the electromagnetic forces obey Newton's 3rd.



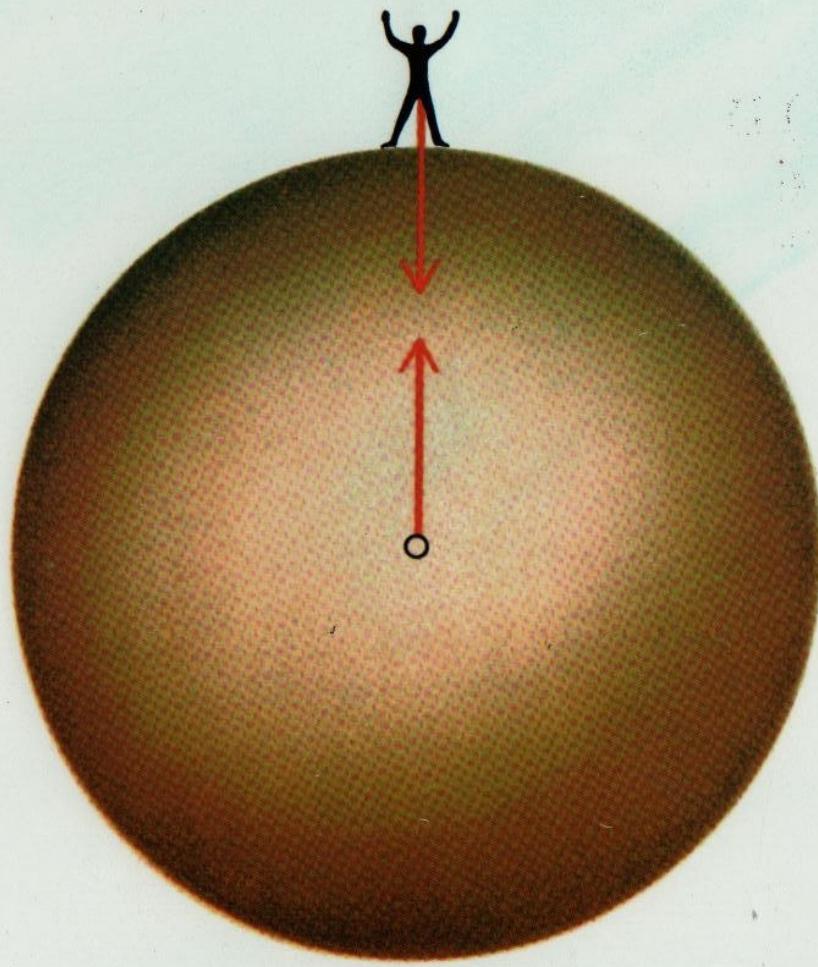
$$\vec{F}_{21} = -\vec{F}_{12}$$



Newton's 3rd law (cont.)



(a)

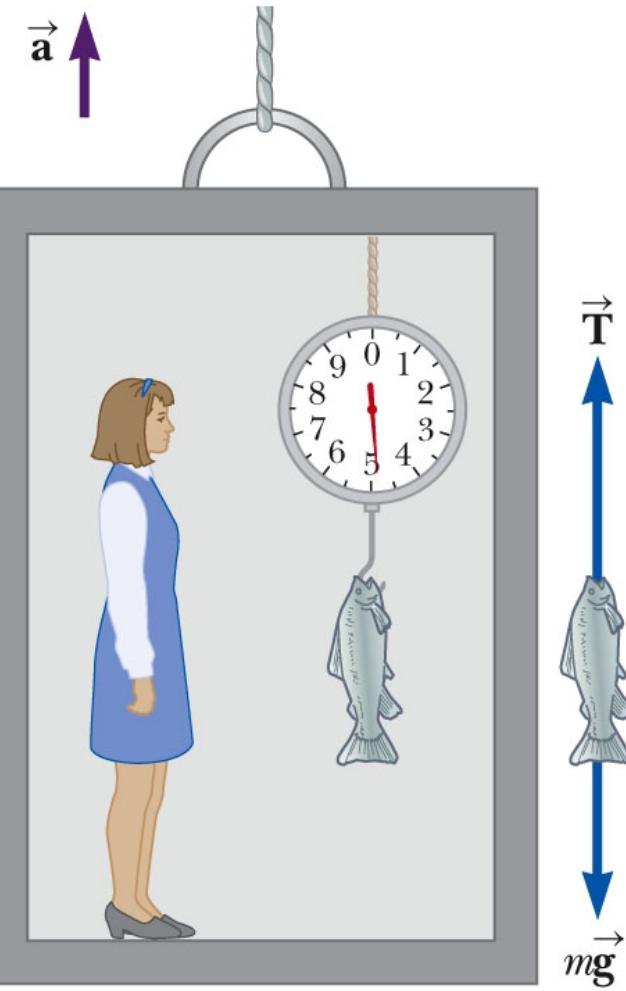


(b)

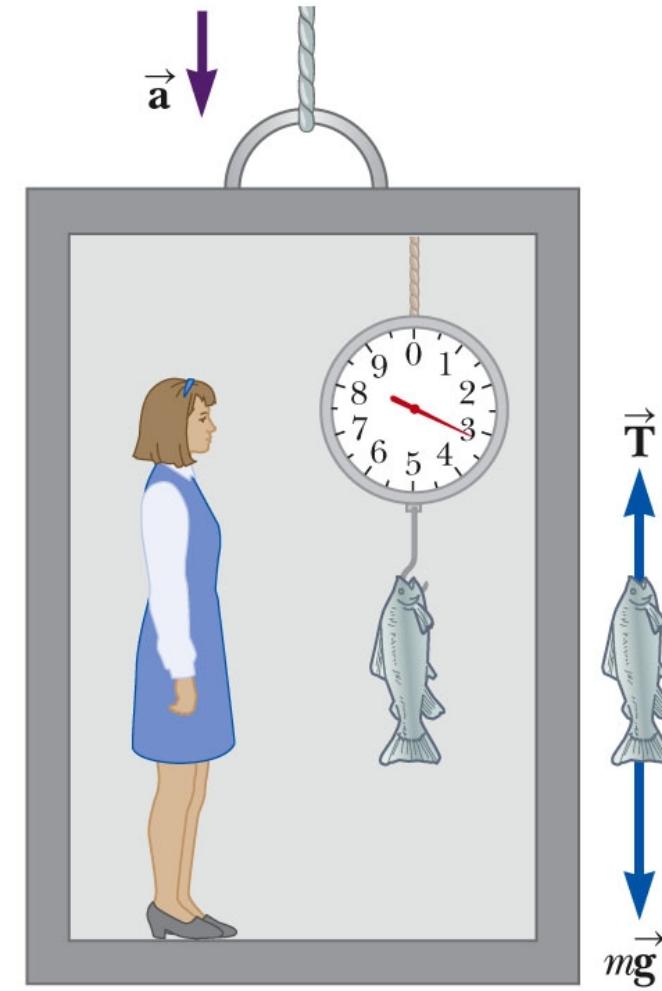
Weight = the [force] of gravity near a planet = $mg = F_g$

Apparent weight may differ from weight in accelerating reference frames or when buoyant forces are present. **DEMO**

When the elevator accelerates upward, the spring scale reads a value greater than the weight of the fish.



When the elevator accelerates downward, the spring scale reads a value less than the weight of the fish.



The Application of Newton's Laws

Problem solving method

1. Conceptualize

- What is problem asking for?
- Write down knowns and unknowns.
- Draw picture.

2. Categorize

- Equilibrium problem – object stationary (or constant velocity)
- Newton's 2nd law problem – object accelerates

3. Analyze

- Isolate object of interest and draw forces acting on it. Draw **FBD!**
- Don't draw the forces object exerts on surroundings (usually).
- Form equations for x and y components independently.
- Plug and chug.

4. Finalize

- Check units, dimensions, etc.

$$W_{app} = \text{force of hook on fish!}$$

Examples)

If $m_{\text{fish}} = 3 \text{ kg}$, find

W_{apparent} for ...

a) $a=0$

$$F_{\text{net}} = ma$$

$$W_{\text{app}} + F_g = ma = 0$$

$$W_{\text{app}} = -F_g = 29.4 \hat{j} \text{ N}$$

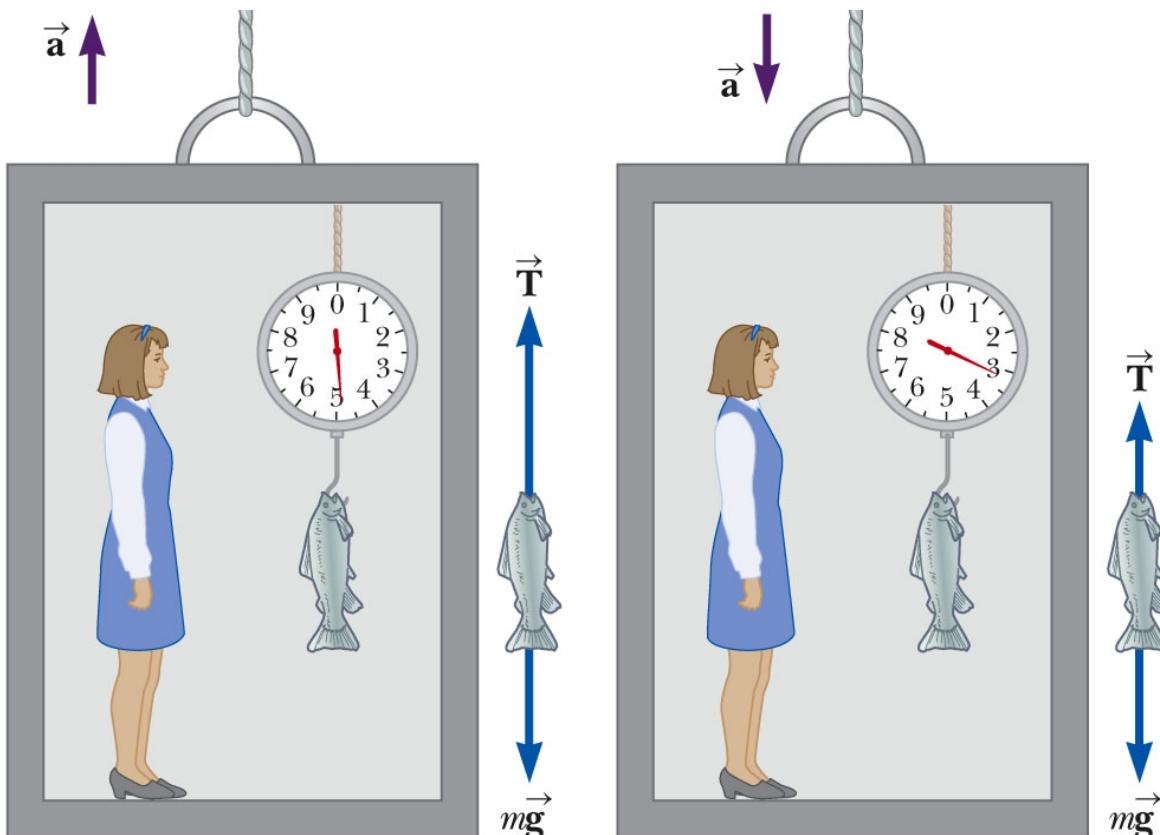
b) $a = 3 \text{ m/s}^2 \hat{j}$

$$W_{\text{app}} + F_g = ma$$

$$W_{\text{app}} - 3 \cdot 9.8 \hat{j} = 3 \cdot 3 \hat{j}$$

$$W_{\text{app}} = 9 + 29.4 = 38.4 \text{ N } \hat{j}$$

$$\text{or } W_{\text{app}} = m(9.8+3) = 38.4 \text{ N } \hat{j}$$



c) $a = -3 \text{ m/s}^2 \hat{j}$
(You try!)

$$W_{\text{app}} = 20.4 \text{ N } \hat{j}$$

Outline for Day W6,D1

Newton's laws problems: hockey puck,
frictionless incline, traffic lights, Atwood's machine

Friction: kinetic and static

Examples: block on level surface, block on incline

UCM: centripetal acceleration and force.

Homework

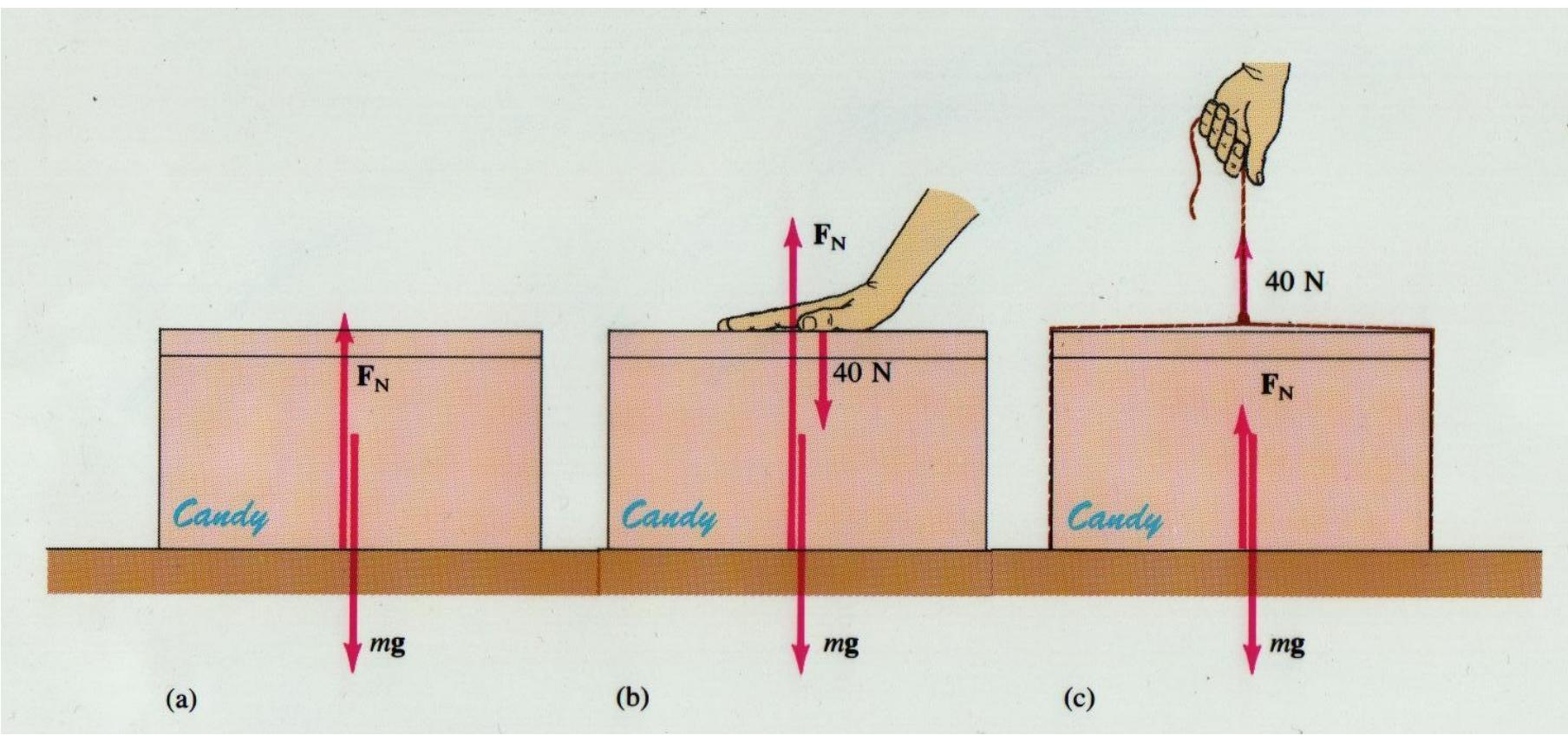
Ch. 5 Read 5.1-5.5; Do Probs. 1,2,3,6,7,19,23,35,36,38,45,50
Due on Friday.

Notes: “NEW STUFF” now has Ch. 4 key and
Ch. 1-5 Equation review. Chs. 1-5.
Exam I next Monday.

The Application of Newton's Laws

Box on table (see Ch. 4 Probs. 13, 28)

Find the normal force in each case if $m=5 \text{ kg}$ and the box remains stationary. (Use $g=10 \text{ m/s}^2$)



$$\begin{aligned}\mathbf{F}_{\text{net}} &= \mathbf{F}_N + \mathbf{F}_g \\ \mathbf{F}_N &= 50 \text{ N} \hat{j}\end{aligned}$$

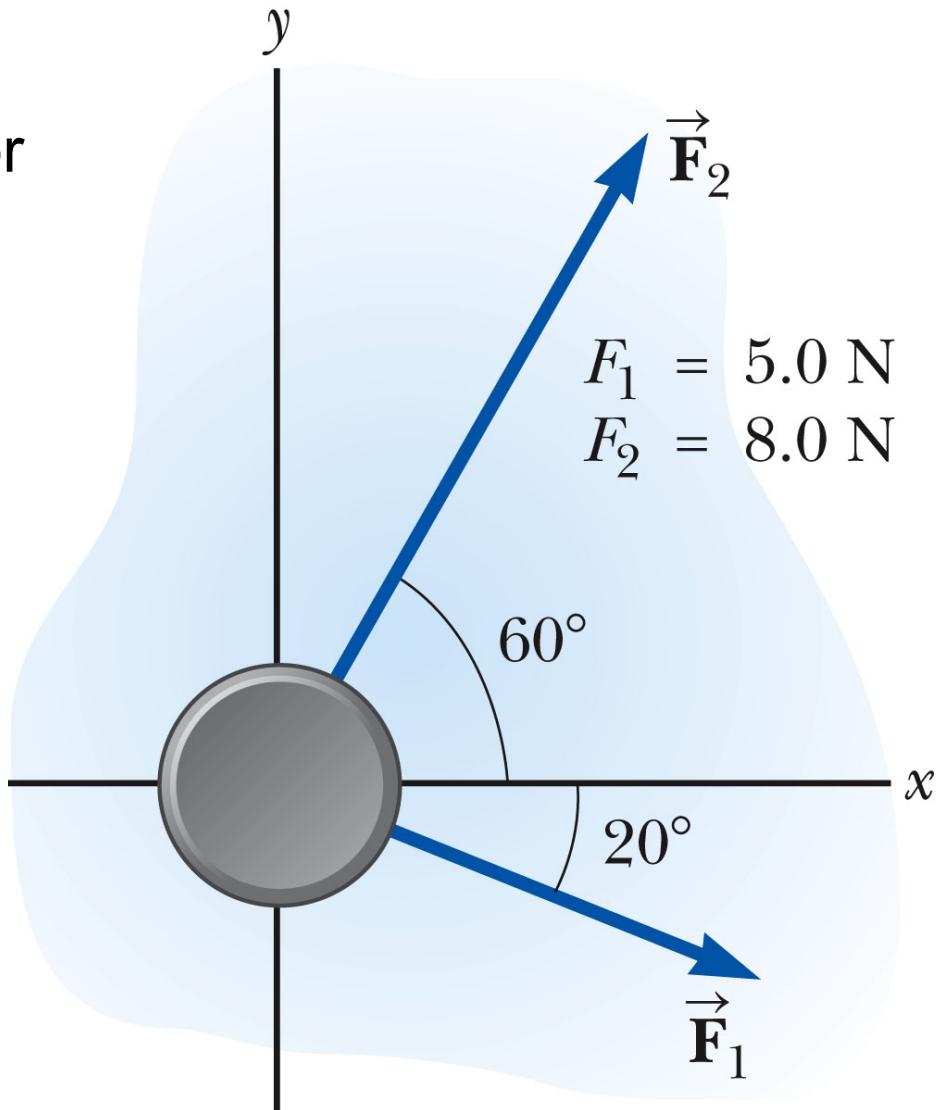
$$\begin{aligned}\mathbf{F}_{\text{net}} &= \mathbf{F}_H + \mathbf{F}_N + \mathbf{F}_g \\ \mathbf{F}_N &= 90 \text{ N} \hat{j}\end{aligned}$$

$$\begin{aligned}\mathbf{F}_{\text{net}} &= \mathbf{F}_H + \mathbf{F}_N + \mathbf{F}_g \\ \mathbf{F}_N &= 10 \text{ N} \hat{j}\end{aligned}$$

The Application of Newton's Laws

Puck on frictionless ice

Find the acceleration vector for the 0.2 kg hockey puck.



The Application of Newton's Laws

Puck on frictionless ice

Find the acceleration vector for the 0.2 kg hockey puck.

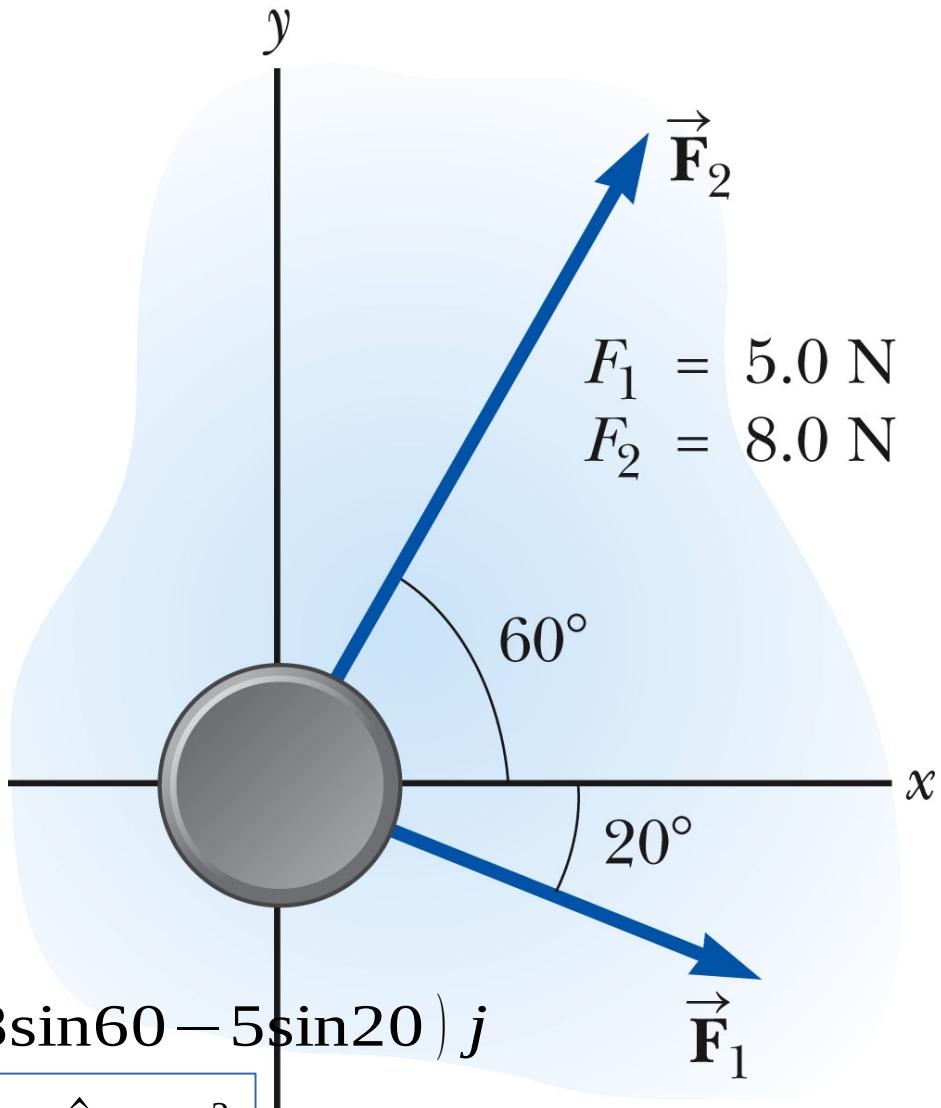
$$\vec{a} = \frac{\vec{F}_1 + \vec{F}_2}{0.2 \text{ kg}}$$

$$\vec{F}_1 = (5\cos 20) \hat{i} - (5\sin 20) \hat{j}$$

$$\vec{F}_2 = (8\cos 60) \hat{i} + (8\sin 60) \hat{j}$$

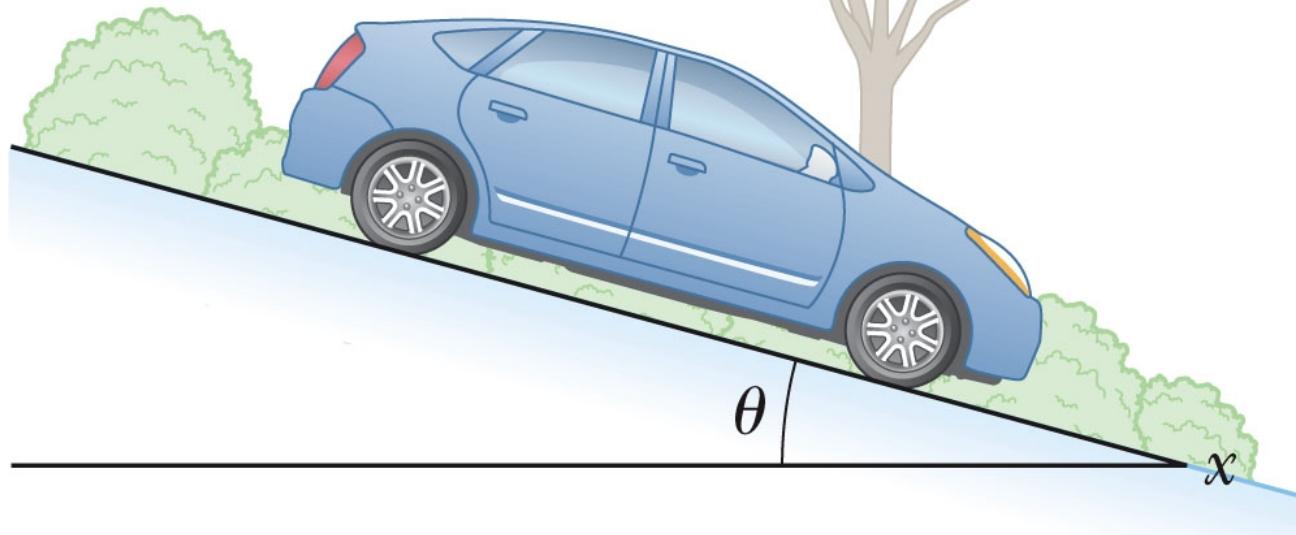
$$\vec{F}_{1+2} = (8\cos 60 + 5\cos 20) \hat{i} + (8\sin 60 - 5\sin 20) \hat{j}$$
$$\vec{a} = \frac{\vec{F}_{1+2}}{0.2 \text{ kg}}$$

$$\vec{a} = 43.5 \hat{i} + 26.1 \hat{j} \text{ m/s}^2$$



Car on frictionless incline

If the incline is frictionless, draw the free body diagram for the car.

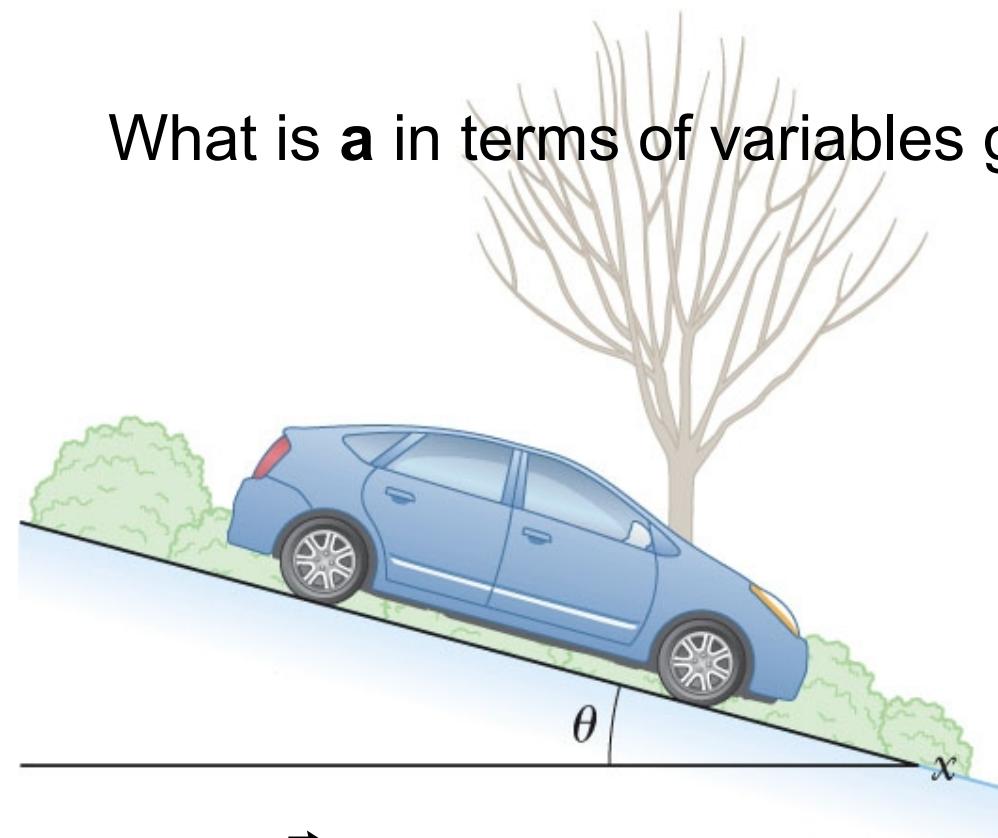


Can we determine the acceleration of the car without knowing its mass?

HINT: Tilt the x axis to line up with the incline!

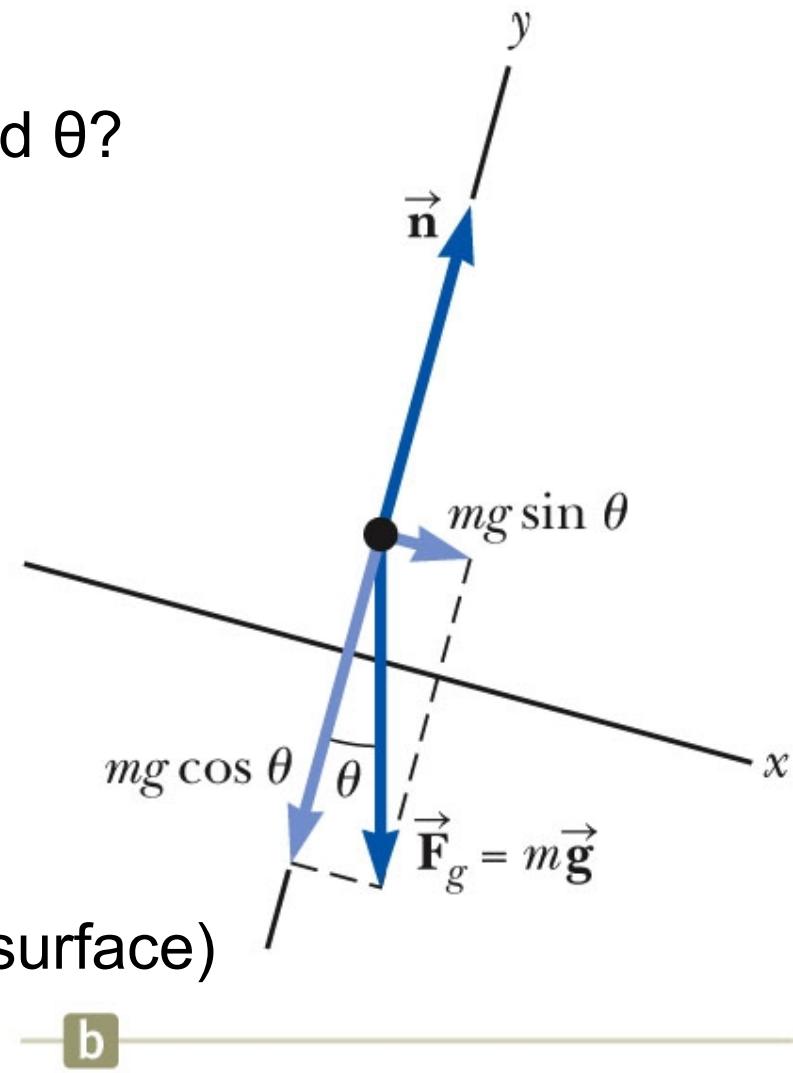
Car on frictionless incline

What is \mathbf{a} in terms of variables g and θ ?



$$\vec{a} = \frac{\vec{F}_{net}}{m} = g \sin \theta \hat{i} \quad (\text{parallel to surface})$$

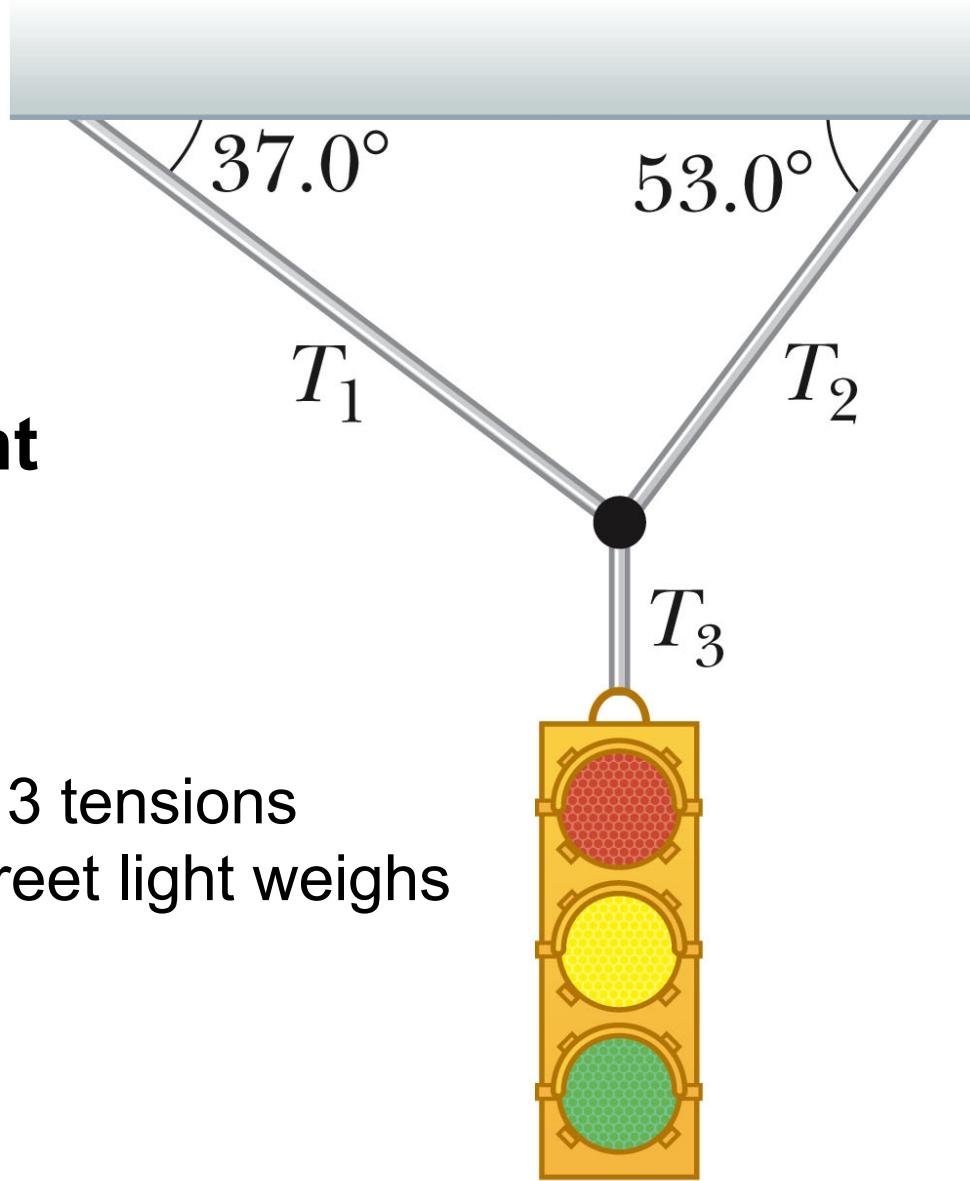
a



b

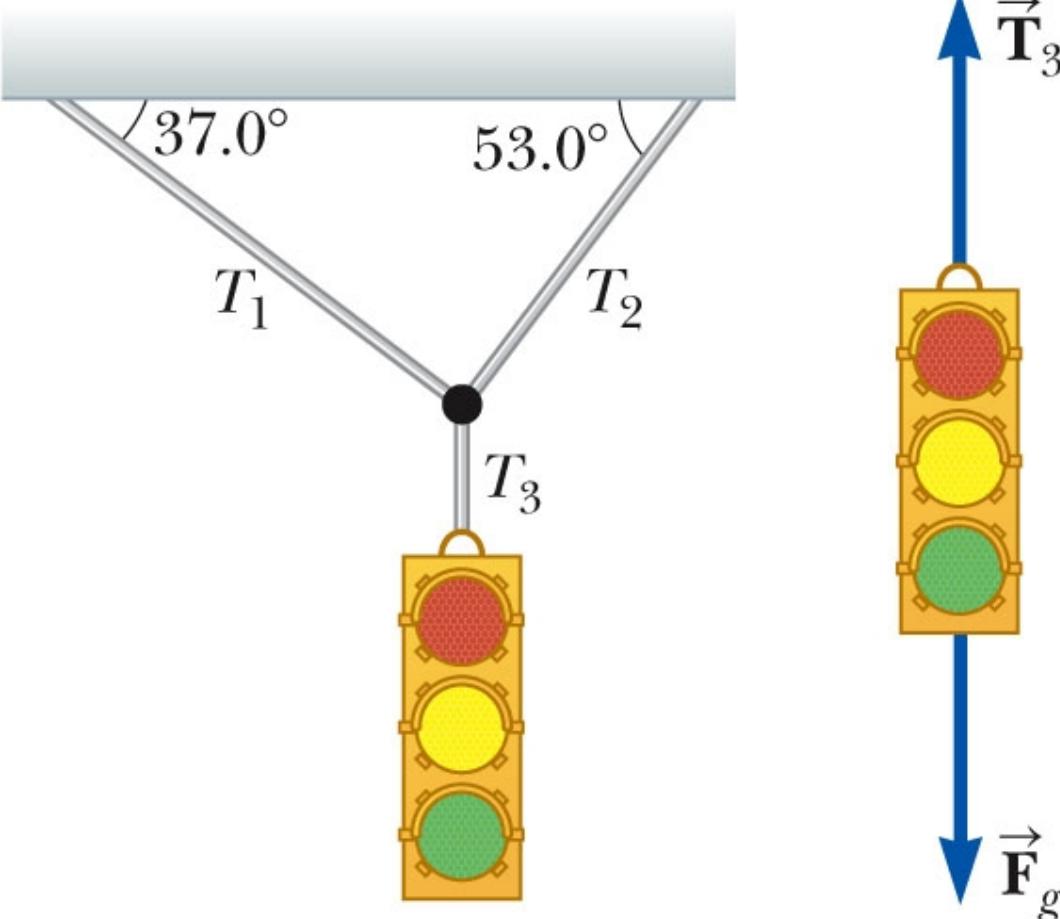
What is \mathbf{a} if $g=9.8$ and $\theta = 30^\circ$?

Street light



Find all 3 tensions
if the street light weighs
200 N.

$$T_3 = mg = 200 \text{ N}$$



a

b

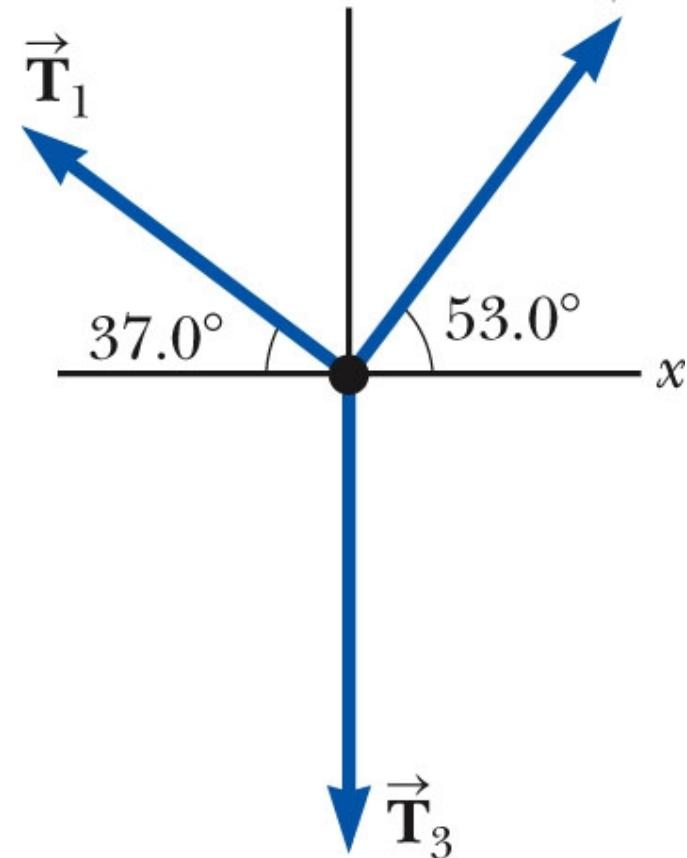
c

Substitute $T_1 = T_2(\cos 53 / \cos 37)$ into "Y:" equation 39

$$T_1 + T_2 + T_3 = 0$$

$$X: T_1 \cos 37^\circ = T_2 \cos 53^\circ$$

$$Y: T_1 \sin 37^\circ + T_2 \sin 53^\circ = T_3$$



Outline for Day W6,D2

Newton's laws problems: Atwood's machine

Friction: kinetic and static

Examples: block on level surface, block on incline

Uniform Circular Motion: centripetal acceleration and force.

Homework

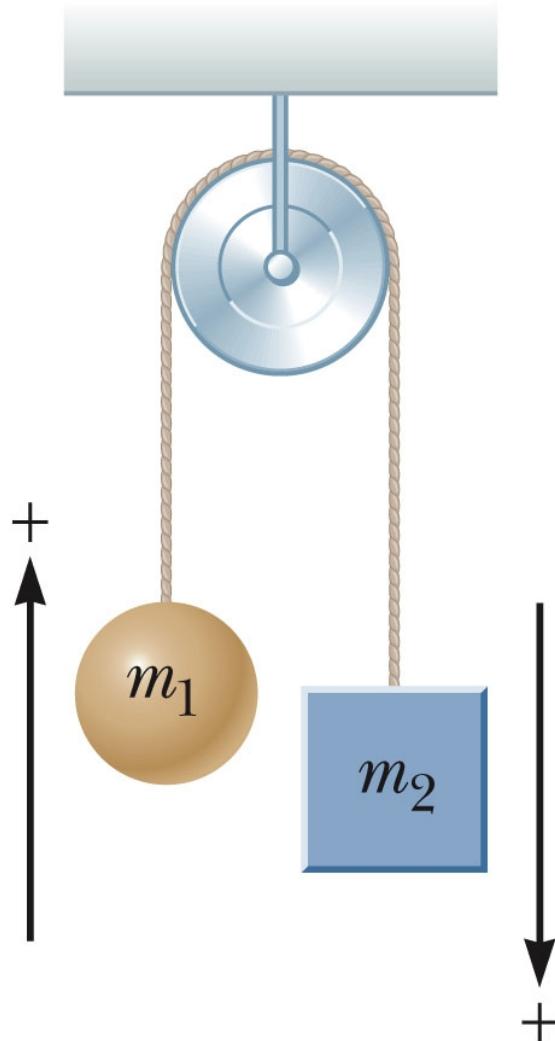
Ch. 5 Read 5.1-5.5; Do Probs. 1,2,3,6,7,19,23,35,36,38,45,50
Due on Friday.

Try “exam-like questions” for review.

Notes: I added slide numbers to the PPT!

Hwk Ch. 4 graded. Means=9.32,9.31

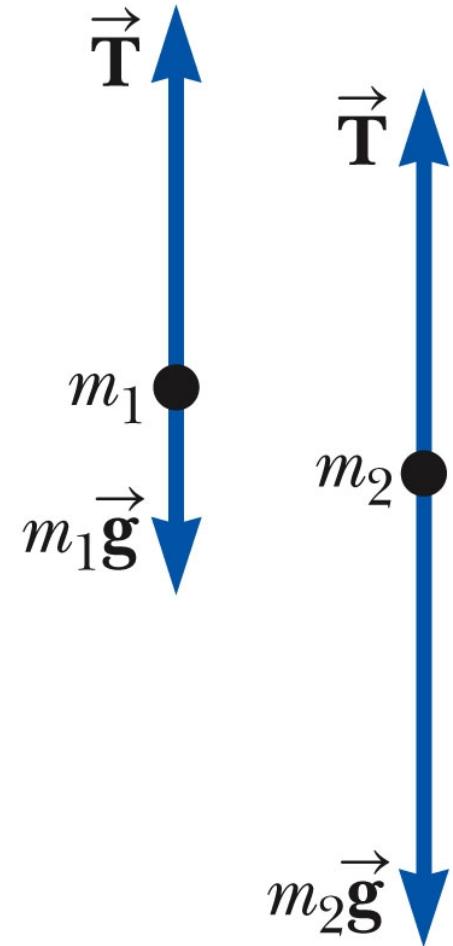
Exam I next Monday on Chs. 1-5. More info on Friday.



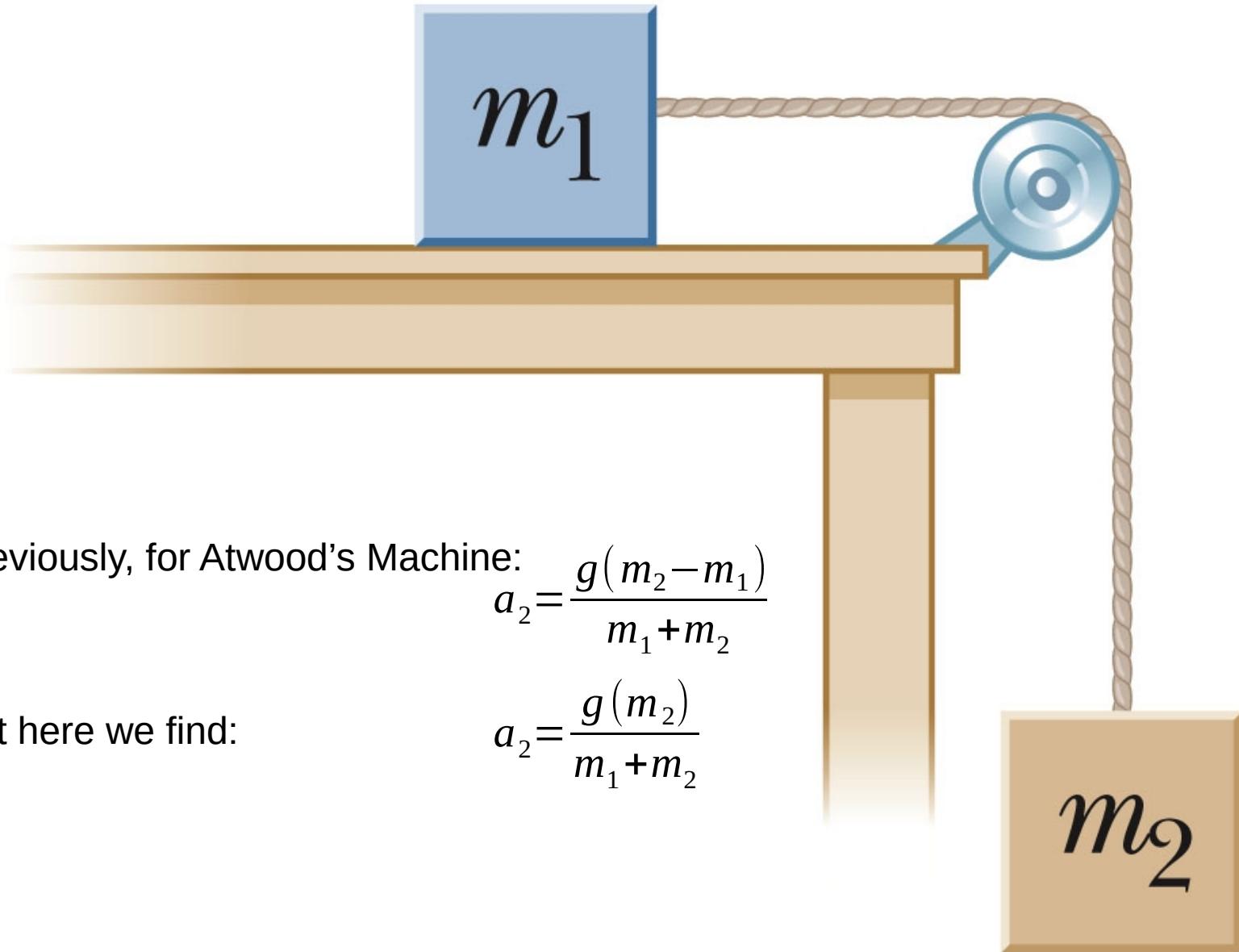
Atwood's Machine

Find acceleration of either mass,
In terms of g , m_1 and m_2 .

a



b



Previously, for Atwood's Machine:

$$a_2 = \frac{g(m_2 - m_1)}{m_1 + m_2}$$

But here we find:

$$a_2 = \frac{g(m_2)}{m_1 + m_2}$$

m_2

Friction



Kinetic friction: a force acting between two objects sliding against each other which opposes their direction of motion.

- * $f_k = \mu_k F_N$ where μ_k = coefficient of kinetic friction, and F_N is the magnitude of normal force between the objects.
- * f_k converts energy of motion into thermal energy.
- * We're assuming f_k is independent of speed. (Is it?)
- * Direction of f_k is opposite the v of the object of interest

Static friction: a shear (tangential) force between two objects which must be exceeded before they can slide.

- * $f_s \leq f_{s,\max} = \mu_s F_N$ where μ_s = coefficient of static friction.
- * $f_s = F_{\text{applied}}$ until F_{applied} reaches $f_{s,\max}$, then slippage occurs.



Wood on wood has $\mu_s \sim 0.4$, and $\mu_k \sim 0.2$.

Q: How hard must boy pull to budge the 90 kg box?

$$\text{Ans: } F_{\text{boy}} = f_{s,\max} = \mu_s F_N = \mu_s 90 * 9.8 = 353 \text{ N}$$

Q: How hard must he pull to slide it at a constant speed?

$$\text{Ans: } F_{\text{boy}} = f_k = \mu_k F_N = 0.2 * 90 * 9.8 = 176 \text{ N}$$



Wood on wood has $\mu_s \sim 0.4$, and $\mu_k \sim 0.2$.

Q: What is the f_s on the box when it's stationary and $F_{\text{applied}} = 250 \text{ N}$ to the right?

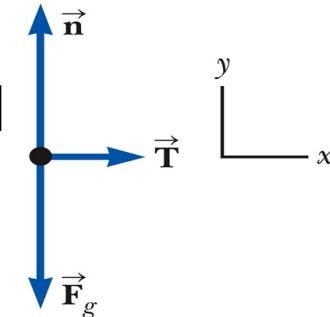
$$\text{Ans: } f_s = -F_{\text{applied}} = -250 \text{ N} \hat{i}$$

Q: What is the acceleration of the box if $F_{\text{app}} = 180 \text{ N} \hat{i}$ and the box is sliding to the right?

$$\text{Ans: } \mathbf{a} = \mathbf{F}_{\text{net}} / m = (F_{\text{app}} - f_k) / m = (180 - 176) / 90 \text{ kg} = .044 \text{ m/s}^2 \hat{i}.$$

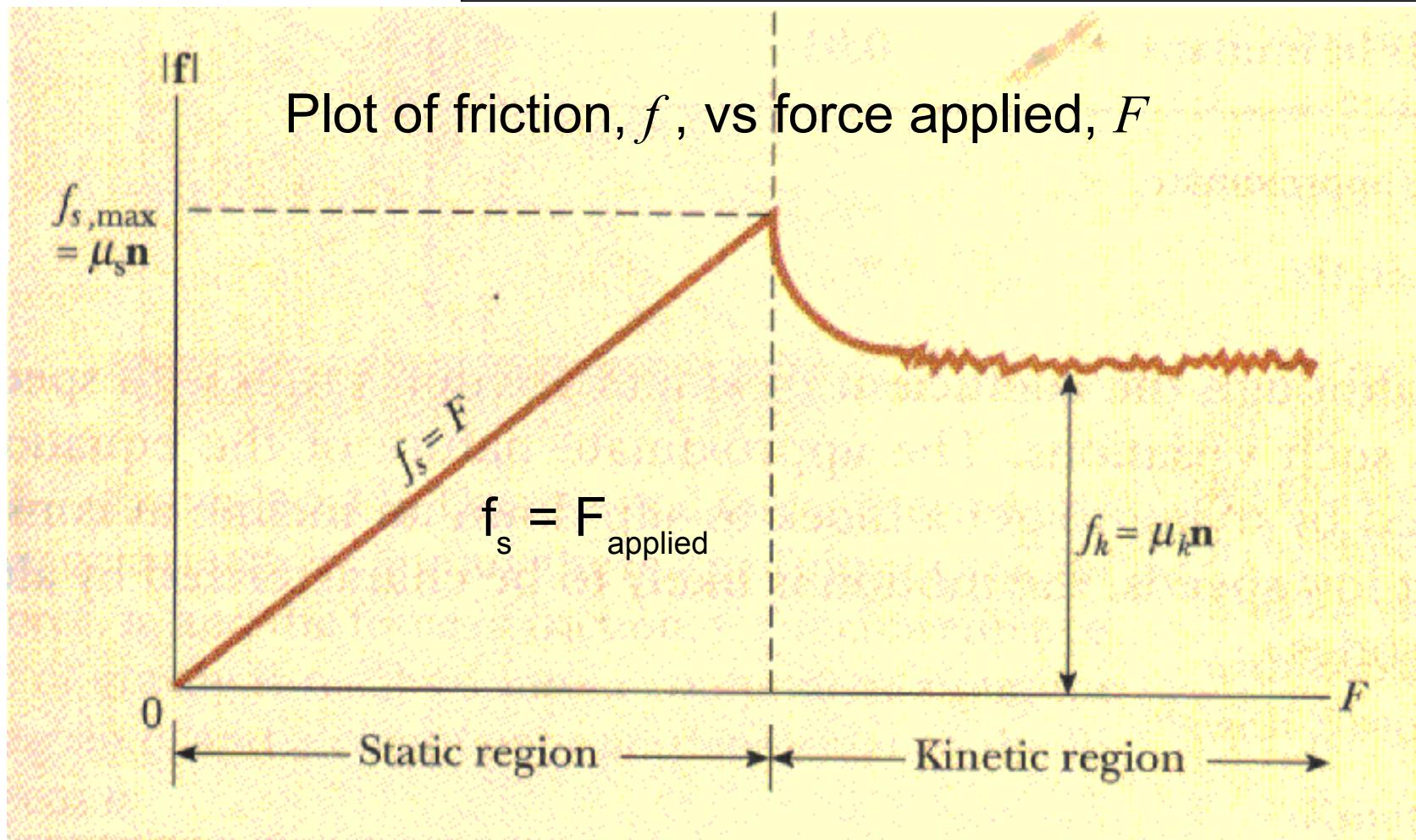
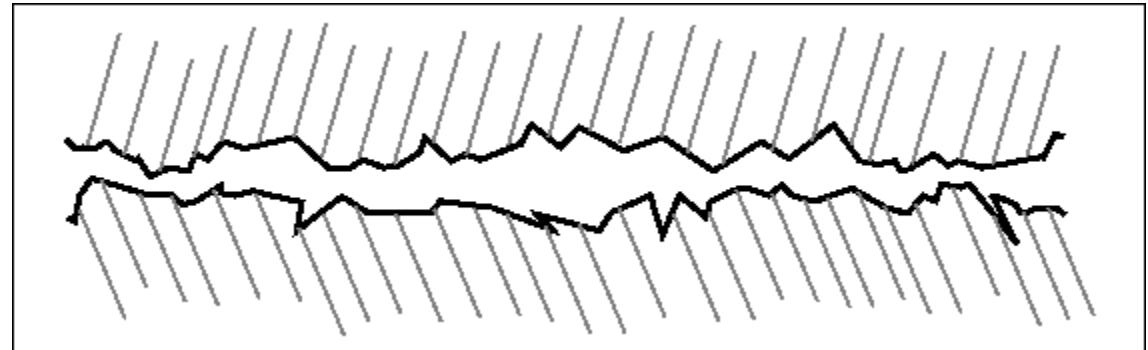
Q: What is the acceleration of the box if $F_{\text{app}} = 170 \text{ N} \hat{i}$ and the box is sliding to the right?

$$\text{Ans: } \mathbf{a} = \mathbf{F}_{\text{net}} / m = (F_{\text{app}} - f_k) / m = (170 - 176) / 90 \text{ kg} = -.067 \text{ m/s}^2 \hat{i}.$$

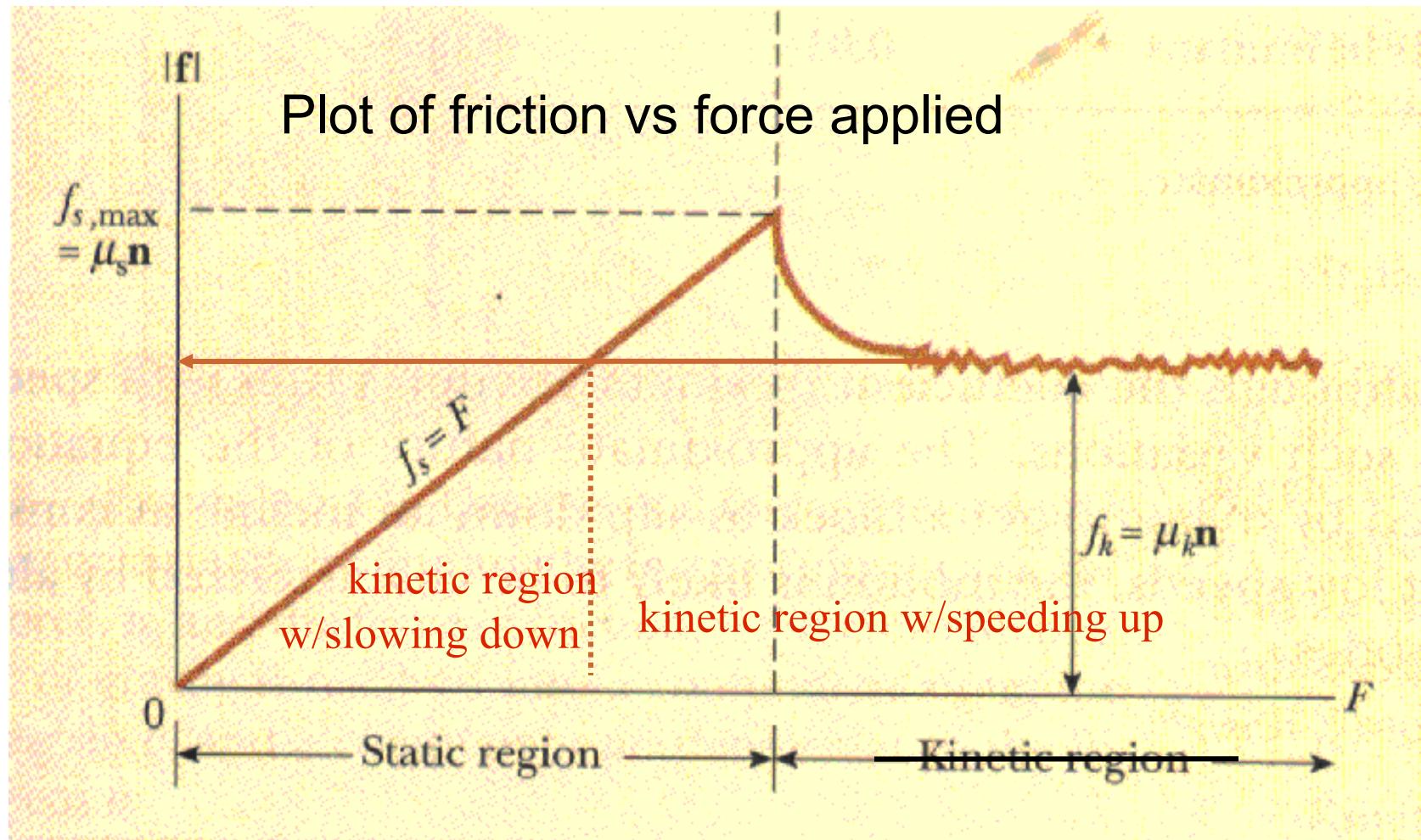
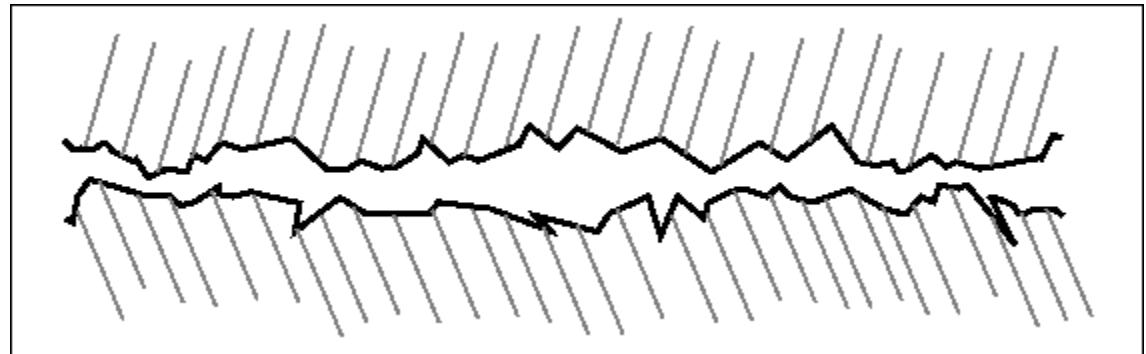


Why friction?

Take a close look:



Close-up of surfaces.



Outline for Day W6,D3

Exam 1 information

Friction: block on incline

Uniform Circular Motion: centripetal acceleration and force.

Homework

Ch. 5 Read 5.1-5.5; Do Probs. 1,2,3,6,7,19,23,35,36,38,45,50
Due today by 1:00.

Try “exam-like questions” for review.

Notes: I added slide numbers to the PPT!

Ch. 4 hwk key online soon.

Exam I next Monday on Chs. 1-5. More info on Friday.

Exam 1 Info

Place: usual classroom, Meyer 113

Time: usual class time, stop after 52 minutes

Format: multiple choice, problems, fill-in-the-blank, T or F

Problems are like “exam-like problems” but without choices.

Expect 3 pages, about 24 questions.

Calculators allowed. Phones, textbook & notes not allowed.

Come forward for questions.

Scratch paper provided.

5 equations of uniform acceleration provided.

Coverage: Chs. 1-5

Skip 1.1, 1.2, 1.6, 2.8, 4.8, and 5.6 (drag).

Study resources: “exam-like problems”, practice quizzes, PDFs of powerpoints, notes, textbook summaries,

TABLE 5.1*Coefficients of Friction*

	μ_s	μ_k
Rubber on concrete	1.0	0.8
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Glass on glass	0.94	0.4
Copper on steel	0.53	0.36
Wood on wood	0.25–0.5	0.2
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Teflon on Teflon	0.04	0.04
Ice on ice	0.1	0.03
Synovial joints in humans	0.01	0.003

Note: All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

Motion



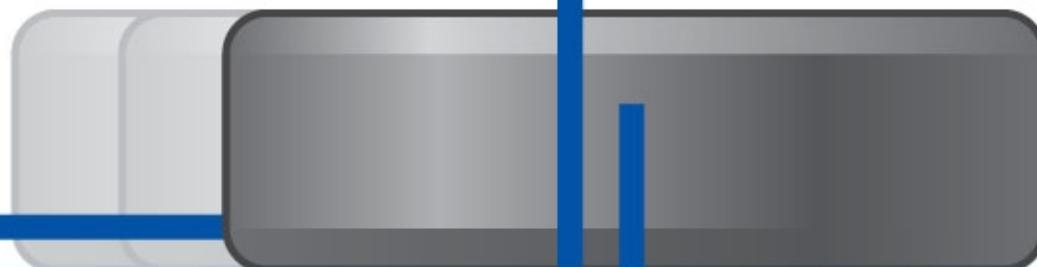
\vec{n}



$m\vec{g}$

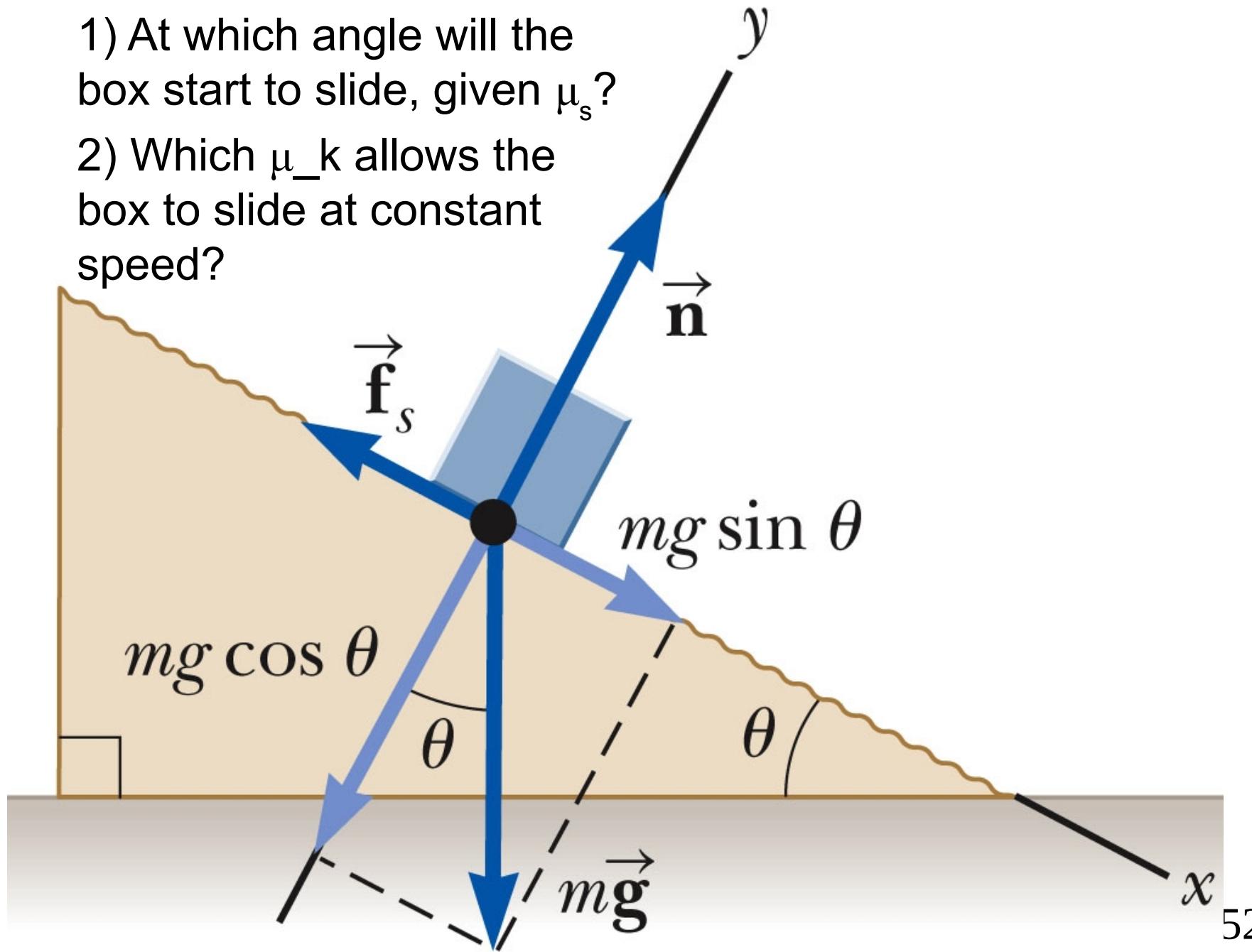
\vec{f}_k

$$\mathbf{a} = \mathbf{f}_k / m$$

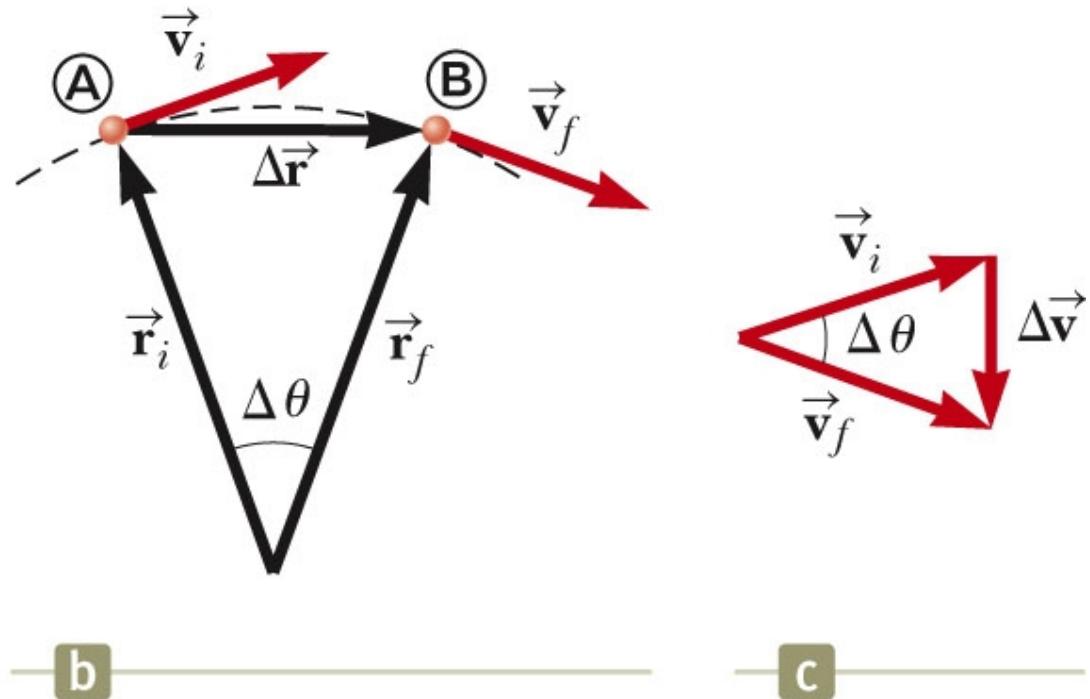
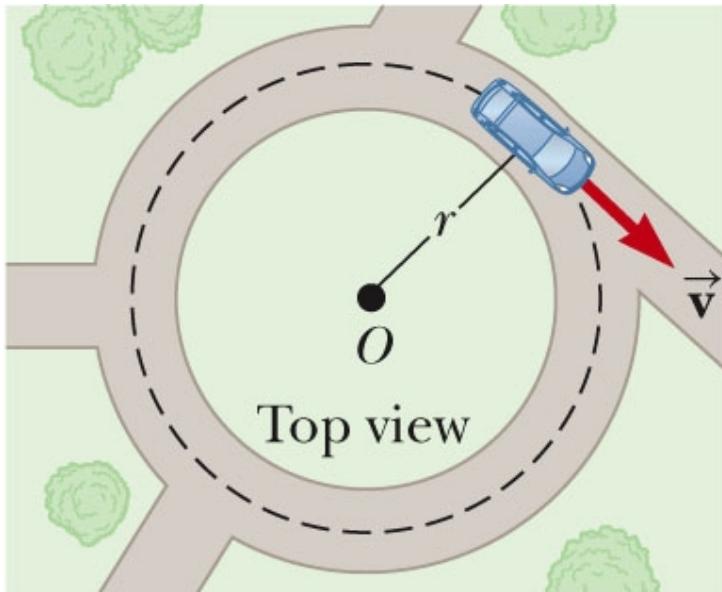


1) At which angle will the box start to slide, given μ_s ?

2) Which μ_k allows the box to slide at constant speed?



Uniform circular motion = object moves at constant speed in a circular path.



Derive centripetal acceleration: $a_c = a_r = \lim_{\Delta t \rightarrow 0} \frac{\Delta v}{\Delta t} = \frac{v^2}{r}$

Note: time to make one cycle = period = T = circumf./speed
 $T=2\pi r/v$

Uniform circular motion - Example

P. 5.36 A child sitting 1.40 m from the center of a merry-go-round moves with a speed of 1.3 m/s. Calculate

- the centripetal acceleration of the child and
- the net horizontal force exerted on the child ($m=22.5 \text{ kg}$).



Soln: a) $a_c = v^2/r = (1.3)^2/1.4 = 1.21 \text{ m/s}^2$

b) $F_{\text{net}} = F_c = ma_c = 22.5(1.21) = 27.2 \text{ N}$ towards center.

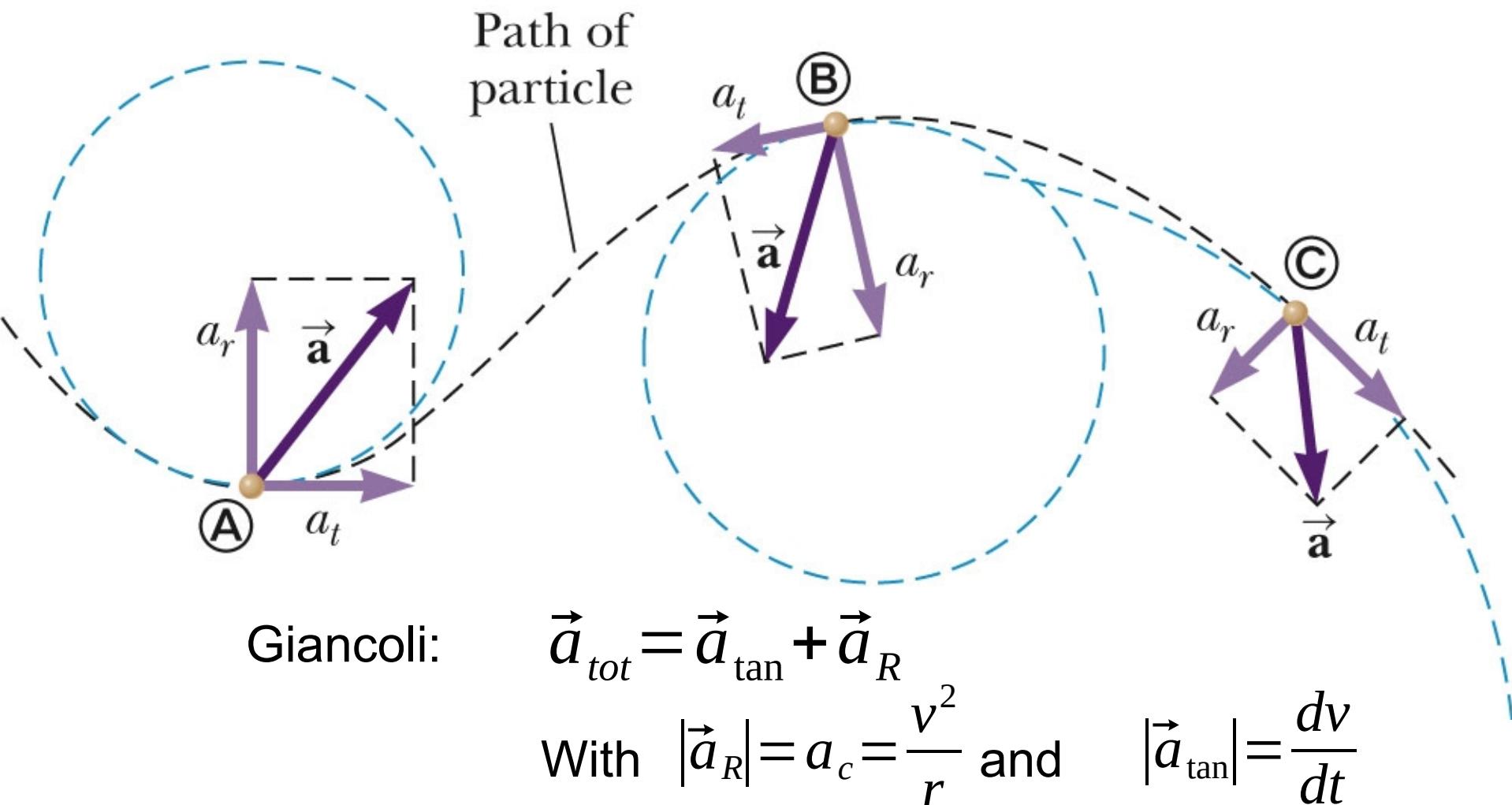
c) What provides the F_c ?

Ans: static friction, $f_s = 27.2 \text{ N}$

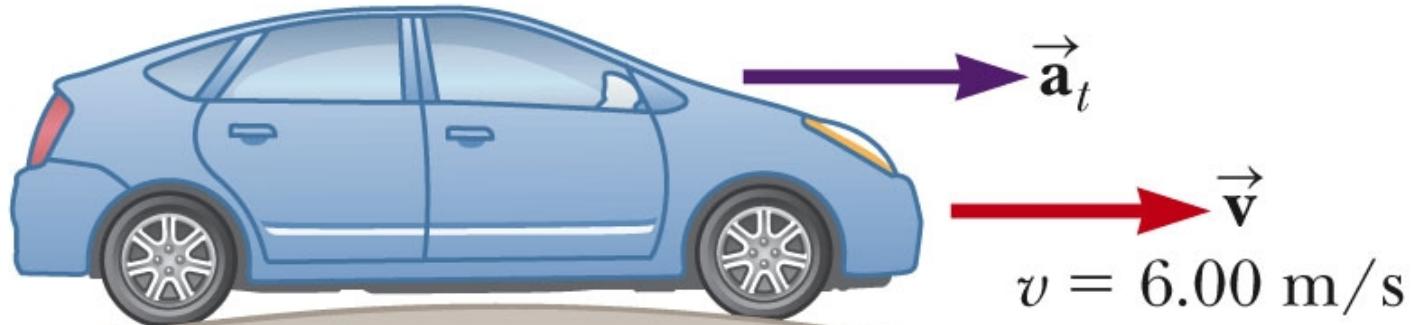
d) What is the period of the child's motion?

Ans: $T = 2\pi r/v = 2\pi(1.4)/(1.3) = 6.77 \text{ sec}$

Total acceleration – sum of tangential and centripetal components



$$a_t = 0.300 \text{ m/s}^2$$



a

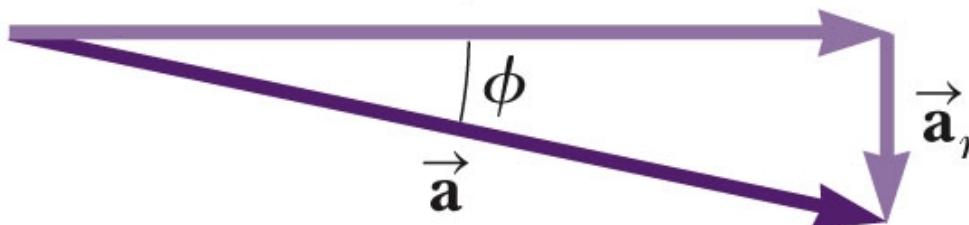
Q: Find \mathbf{a}_{tot} if $r_{\text{hill}} = 25 \text{ m}$.

$$a_r = v^2/r = 36/25 = 1.44 \text{ m/s}^2$$

$$a_t = 0.3 \text{ m/s}^2$$

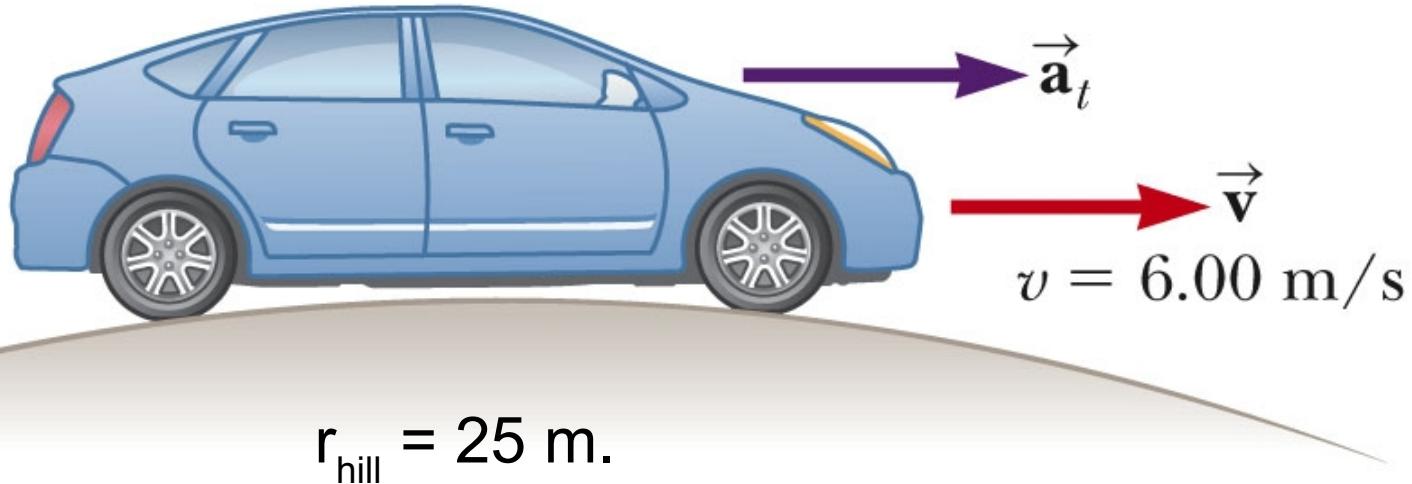
$$\vec{a}_{\text{tot}} = \vec{a}_{\tan} + \vec{a}_R$$

$$\vec{a}_{\text{tot}} = 0.3 \hat{i} - 1.44 \hat{j}$$



b

$$a_t = 0.300 \text{ m/s}^2$$



Q: How fast would you have to drive over this hill to feel weightless (i.e., no force exerted by seat).

Ans: this happens when $F_g = F_c$

$$mg = mv^2/r$$

$$(gr)^{1/2} = v$$

$$(9.8 * 25)^{1/2} = v$$

$$v = 15.7 \text{ m/s} \quad (35 \text{ mph})$$