# 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.

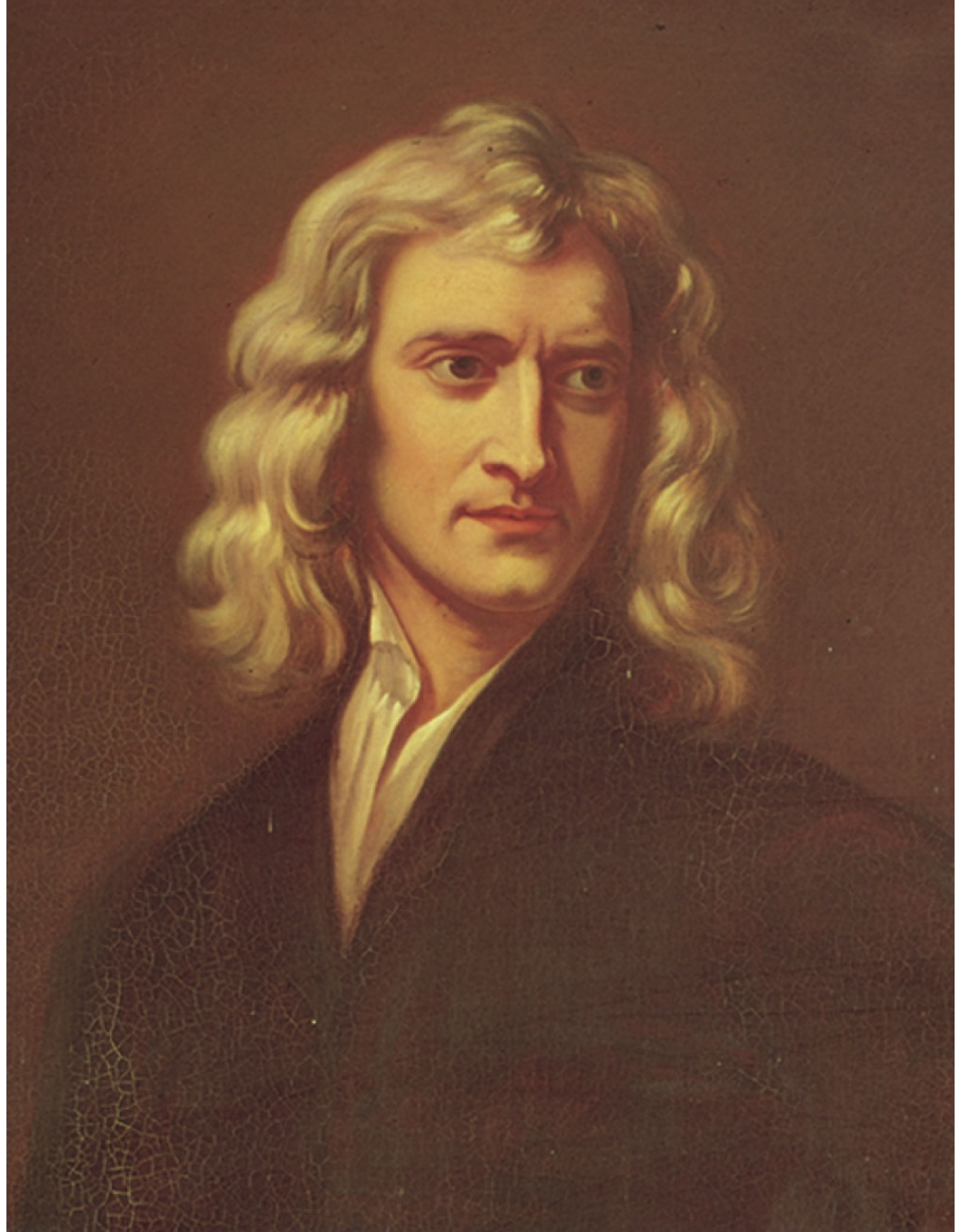
Exam I follows Chapter 5 material.

# 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)

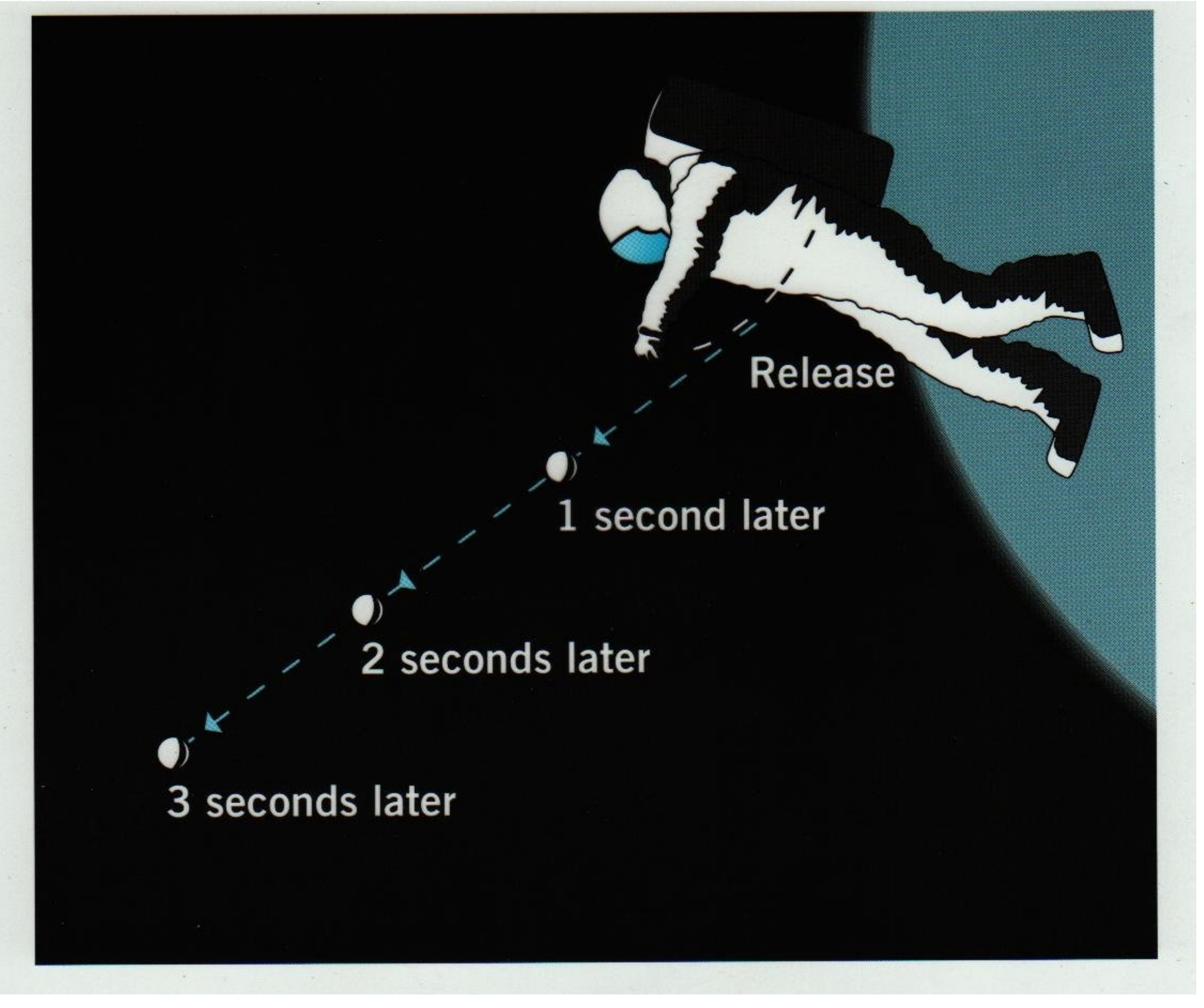


3 laws of motion

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.




$\mathbf{v}$=const if $\mathbf{F}_{net} = 0$

Overthrows Aristotle and medieval ideas:

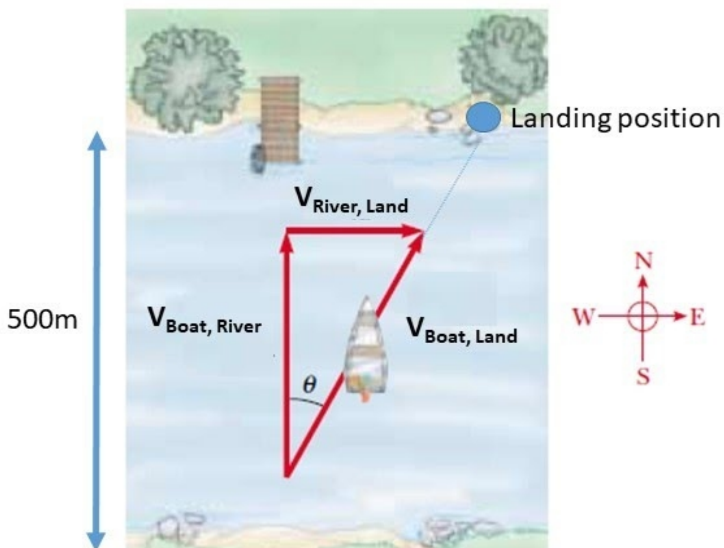
"natural state" is at rest

"impetus" pushes an arrow along

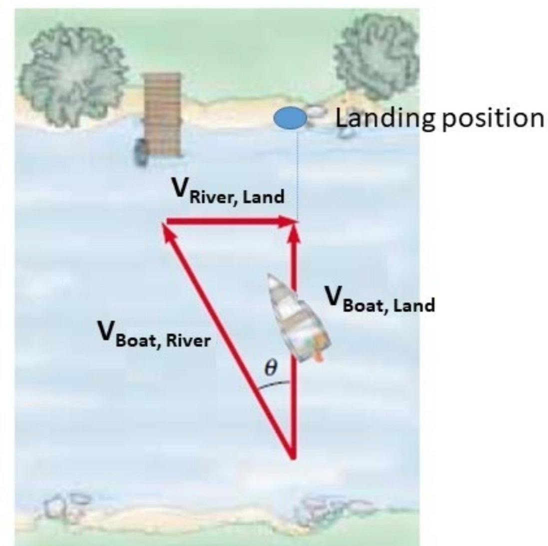
# Frames of reference and relative motion

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 $\mathbf{v}_{RL}$ = 3 m/s E, $\mathbf{v}_{BR}$ = 8 m/s N.

**P**1) If the boat moves N relative to the river, find $\mathbf{v}_{BL}$.

Find $\mathbf{v}_{BL}$. $\mathbf{v}_{BL} = \mathbf{v}_{BR} + \mathbf{v}_{RL} = 8\hat{j} + 3\hat{i}$ , $|\mathbf{v}_{BL}|$=8.54 m/s, θ=20.6°

How far East does it drift? X/500 = tan θ. X=188 m.

# Outline for Day W5,D2

Relative velocity and motion (cont.)

Types of Forces

Newton's $2^{nd}$ 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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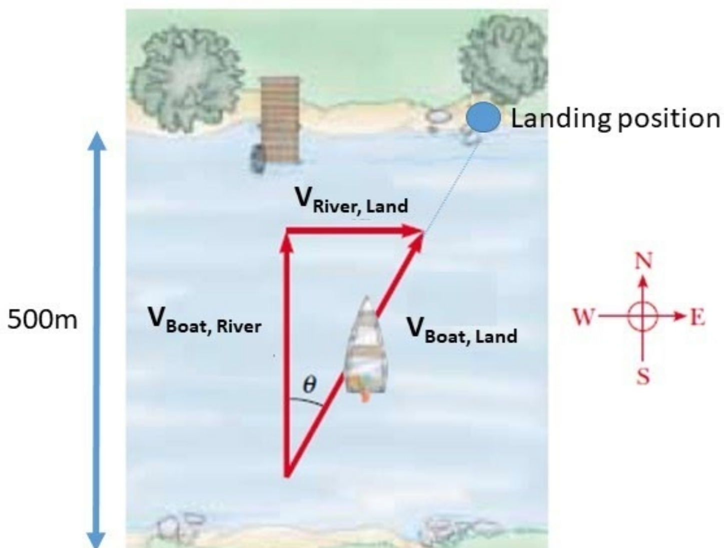
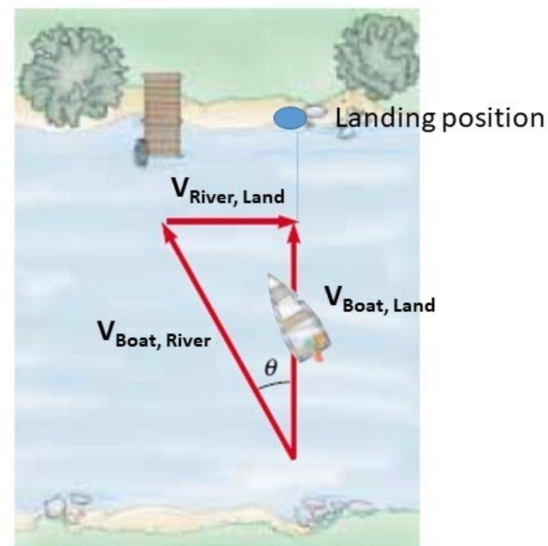
**Problem 1**




**Problem 2**




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

Given $\mathbf{v}_{RL}$ = 3 m/s E, $|\mathbf{v}_{BR}|$ = 8 m/s.

**P**2) What θ is needed so that the boat goes straight N?

Ans: $\sin\theta = \mathbf{v}_{RL}/|\mathbf{v}_{BR}| = 3/8$. $\theta=22.0°$

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

## Relative Motion Problem

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

So we can say

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

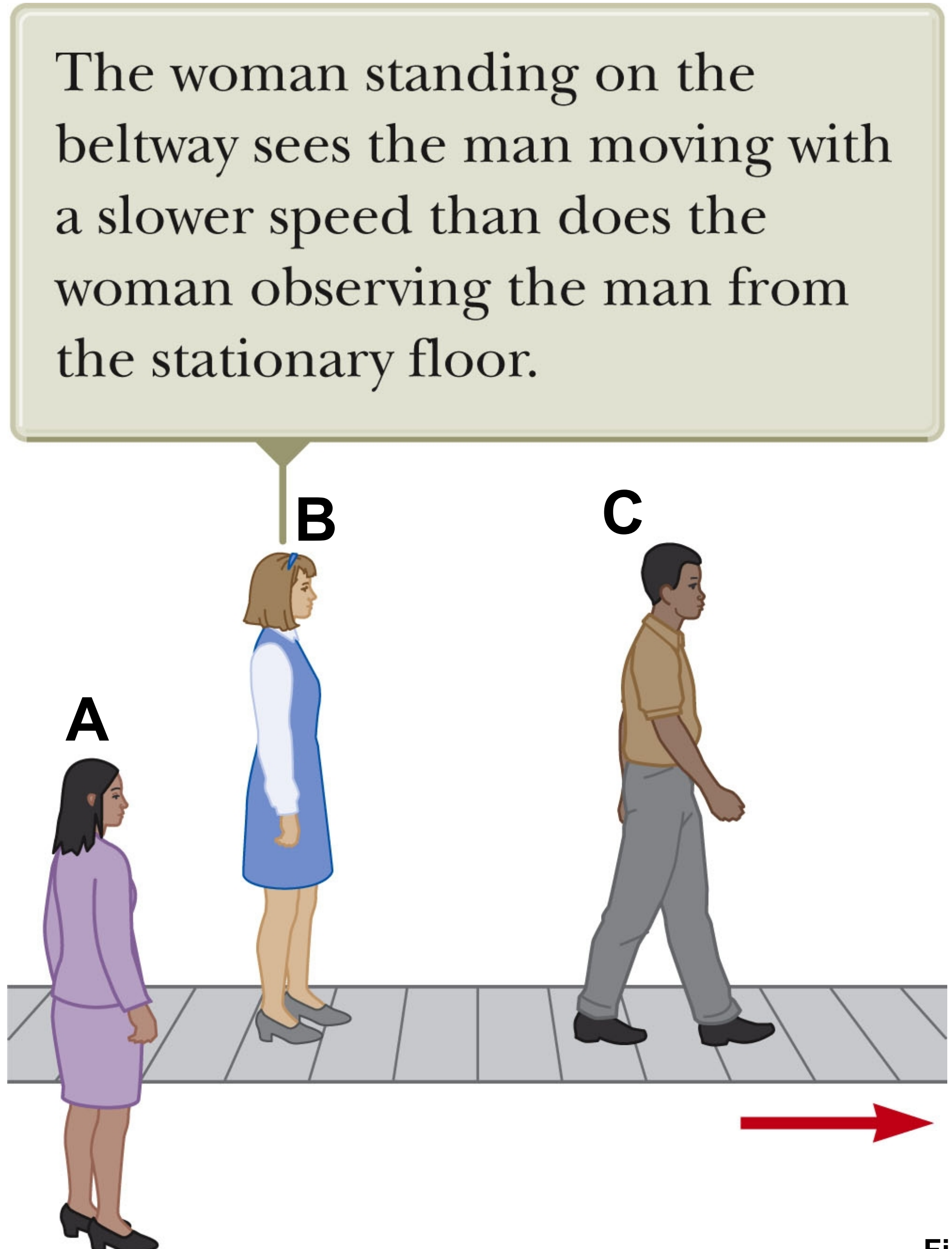
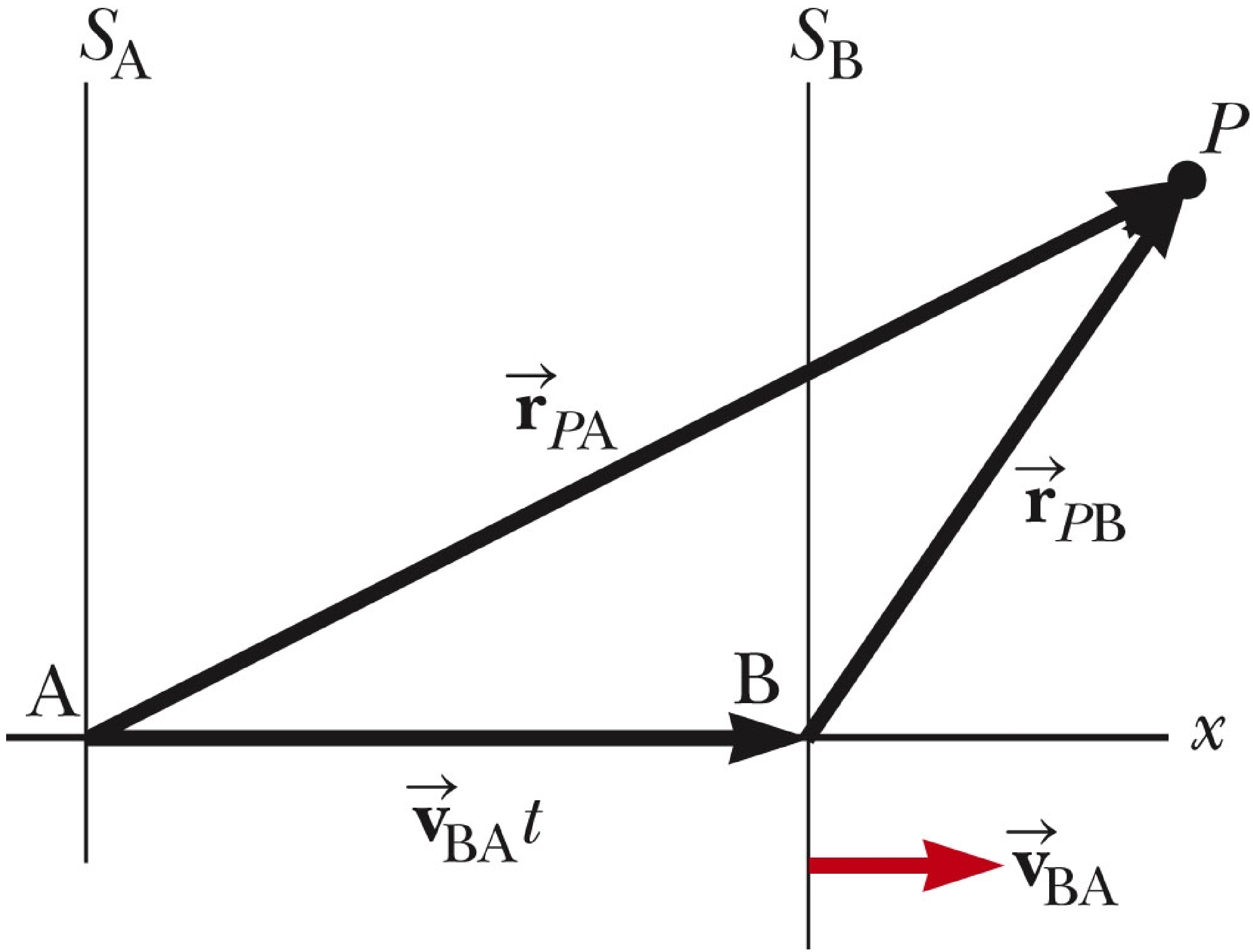



Fig. 4.19, p. 90

Transforming between two frames of reference, A and B.




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

**Fig. 4.20, p. 91**

## 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.

# Inertial Frames of reference (cont.)

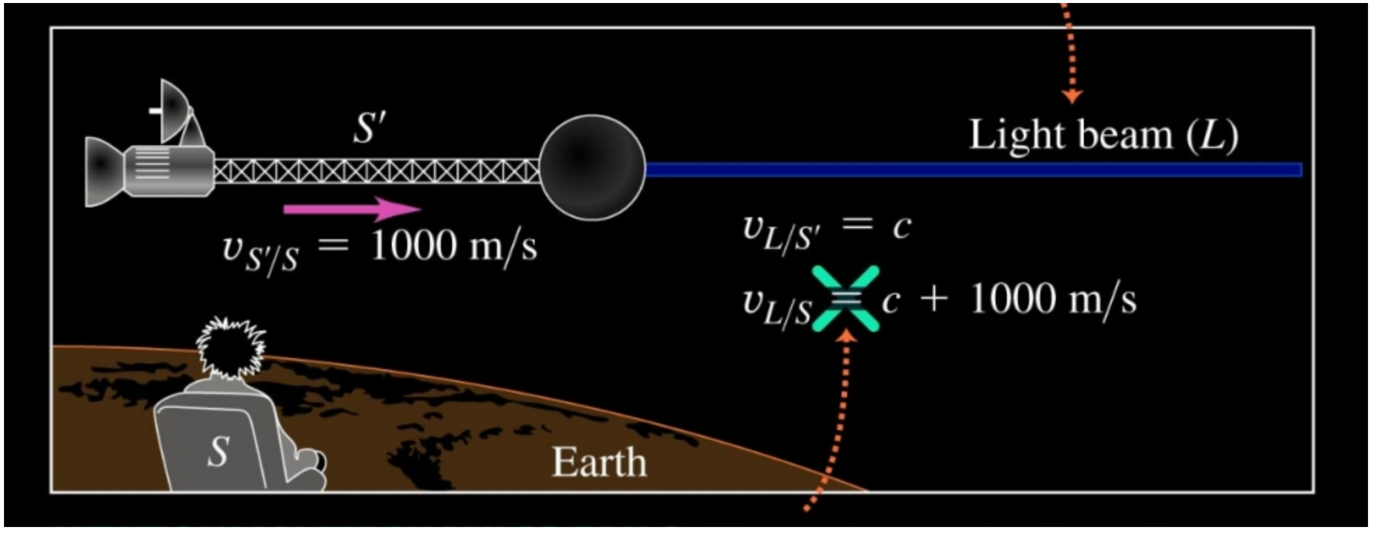
Velocity transformation (from Galilean relativity):

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

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)

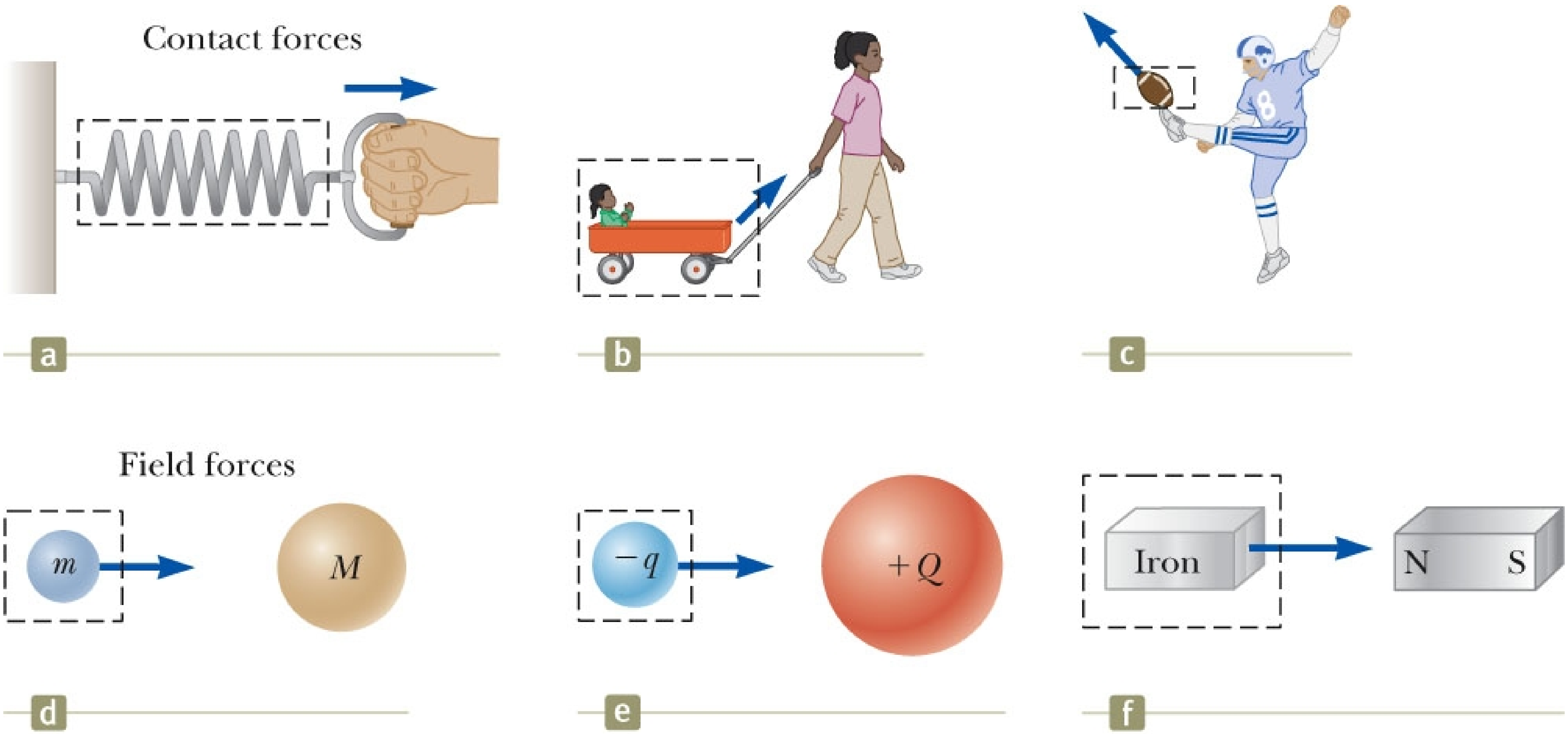
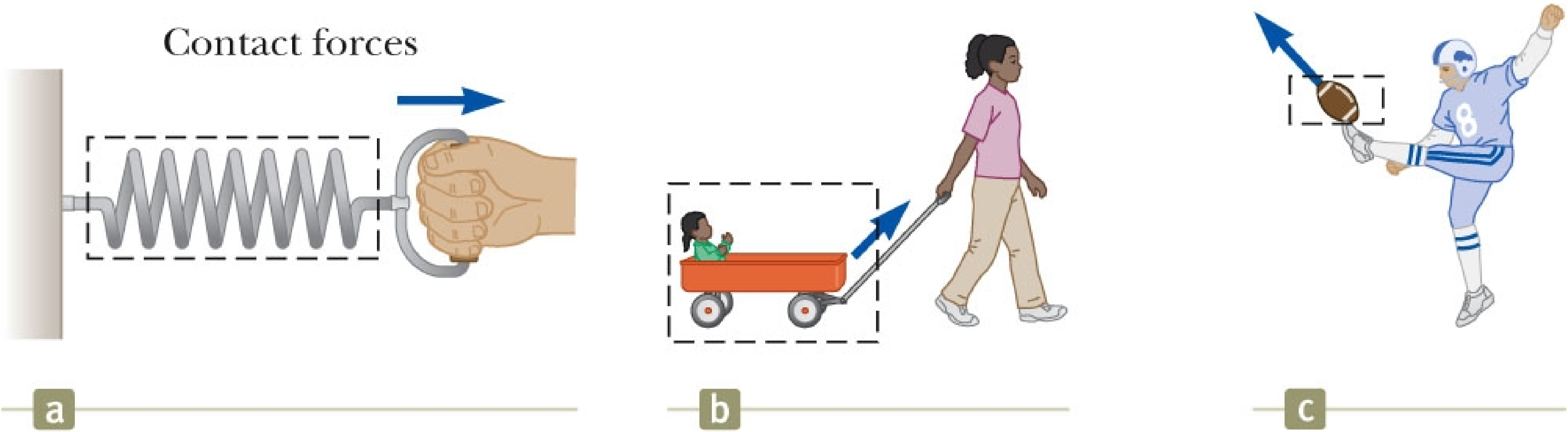



Fig. 5.1, p. 104

# Types of forces

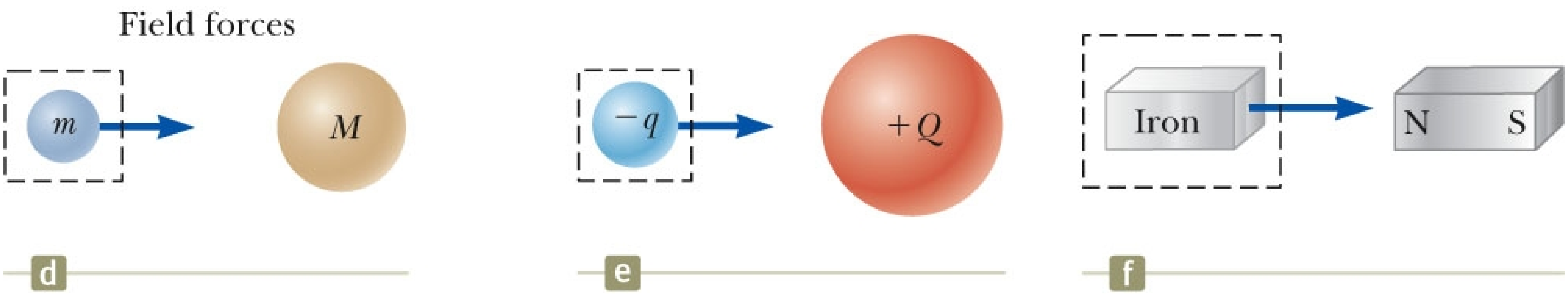



contact forces

- tension – pulling apart
- compression – pushing together
- shear – pushing tangentially
- torsion - twisting

Fig. 5.1, p. 104

# Types of forces




## Field forces

gravitational electric magnetic

Fig. 5.1, p. 104

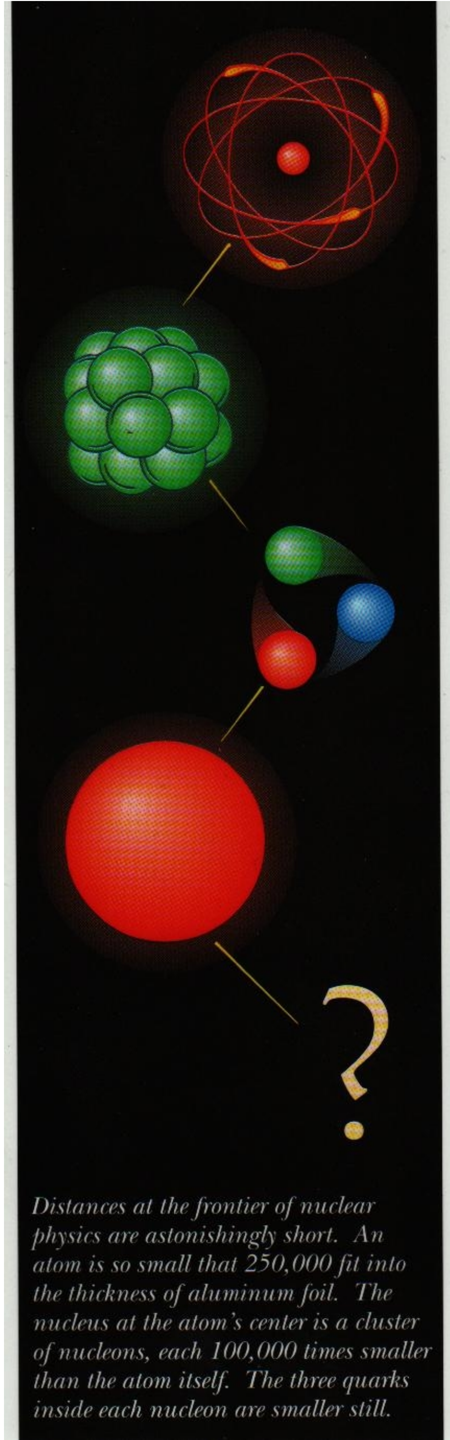
# The 4 Fundamental forces

Gravity

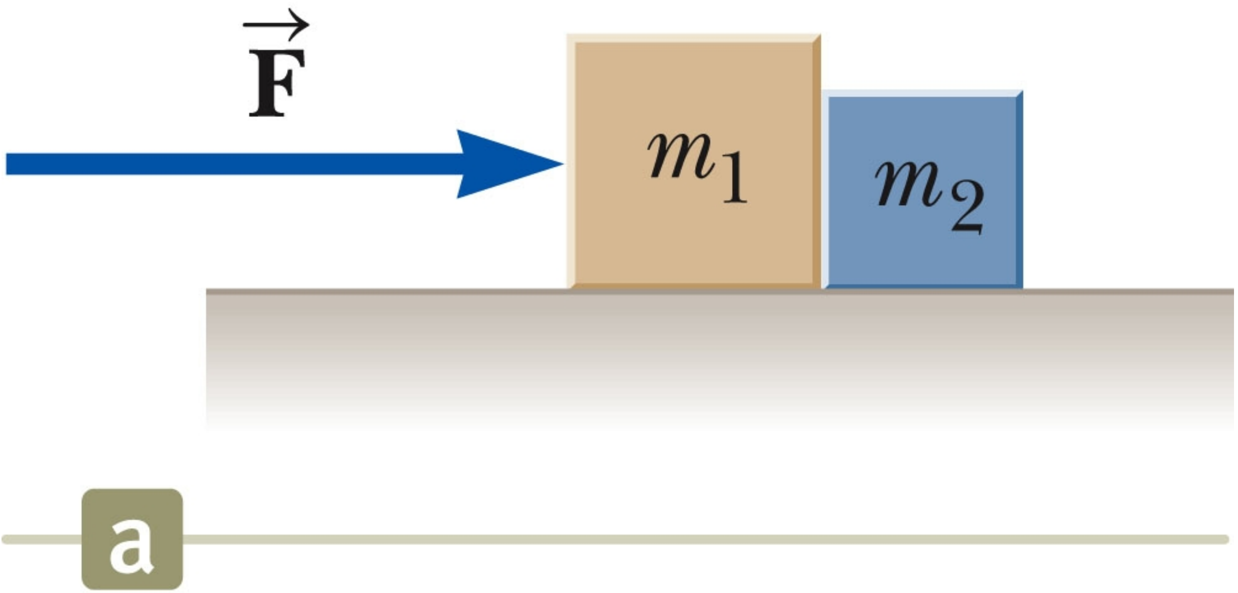
Electromagnetic Force

Nuclear Strong Force – holds nuclei together

Nuclear Weak force – decay of n and p



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 m1, m2, and m1+m2, the accelerations are different.

# Outline for Day W5,D3

Newton's $2^{nd}$ law

Newton's $3^{rd}$ 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

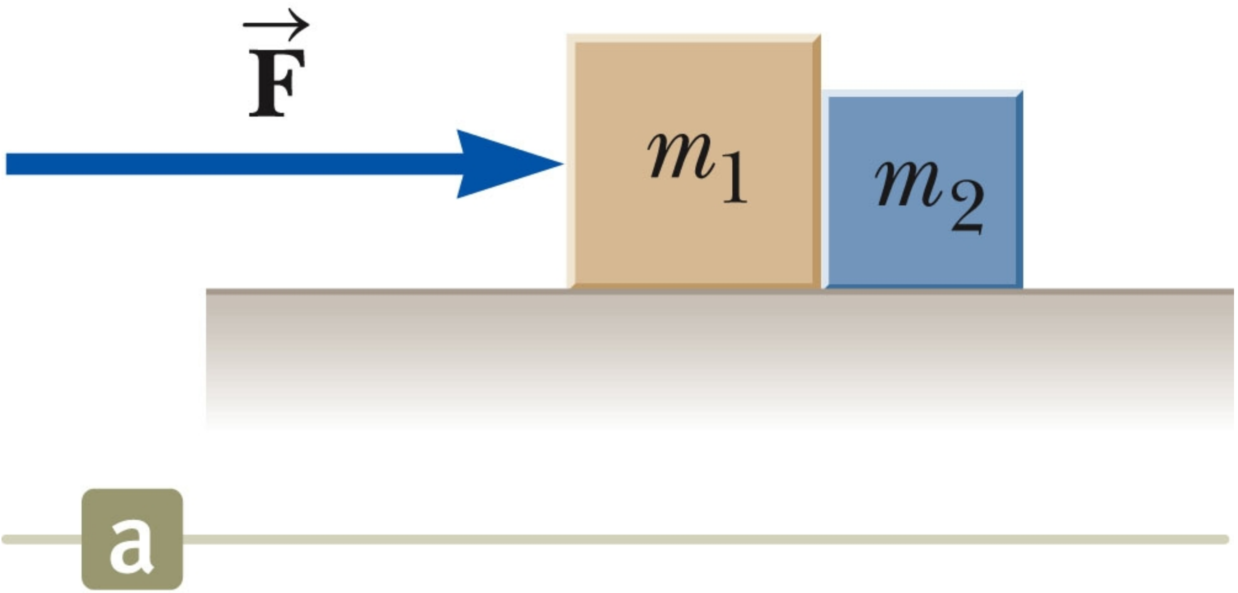
Ch. 5 Read 5.1-5.5, P. 1,2,3,6,7,19,23,35,36,38,45,50 Next Fri

## 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 $2^{nd}$ 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 **F** = 10 N î.

1) Find $\mathbf{a}_1$ if **F** acts only on $m_1$.

2) Find $\mathbf{a}_2$ if **F** acts only on $m_2$.

3) Find $\mathbf{a}_{1+2}$ if **F** acts on both $m_1$ and $m_2$.

4) In #3, what is the force on $m_1$ by $m_2$, $\mathbf{F}_{12}$?

# Newton's 2nd law (cont.)

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

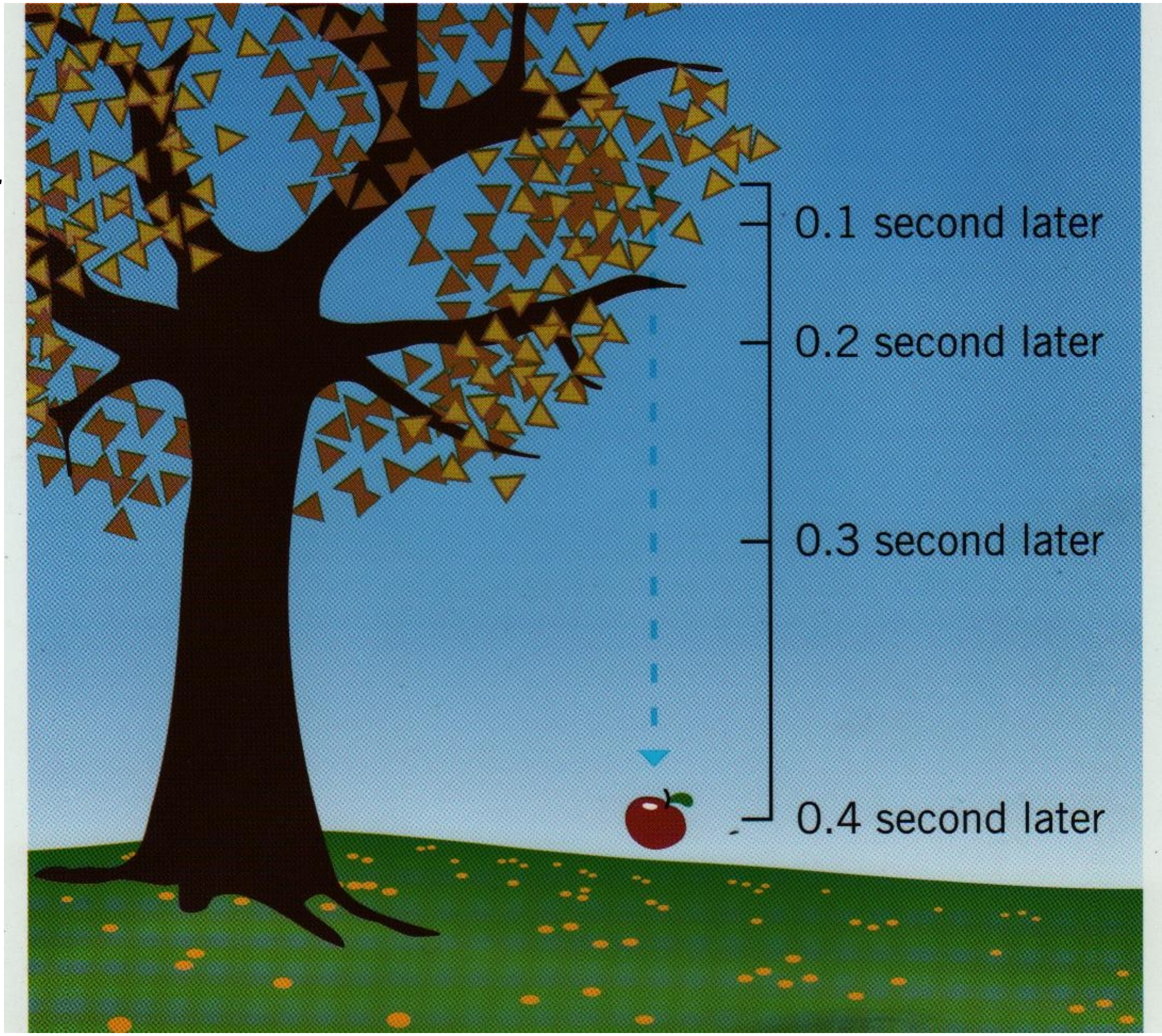
Yes: $F_{net} = F_g$ if only gravity acts. Then $a = F_g/m = mg/m = g$

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

<u>Weight</u> = the force of gravity on an object

$$W=F_g=mg$$

<u>Mass</u> = the amount of matter in an object



# Newton's $2^{nd}$ 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. $F_{net} = m a$

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

Convert to m/s: -95 km/hr (1hr/3600s)(1000 m/km) =-26.4 m/s

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

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

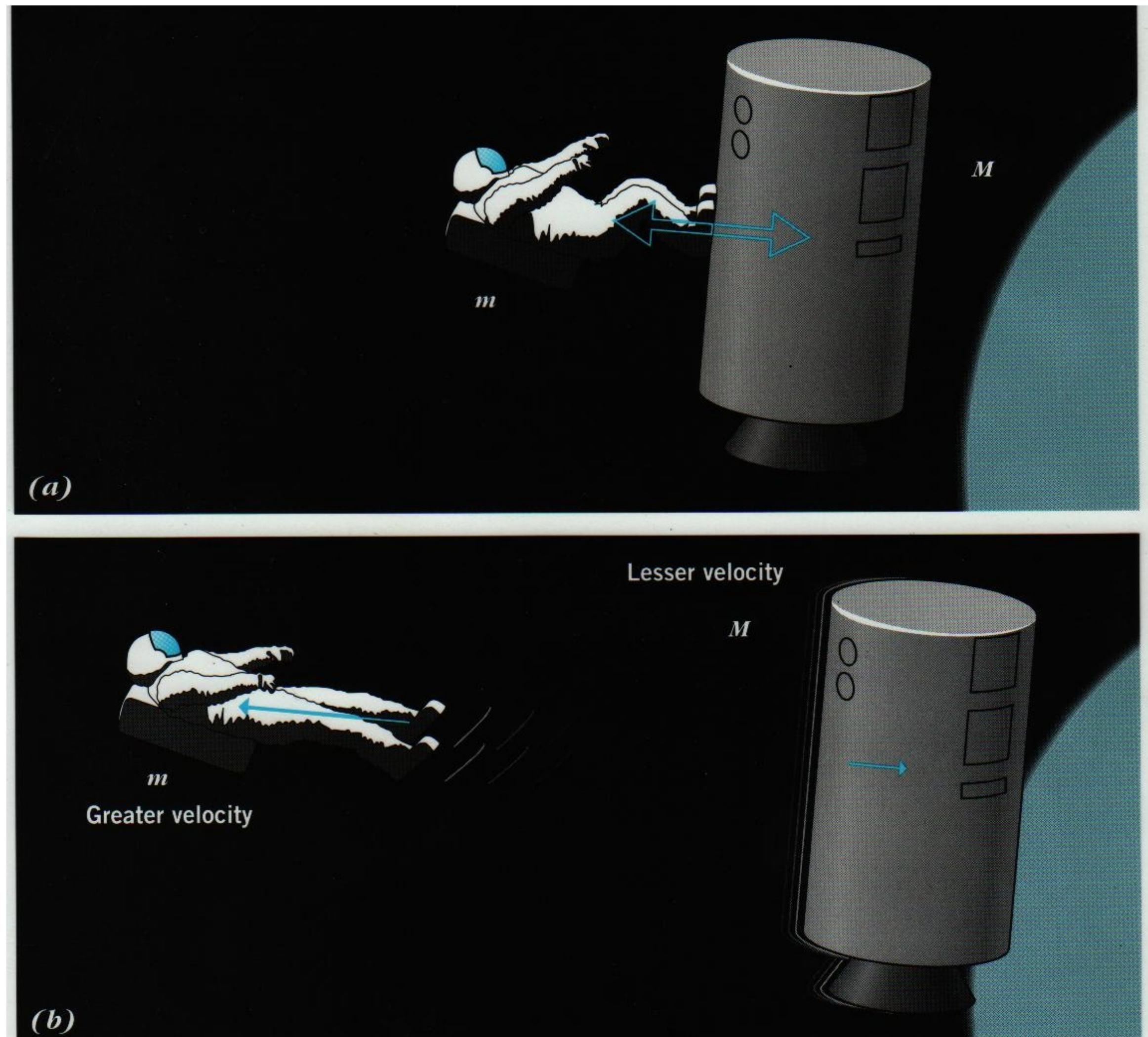
(The – sign means F is in opposite direction of the velocity.)

# 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" sub-script means "on 1 by 2".



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

Example)

Let $m_1$ = 70 kg (astronaut) and $M_2$=700 kg (satellite)

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

b) What is $\mathbf{a}_2$?

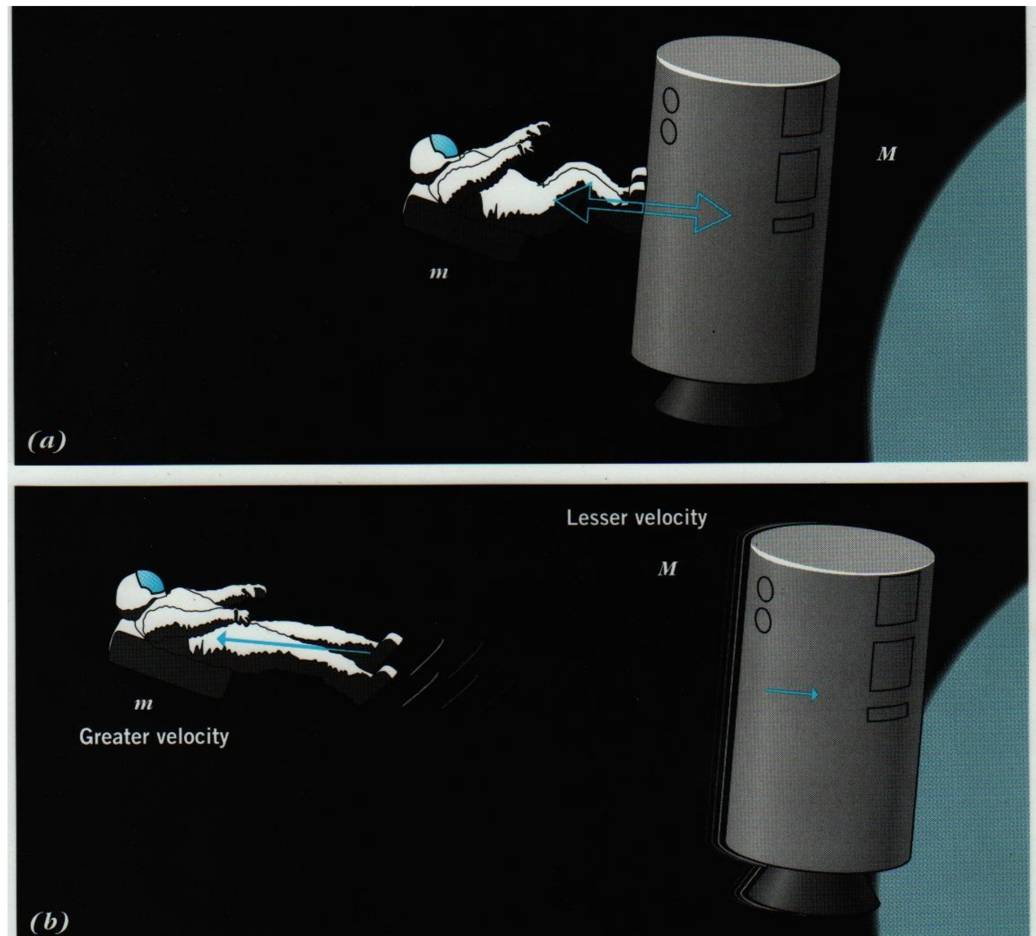
$\mathbf{a}_2 = \mathbf{F}_{21} / m_2$

$\mathbf{a}_2$=1000/700=1.43m/s$^2$î

c) What is $\mathbf{a}_1$?

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

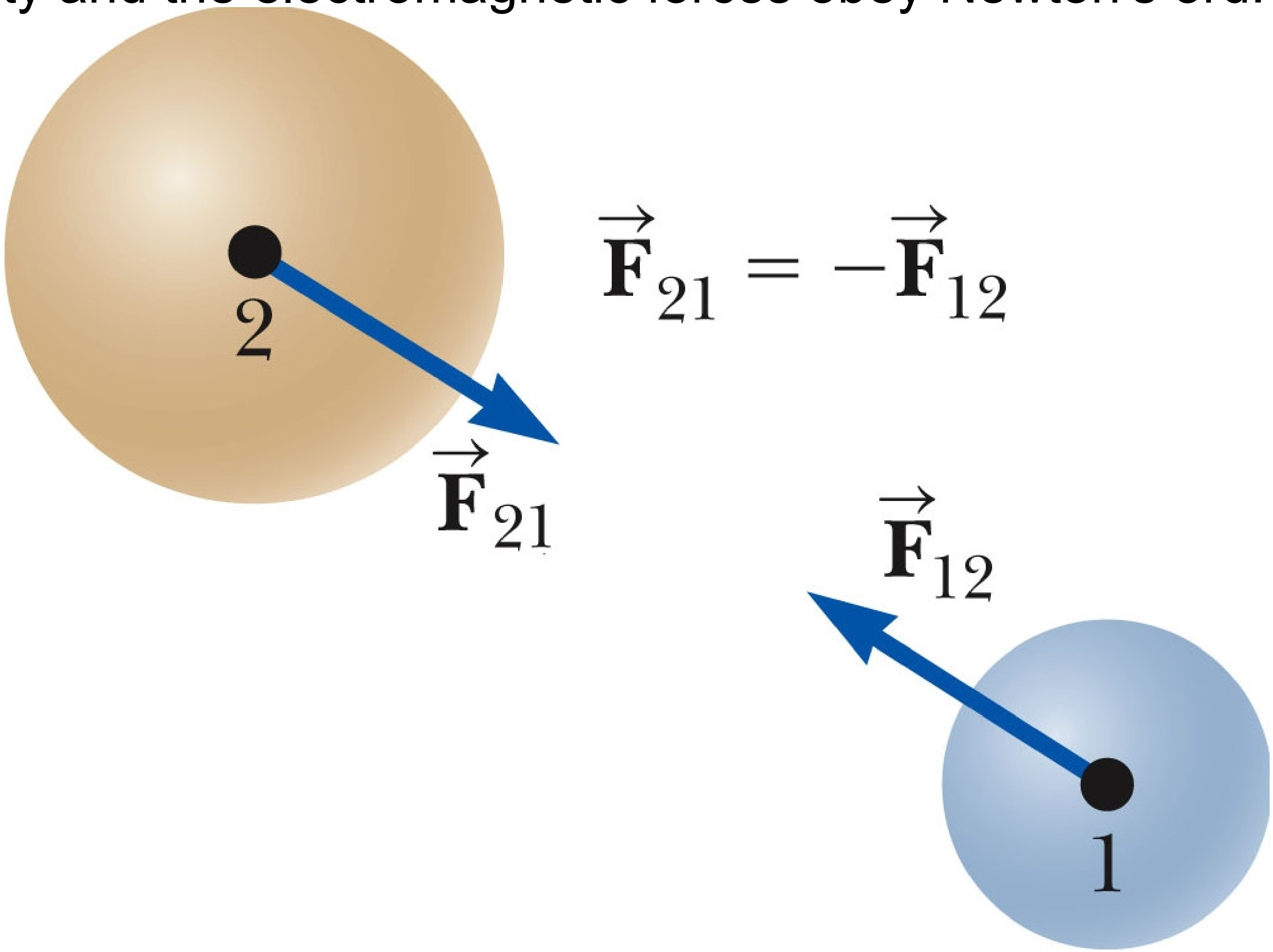
d) What are $|a_1/a_2|$ and $|\Delta v_1/\Delta v_2|$ in terms of $m_1/M_2$?



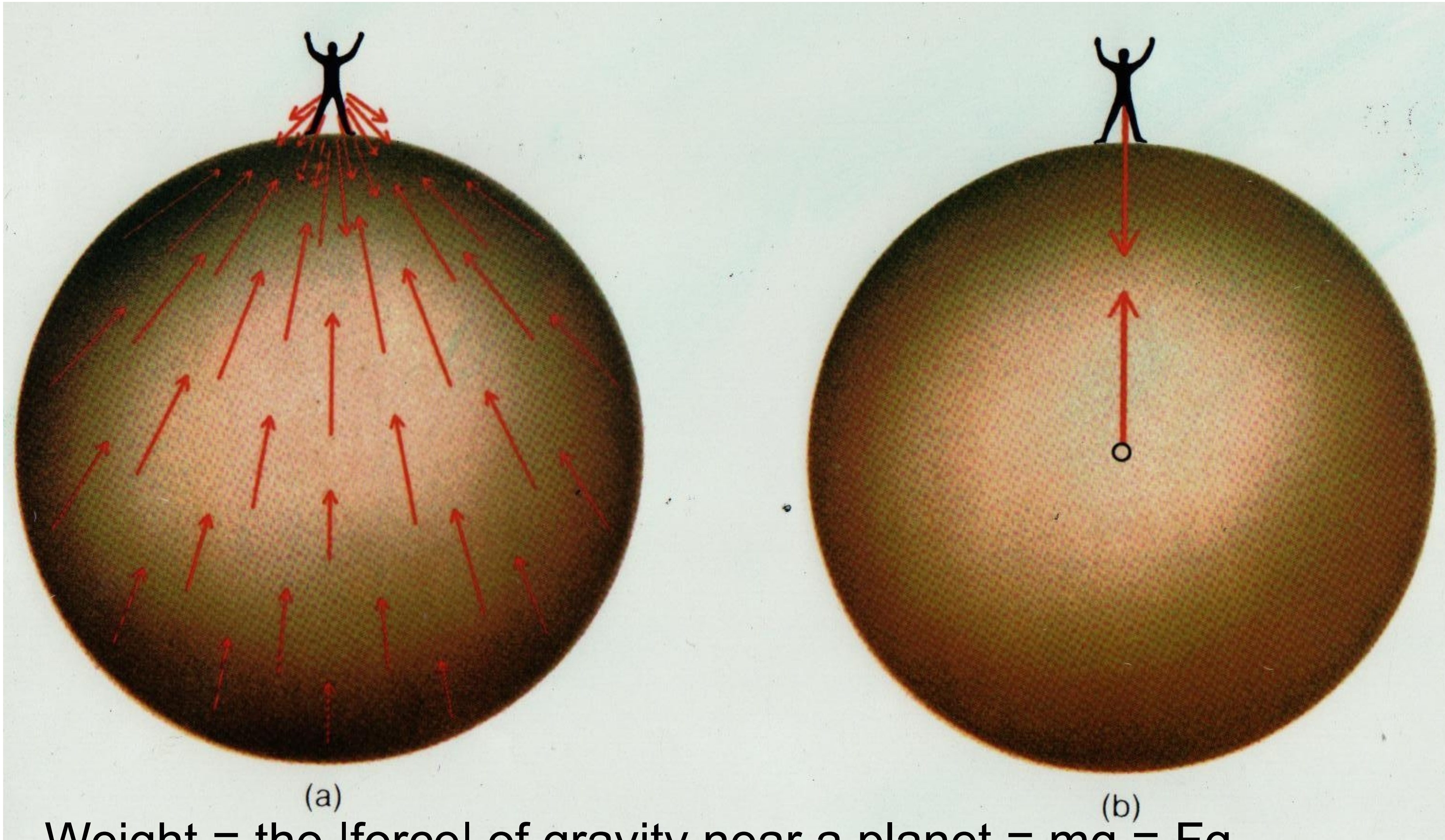
Newton's 3rd law (cont.)

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

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



# Newton's 3rd law (cont.)




Weight = the |force| of gravity near a planet = mg = Fg

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

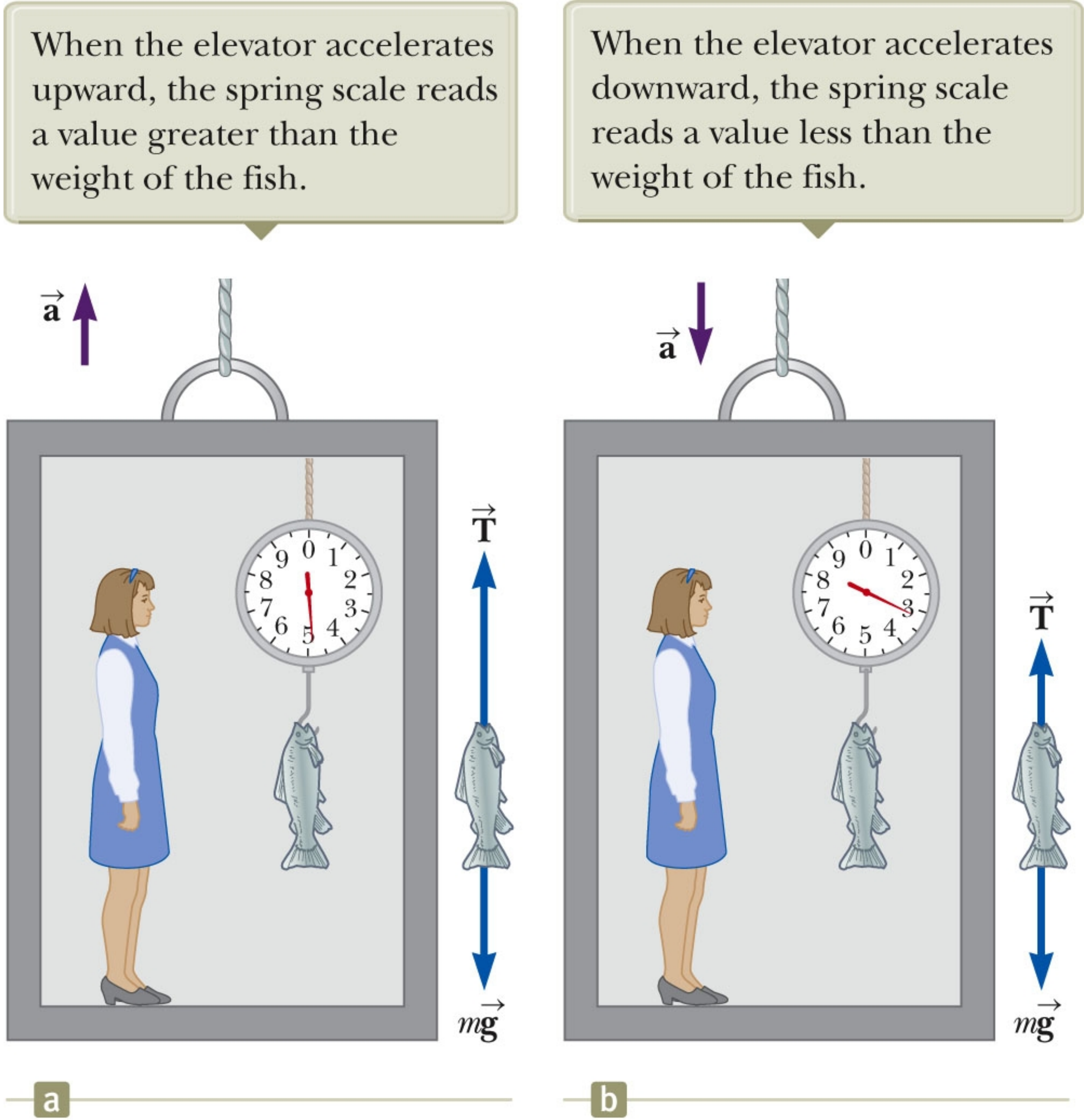

When the elevator accelerates upward, the spring scale reads a value greater than the weight of the fish.
When the elevator accelerates downward, the spring scale reads a value less than the weight of the fish.
$\vec{a}$
$\vec{T}$
$m\vec{g}$
0 1 2 3 4 5 6 7 8 9
a
$\vec{a}$
$\vec{T}$
$m\vec{g}$
0 1 2 3 4 5 6 7 8 9
b

Fig. 5.13, p. 119

# 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 $2^{nd}$ 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.

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

Examples)
If $m_{fish}$ = 3 kg, find
$W_{apparent}$ for …

a) a=0

$F_{net} = ma$

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

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

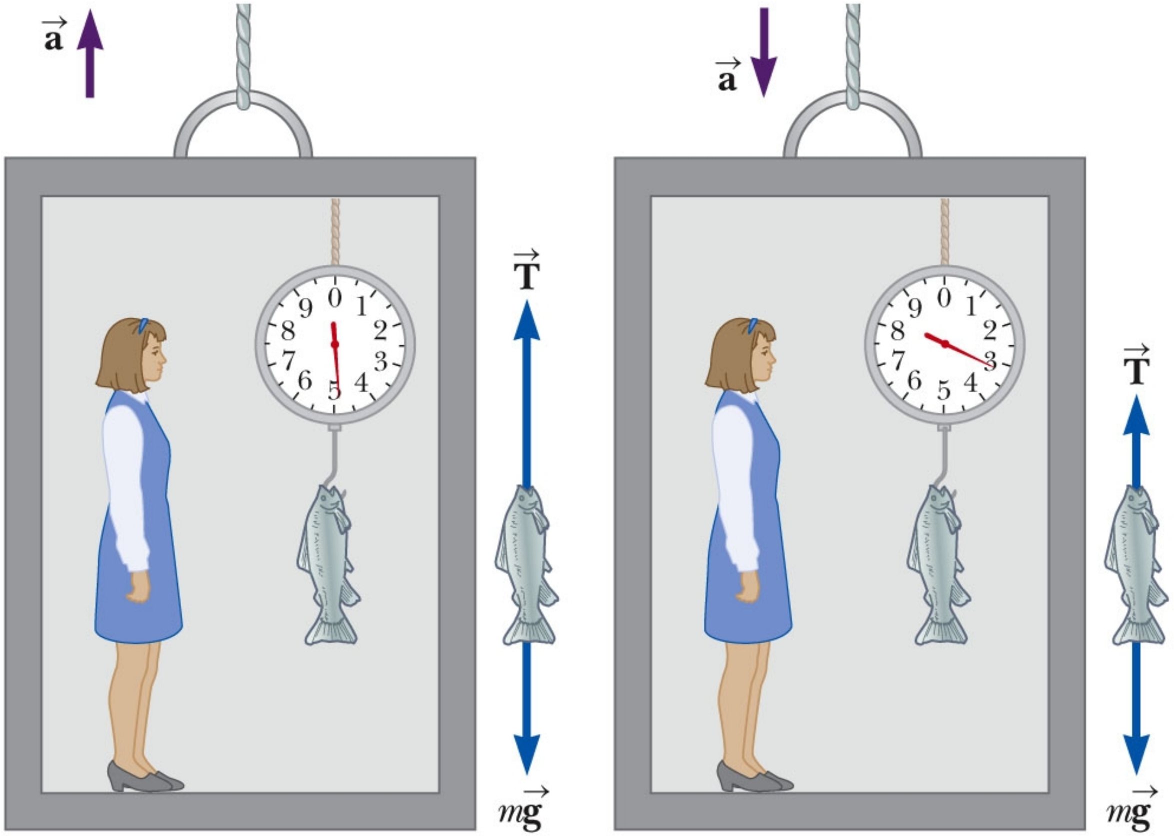
b) $a = 3\ m/s^2\ \hat{j}$

$W_{app}+F_g = ma$

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

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

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




c) $a = -3\ m/s^2\ \hat{j}$
(You try!)
$W_{app}$=20.4 N $\hat{j}$

Fig. 5.13, p. 119

# 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.

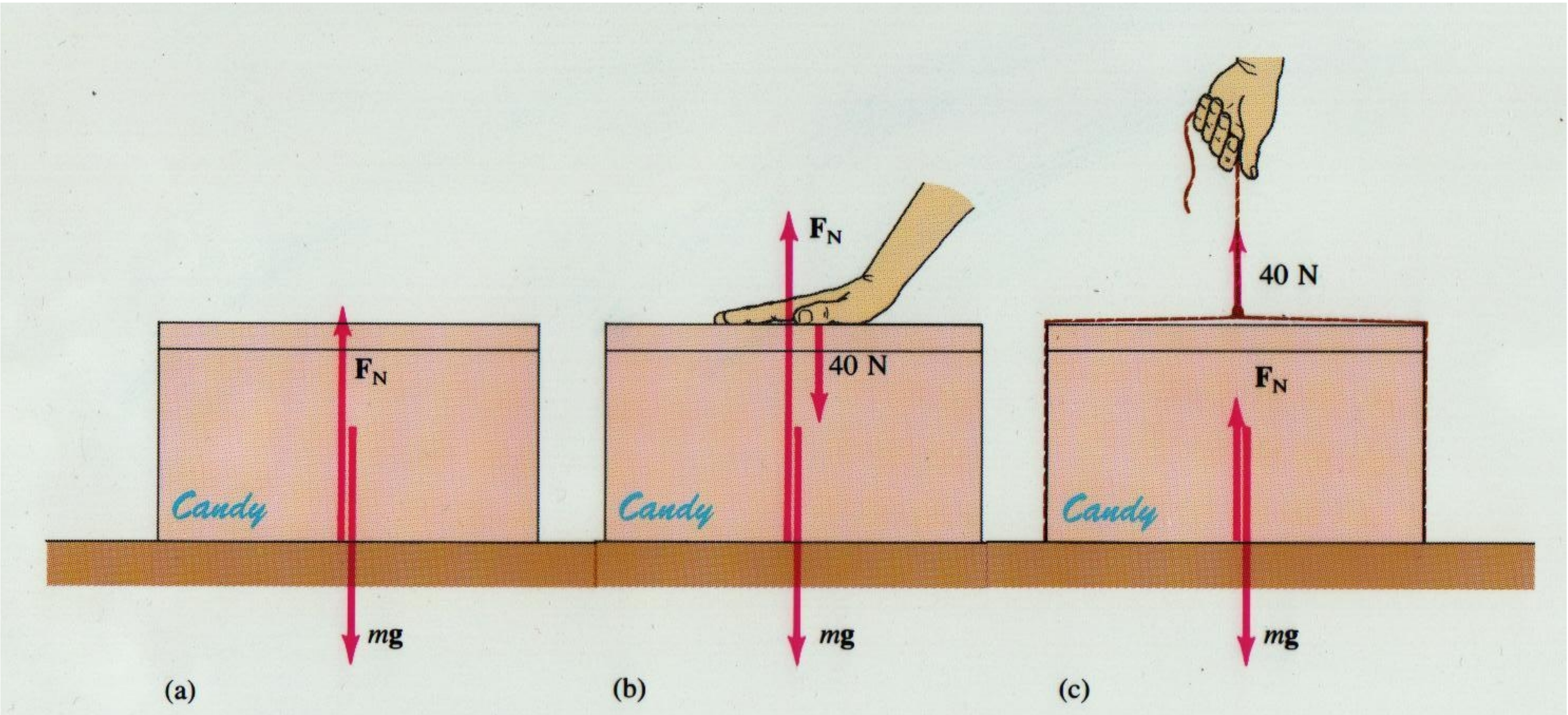
# Notes: "NEW STUFF" now has Ch. 4 key and

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 kg and the box remains stationary. (Use g=10 m/s$^2$)




$$F_{net} = F_N + F_g$$

$$F_N = 50\ N\,\hat{\jmath}$$

$$F_{net} = F_H + F_N + F_g$$

$$F_N = 90\ N\,\hat{\jmath}$$

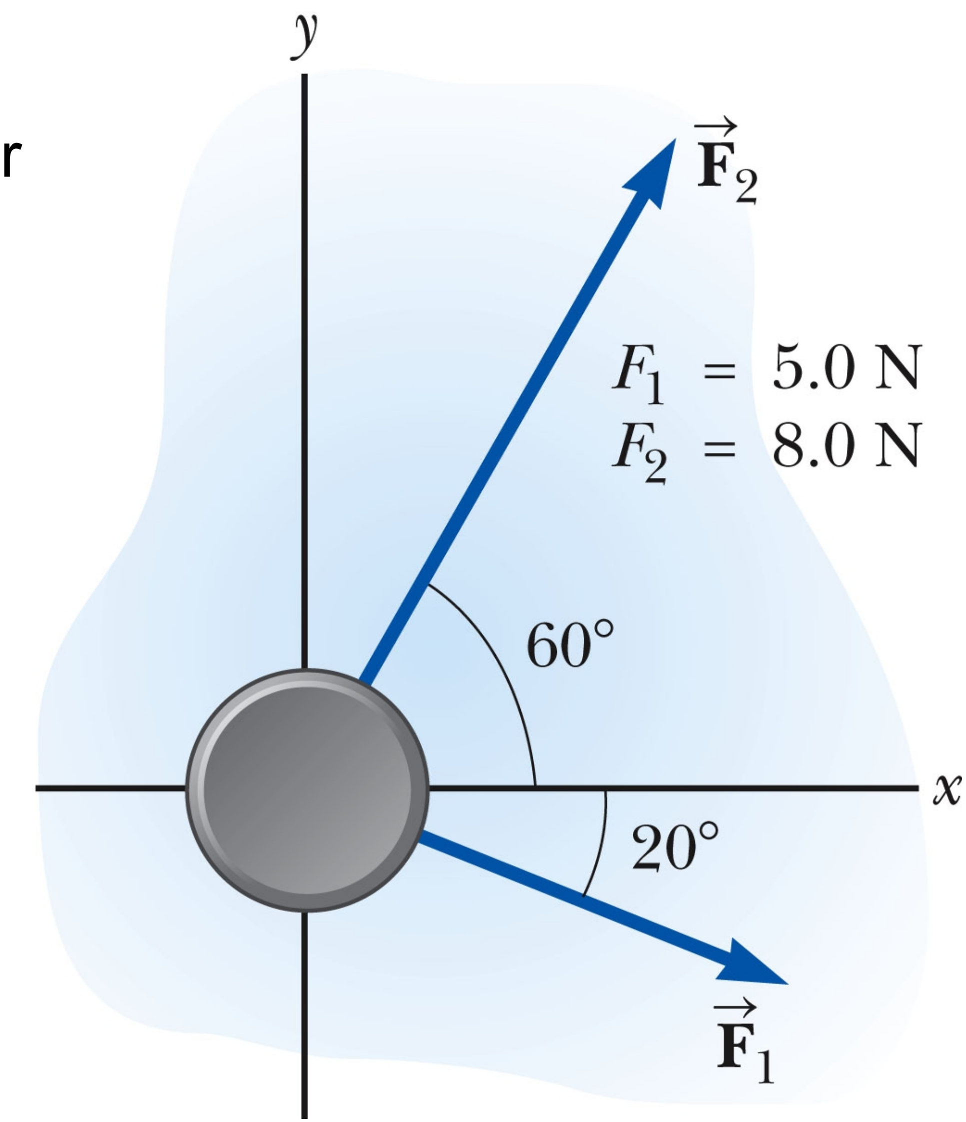
$$F_{net} = F_H + F_N + F_g$$

$$F_N = 10\ N\,\hat{\jmath}$$

# 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

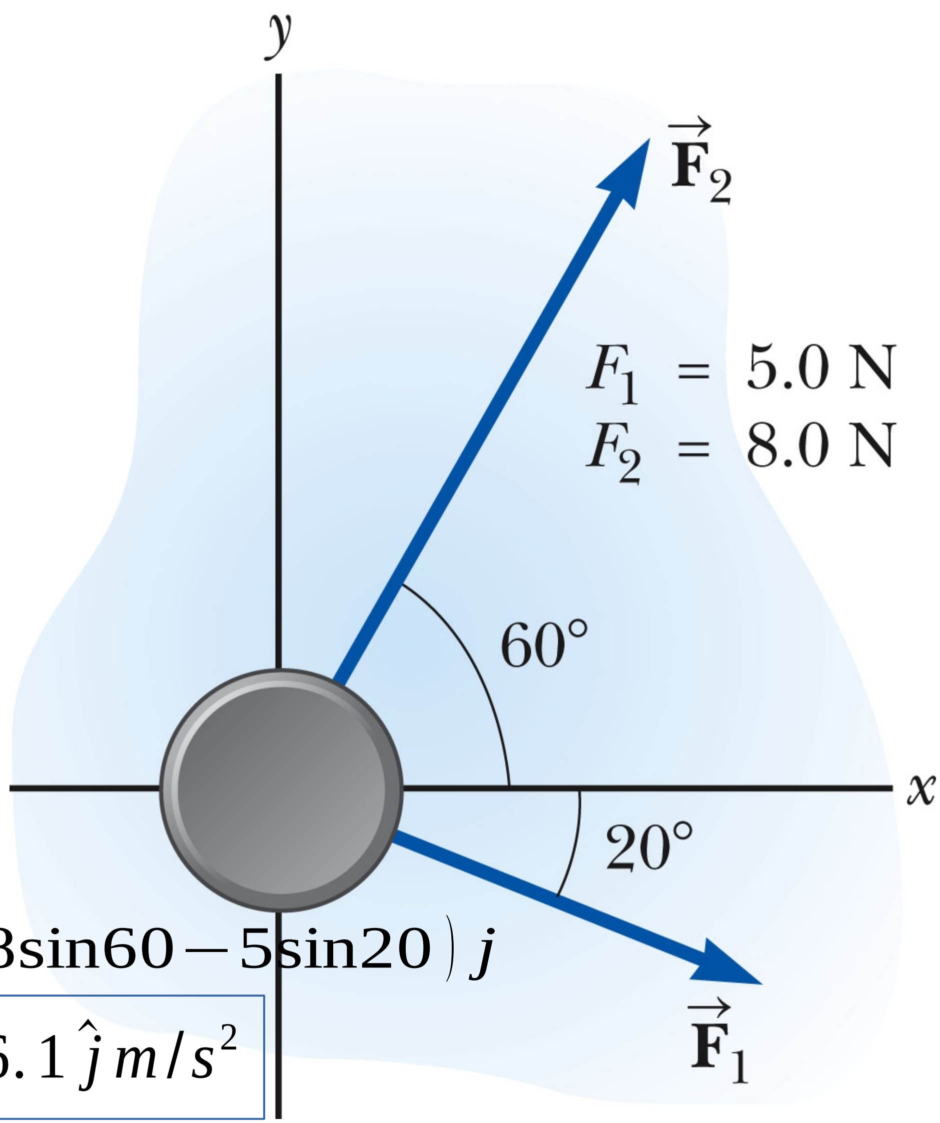
## Puck on frictionless ice

Find the acceleration vector for the 0.2 kg hockey puck.

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

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

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



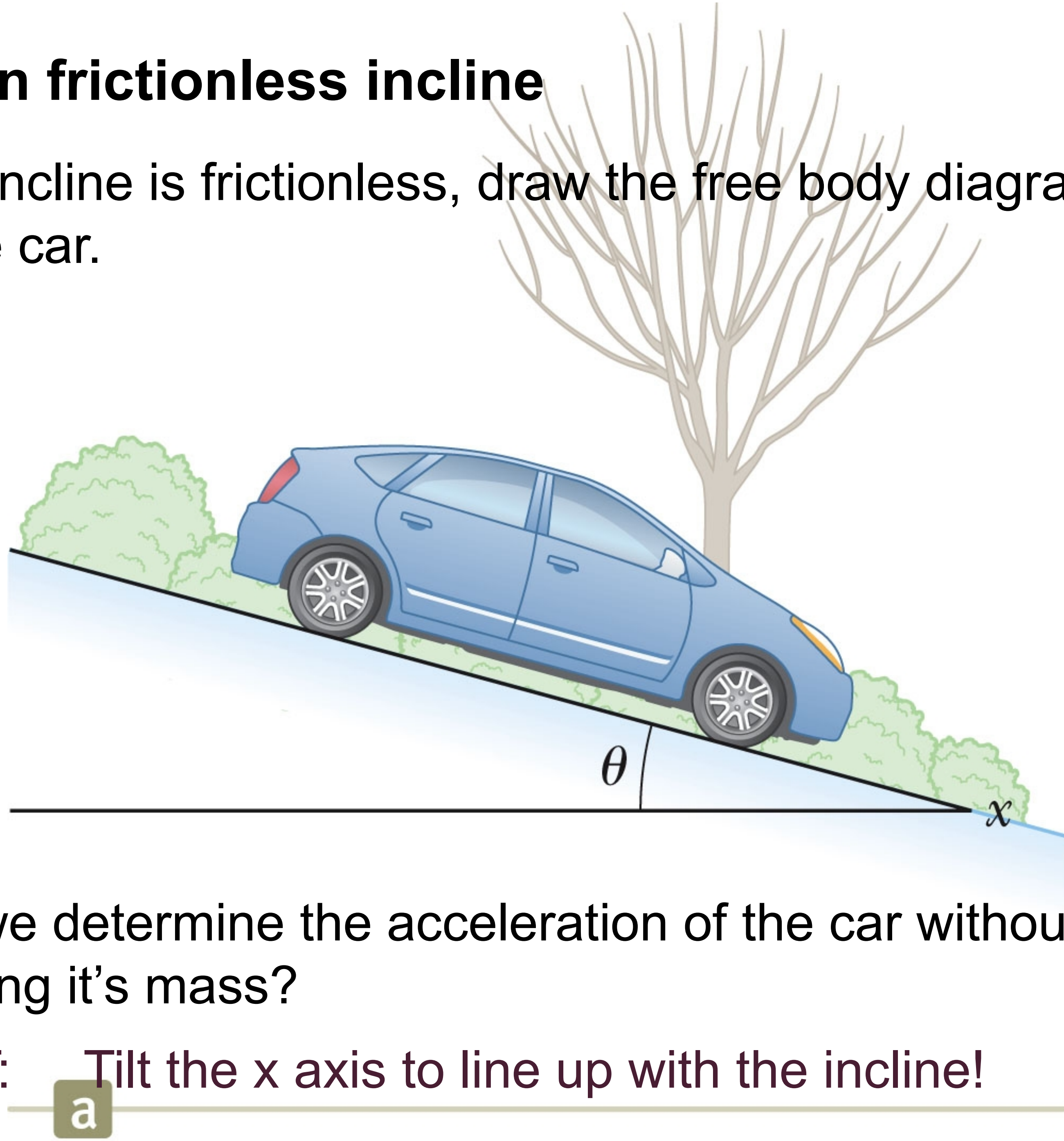

$$\vec{F}_{1+2} = (8\cos 60 + 5\cos 20)\,i + (8\sin 60 - 5\sin 20)\,j$$

$$\vec{a} = \frac{\vec{F}_{1+2}}{0.2\,kg}$$

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

# Car on frictionless incline

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



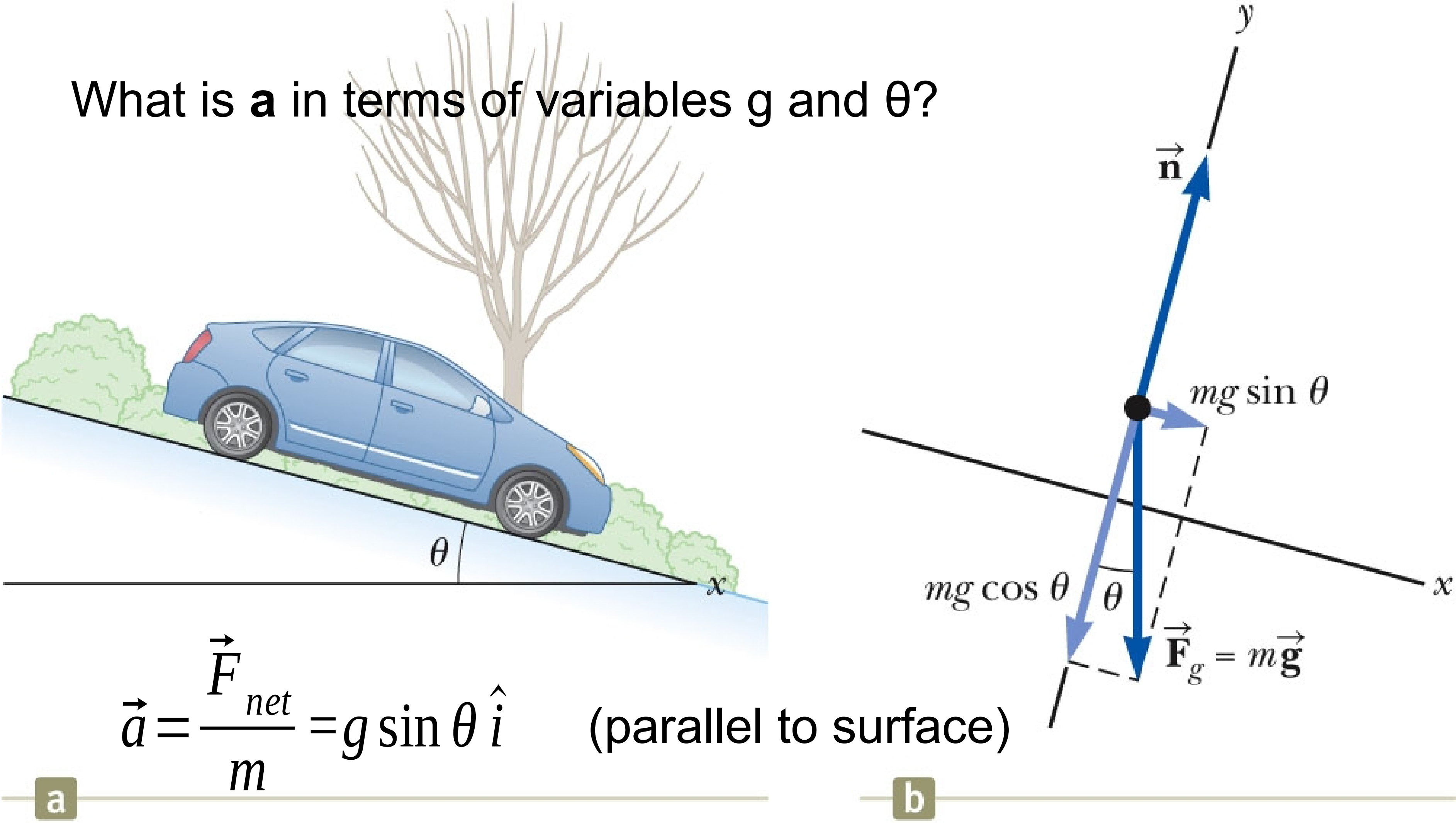

Can we determine the acceleration of the car without knowing it's mass?

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

Fig. 5.11, p. 116

# Car on frictionless incline

What is **a** in terms of variables g and θ?

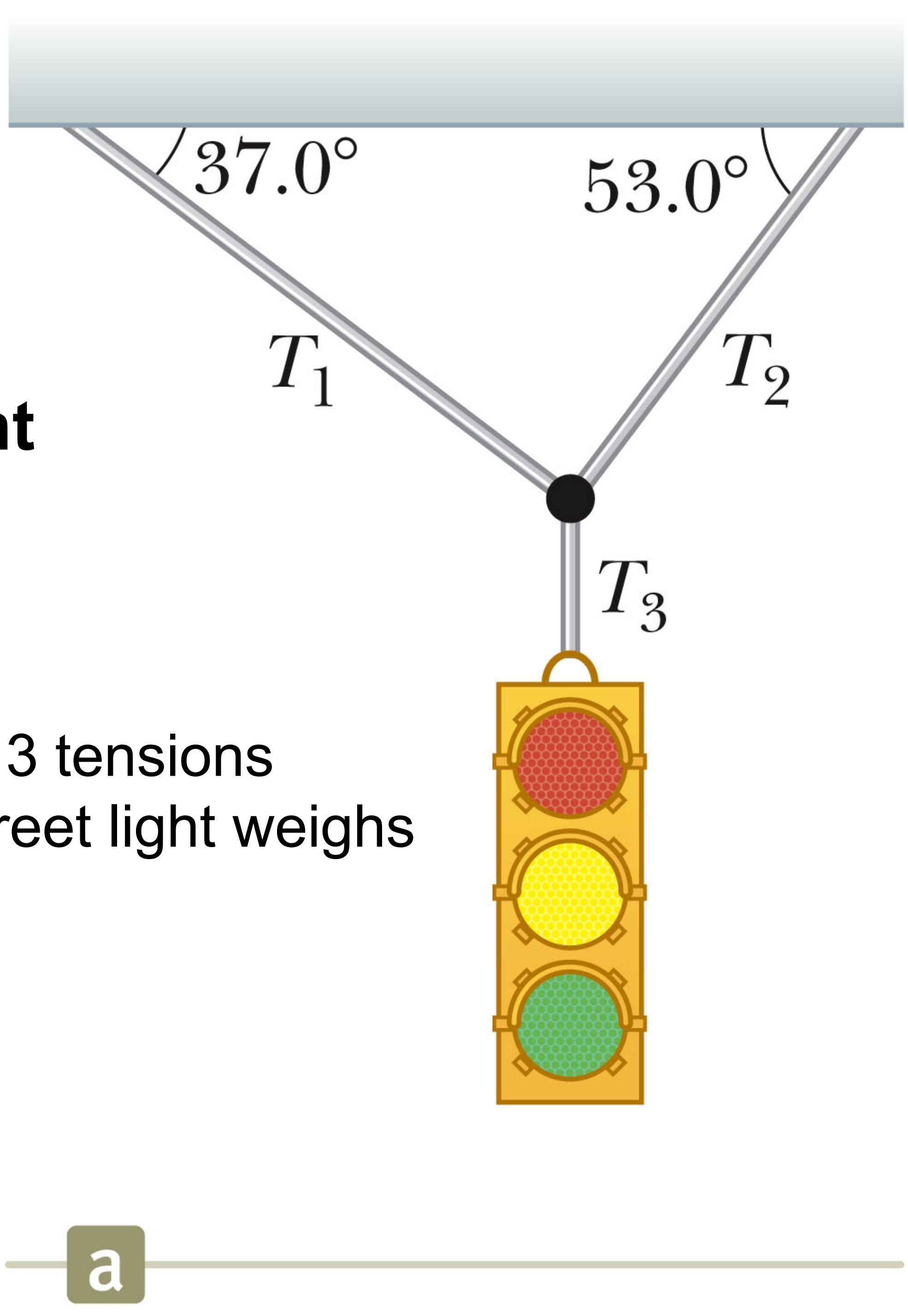



$$\vec{a} = \frac{\vec{F}_{net}}{m} = g \sin\theta \, \hat{i}$$ (parallel to surface)

What is **a** if g=9.8 and θ = 30°?

Fig. 5.11, p. 116

# Street light




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

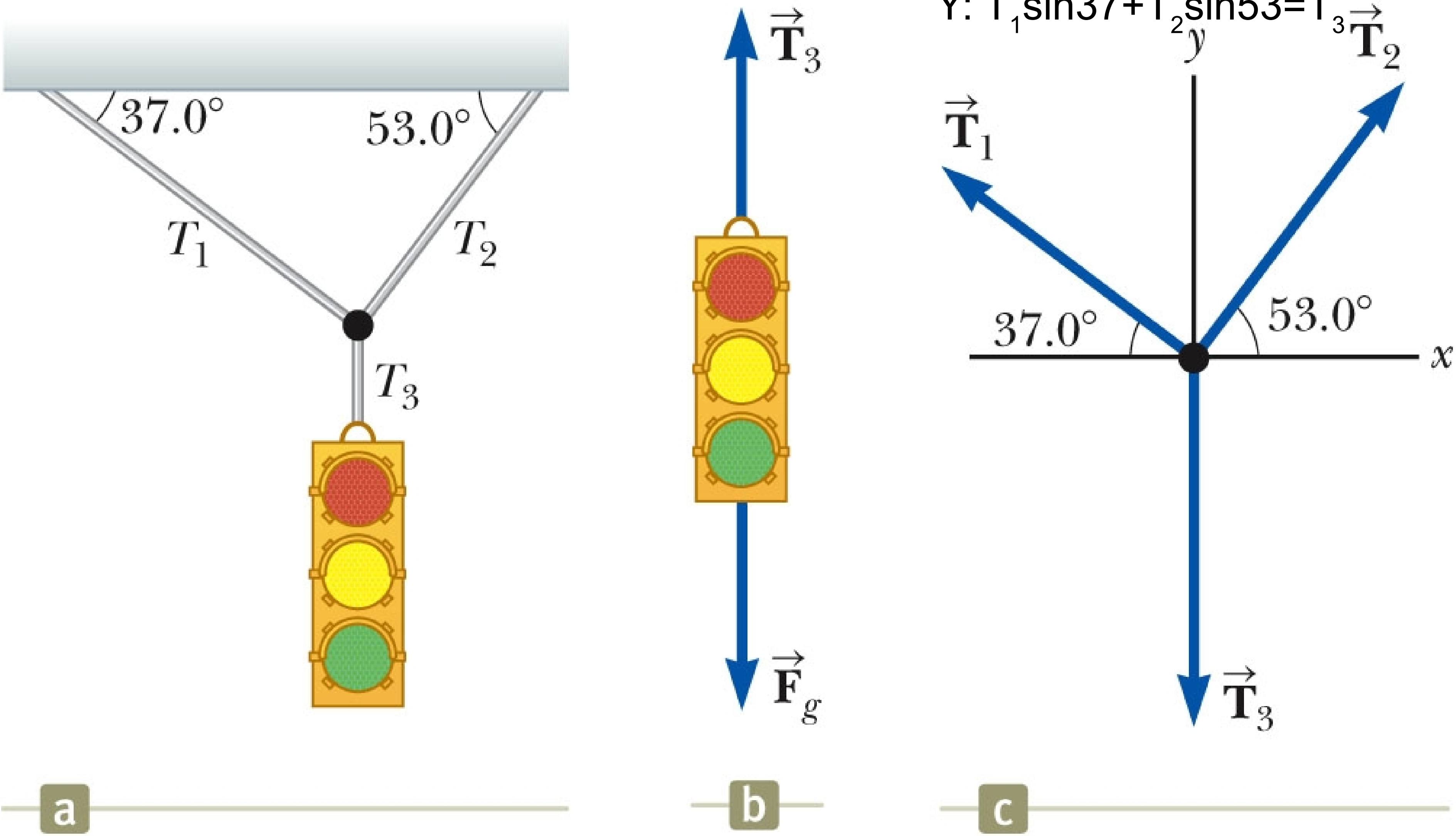
Fig. 5.10, p. 114

$$\mathbf{T}_1+\mathbf{T}_2+\mathbf{T}_3=0$$

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

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

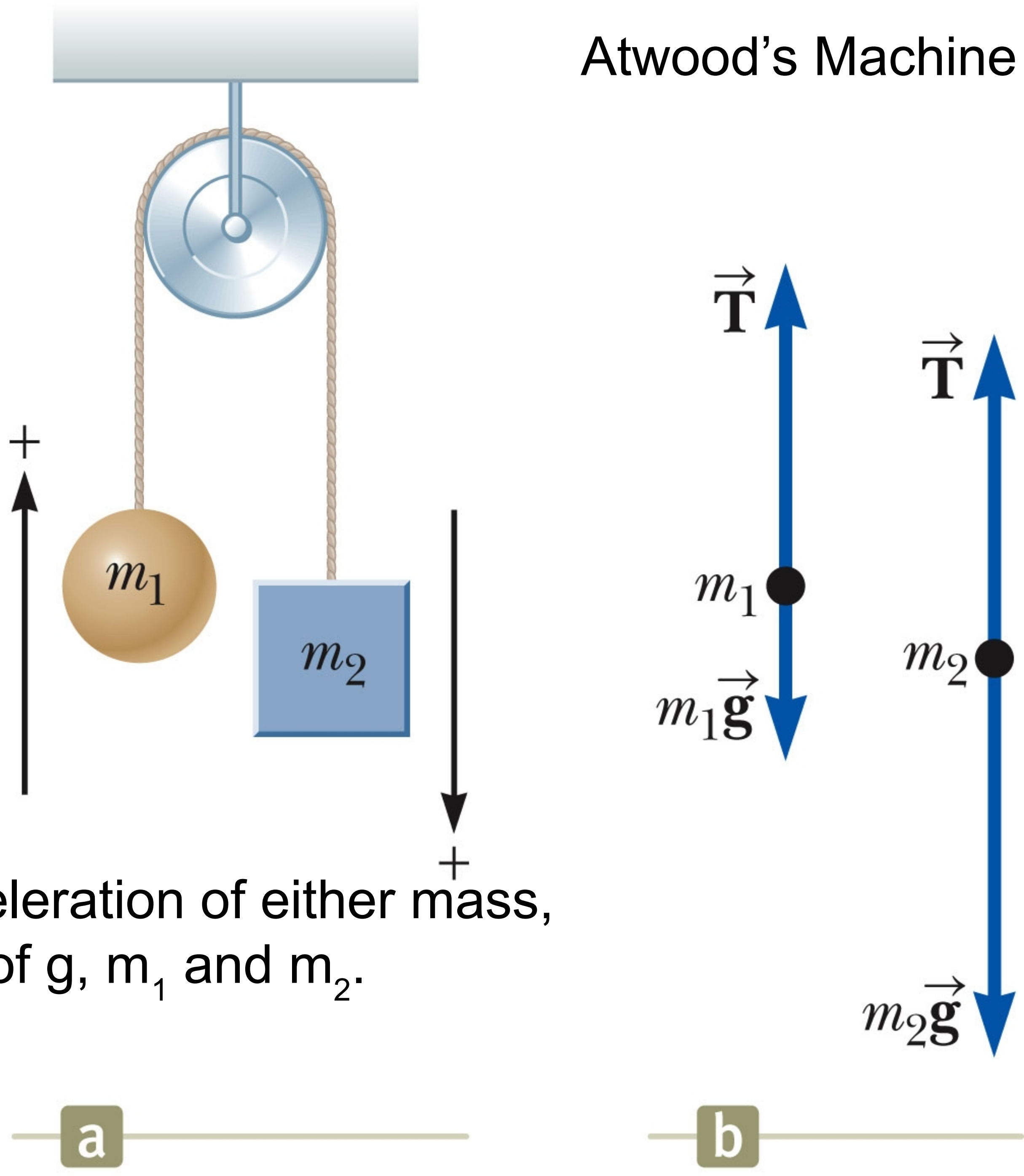
Y: $T_1\sin 37+T_2\sin 53=T_3$




Substitute $T_1=T_2(\cos 53/\cos 37)$ into “Y:” equation ...

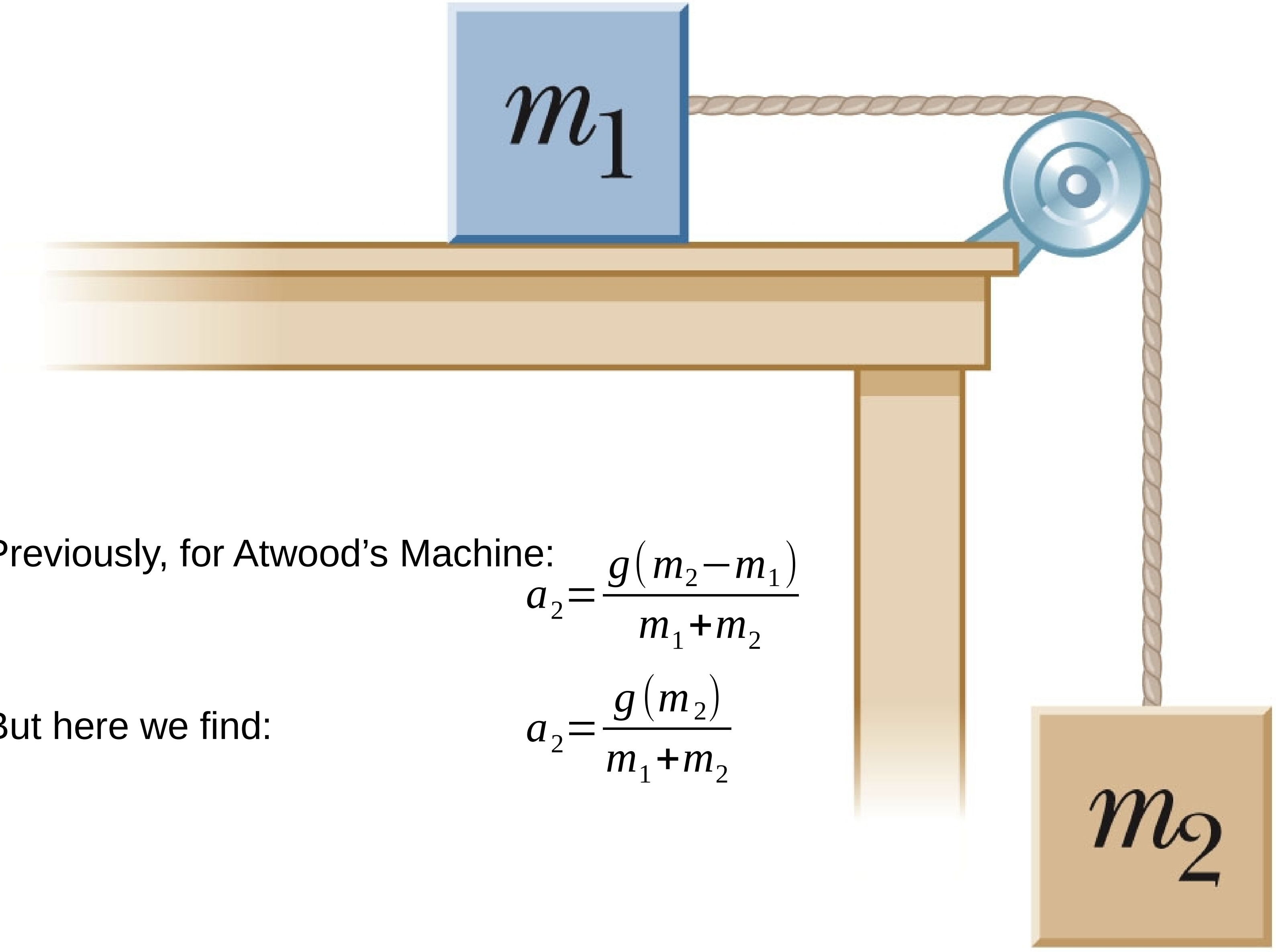
**Fig. 5.10, p. 114**

# Atwood's Machine




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

**Fig. 5.14, p. 120**




Previously, for Atwood's Machine:

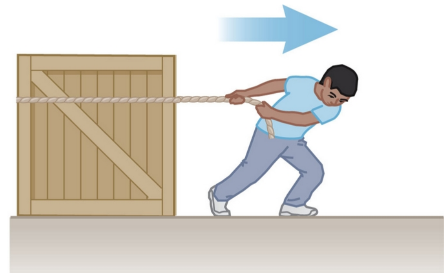
$$a_2 = \frac{g(m_2 - m_1)}{m_1 + m_2}$$

But here we find:

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

Fig. P5.28, p. 133

# Friction



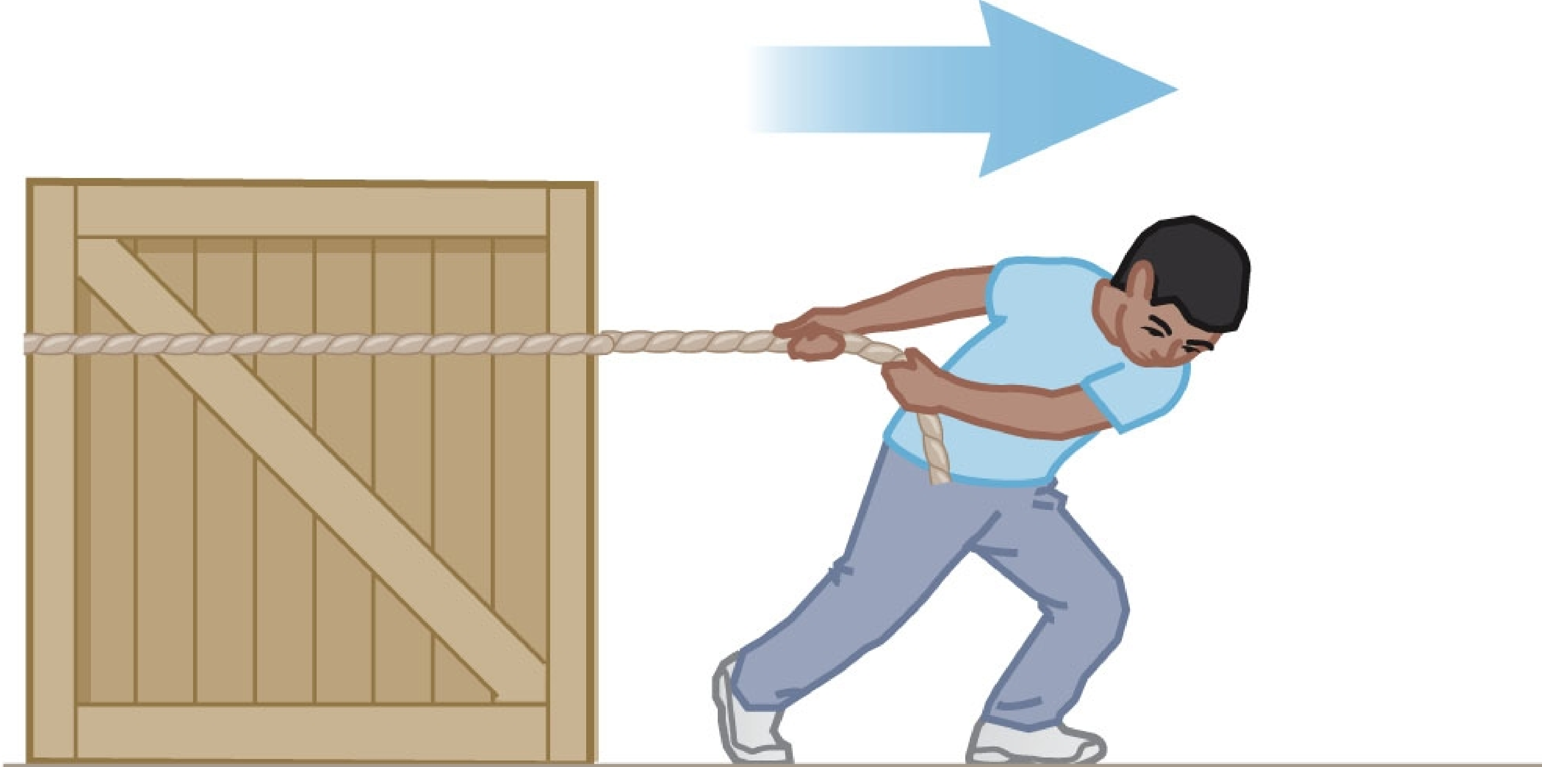
Kinetic friction: a force acting between two objects sliding against each other which opposes their direction of motion.

* $f_k = \mu_k F_N$ where $\mu_k$ = 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 $\mathbf{f}_k$ is opposite the $\boldsymbol{v}$ 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 $\mu_s$ = coefficient of static friction.
* $f_s = \text{Fapplied until Fapplied reaches } f_{s,max}$, then slippage occurs.

Fig. 5.8, p. 113



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?

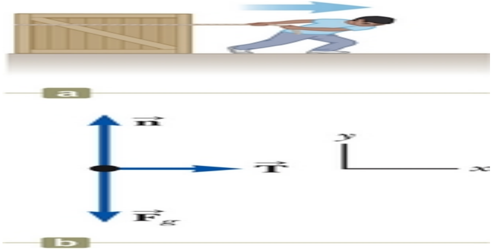
Ans: $F_{boy} = f_{s,max} = \mu_s F_N = \mu_s\, 90*9.8 = 353$ N

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

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

a

5.8, p. 113



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

Q: What is the $\mathbf{f}_s$ on the box when it's stationary and $\mathbf{F}_{applied} = 250$ N to the right?

Ans: $\mathbf{f}_s = -\mathbf{F}_{applied} = -250\text{ N }\hat{\imath}$

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

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

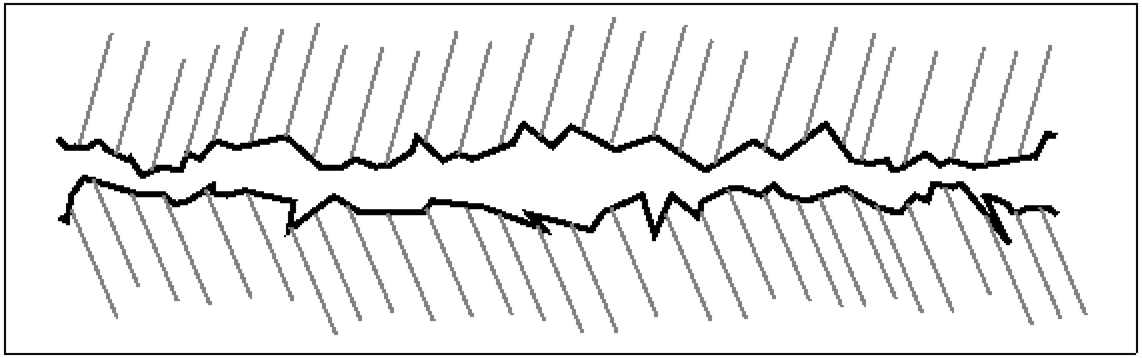
Q: What is the acceleration of the box if $\mathbf{F}_{app} = 170\text{ N}\hat{\imath}$ and the box is sliding to the right?

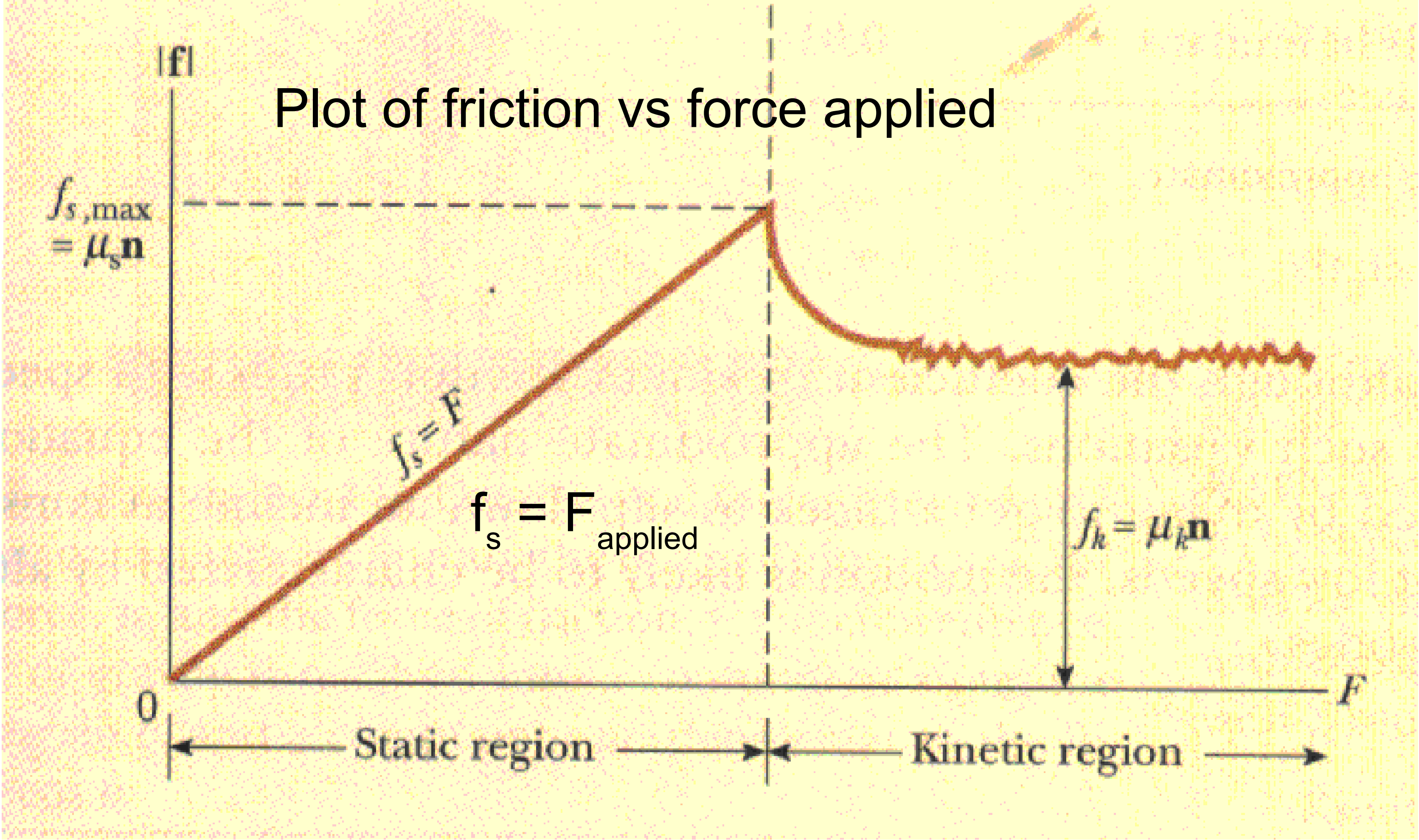
Ans: $\mathbf{a} = \mathbf{F}_{net}/m = (F_{app} - f_k)/m = (170-176)/90\text{kg} = -.067\text{m/s}^2\hat{\imath}$.

Fig. 5.8, p. 113

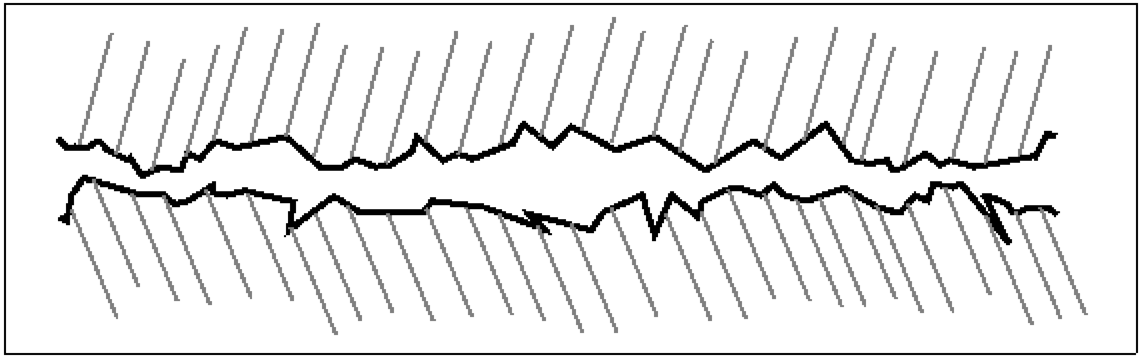
Why friction?

Take a close look:





Close-up of surfaces.



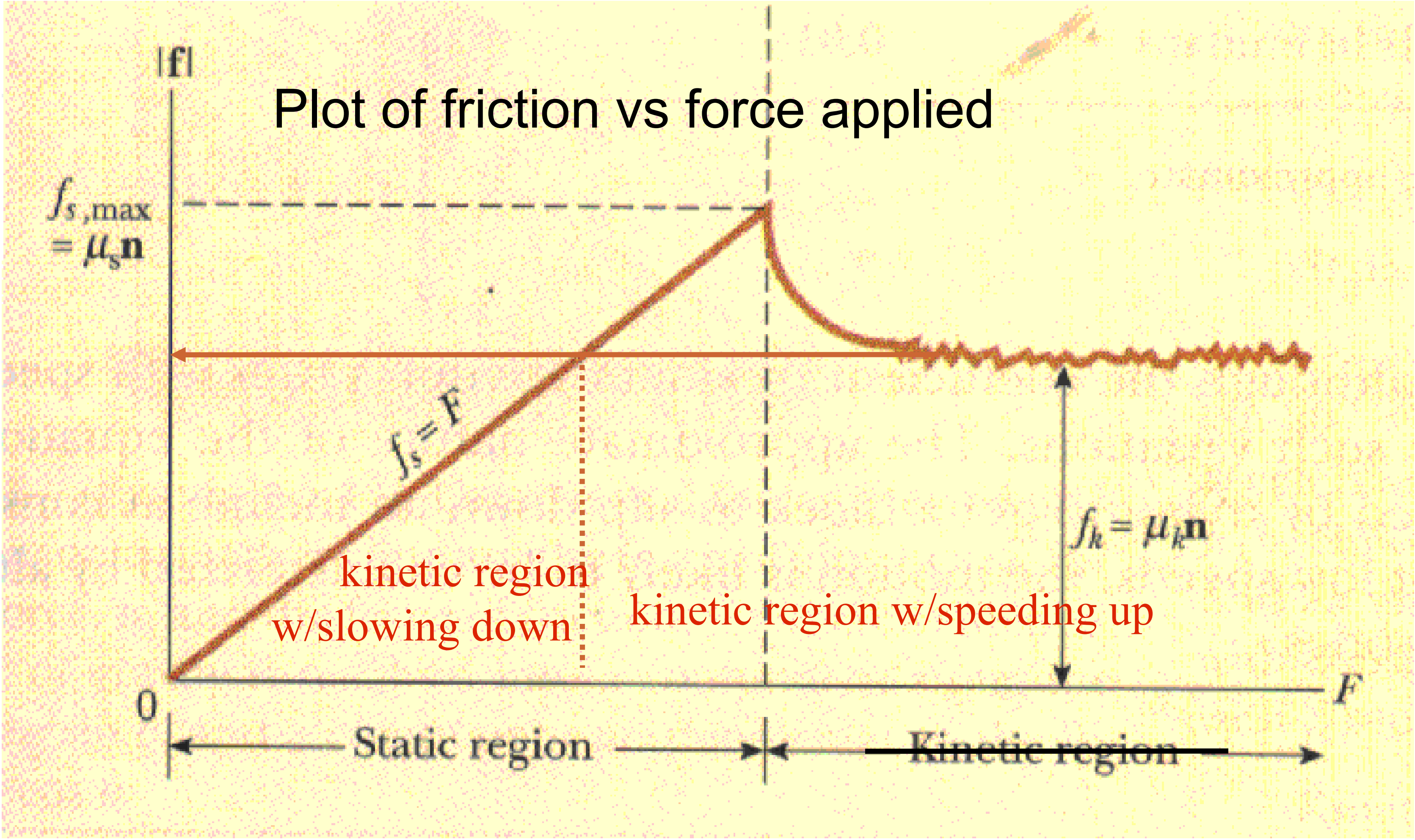
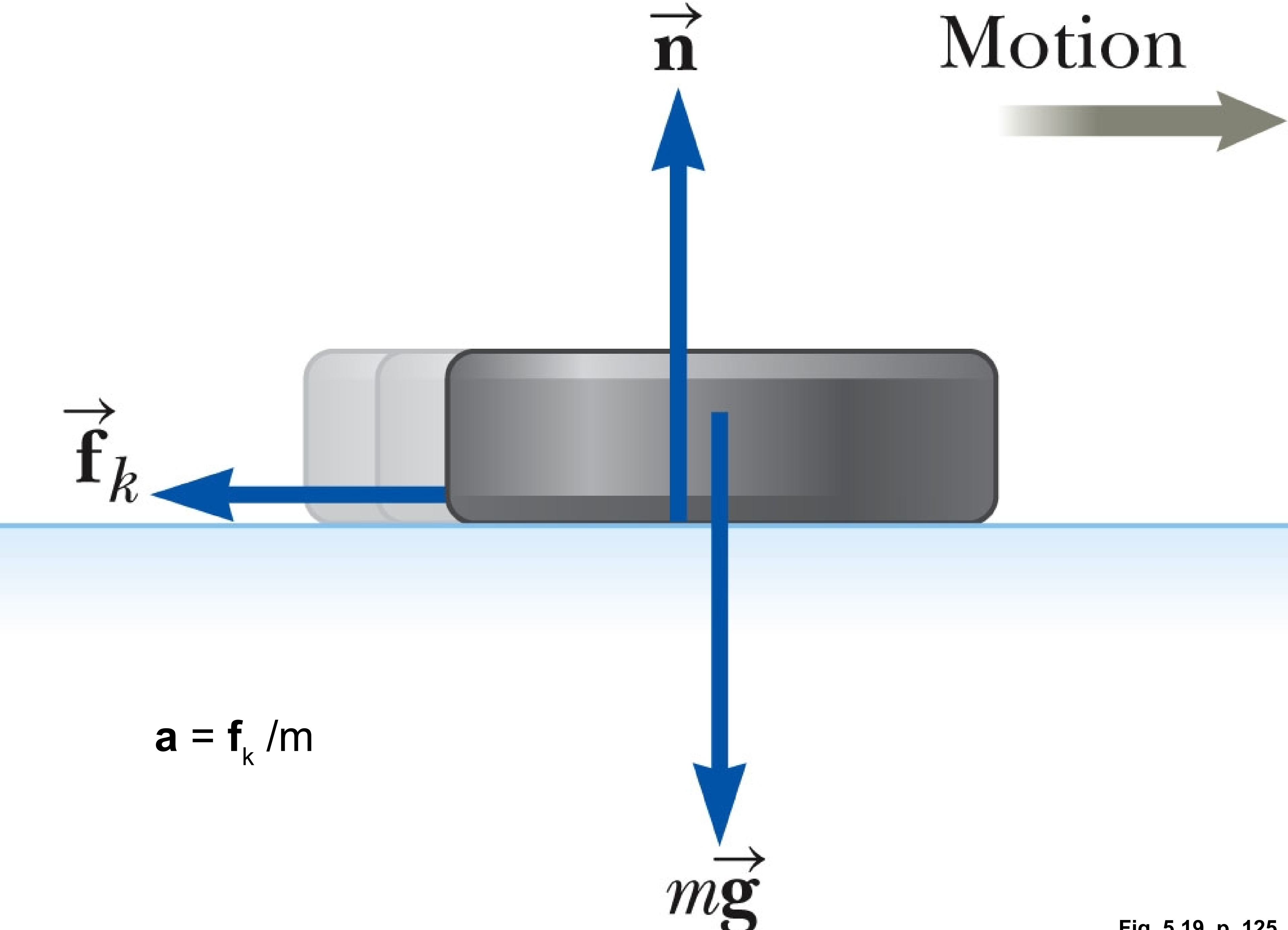


**TABLE 5.1** *Coefficients of Friction*

| | $\mu_s$ | $\mu_k$ |
|---|---|---|
| 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.




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

Fig. 5.19, p. 125

1) At which angle will the box start to slide, given $\mu_s$?

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

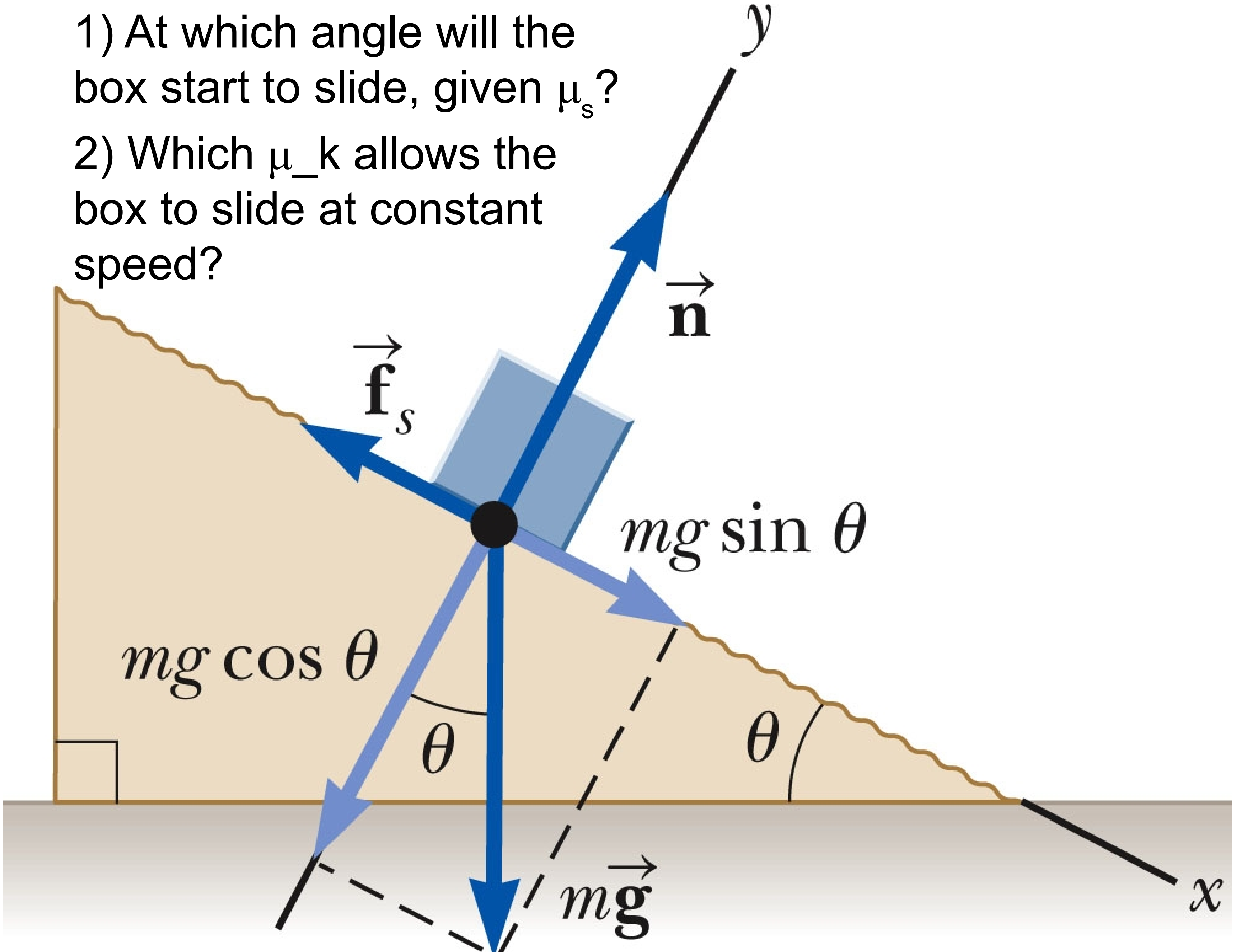
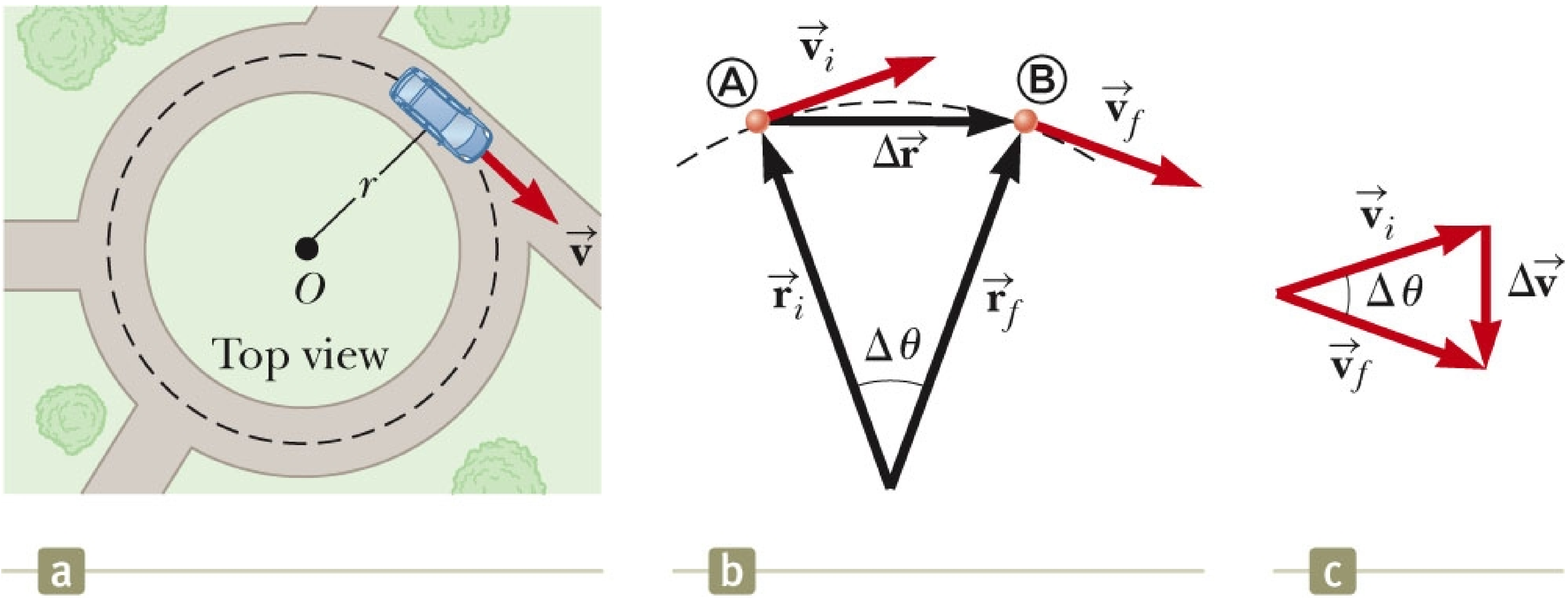



Fig. 5.18, p. 124

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




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

Note: time to make one cycle = period = T = circumf/speed

$T = 2\pi r/v$

Fig. 4.15, p. 86

# 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
a) the centripetal acceleration of the child and
b) the net horizontal force exerted on the child (m=22.5 kg).

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

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

c) What provides the $F_c$?

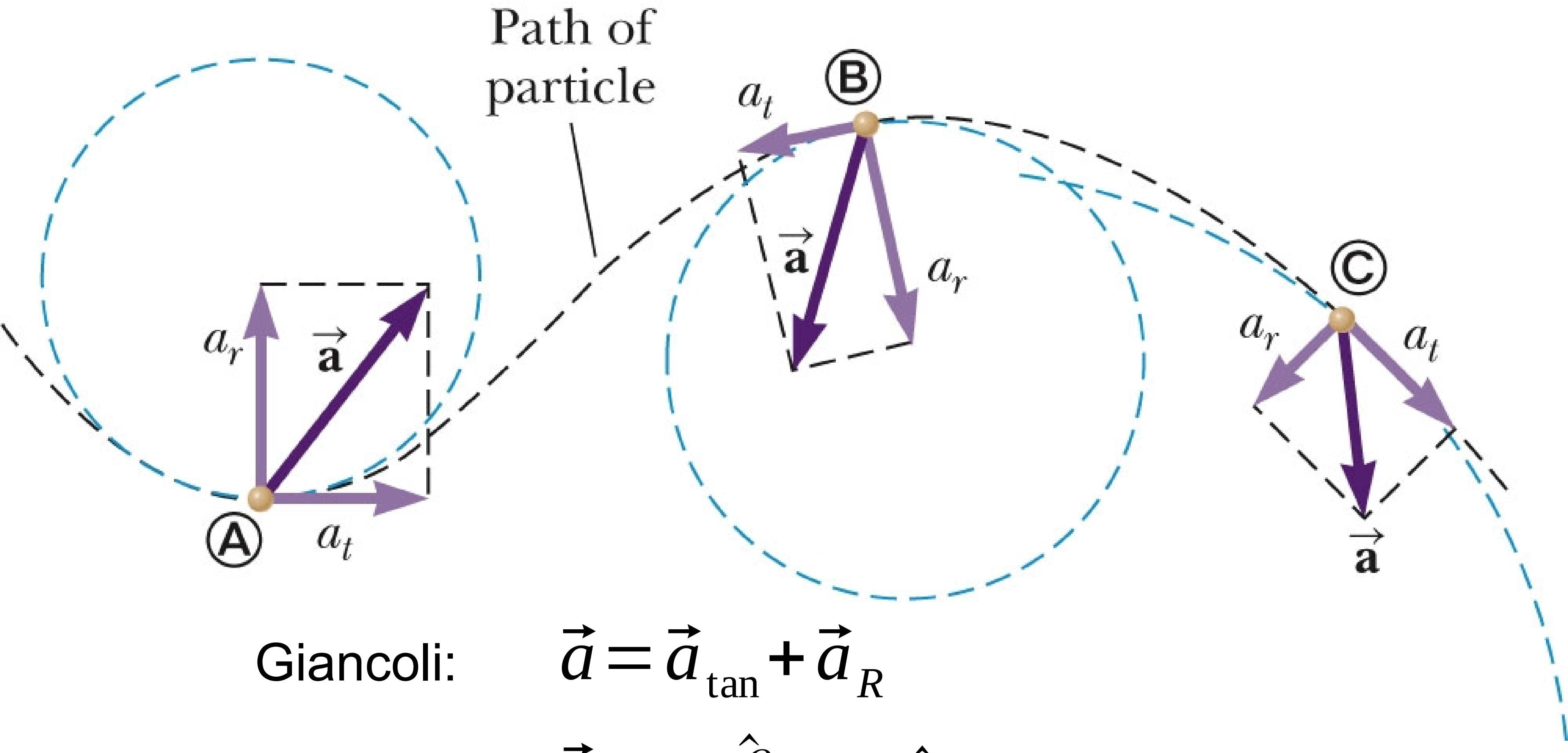
Ans: static friction, $f_s$=27.2 N

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

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

Fig. 4.15, p. 86

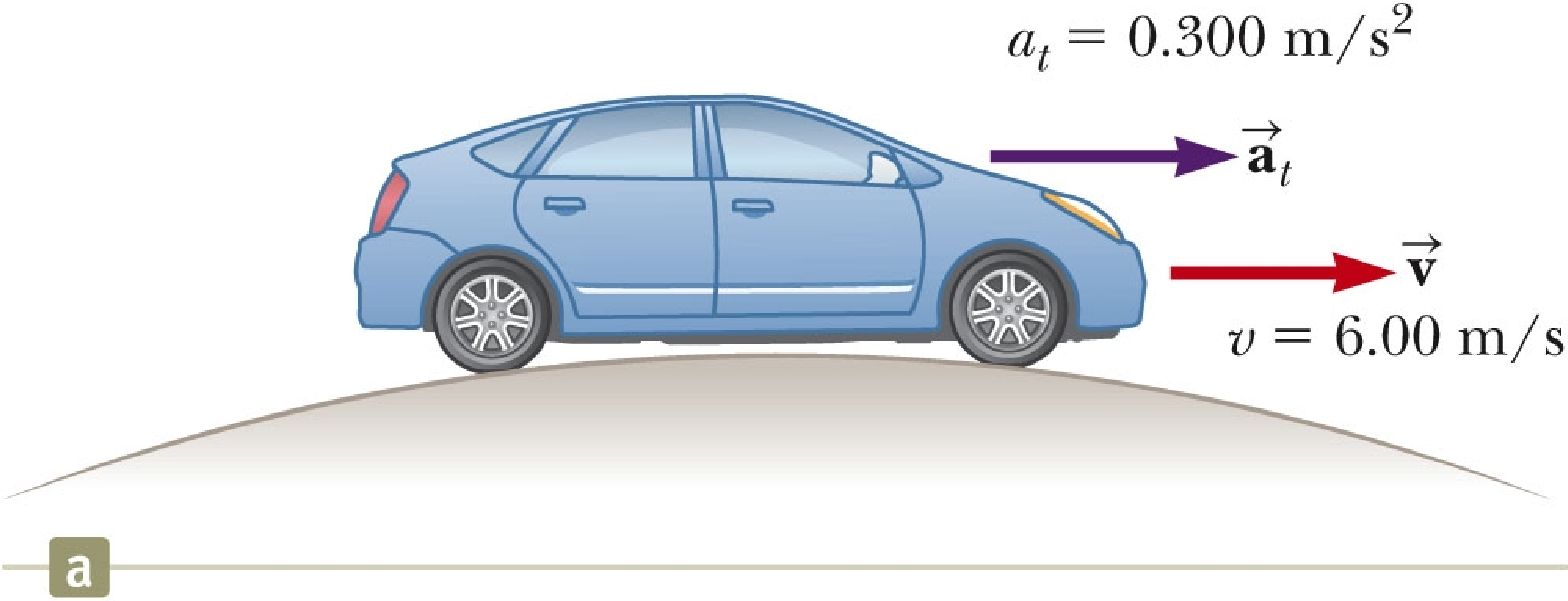
# Total acceleration – sum of tangential and centripetal components




Giancoli: $$\vec{a} = \vec{a}_{\tan} + \vec{a}_R$$

$$\vec{a} = a_t\,\hat{\theta} - a_r\,\hat{r}$$ with $a_r = v^2/r$

Fig. 4.16, p. 88



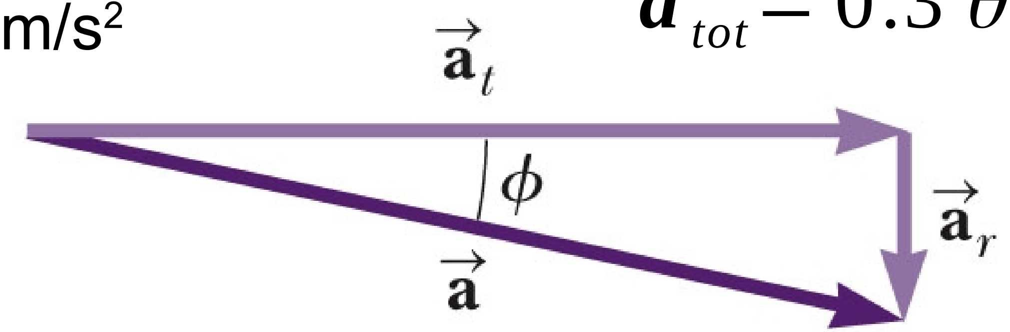

Q: Find $\mathbf{a}_{tot}$ if $r_{hill}$ = 25 m.

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

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

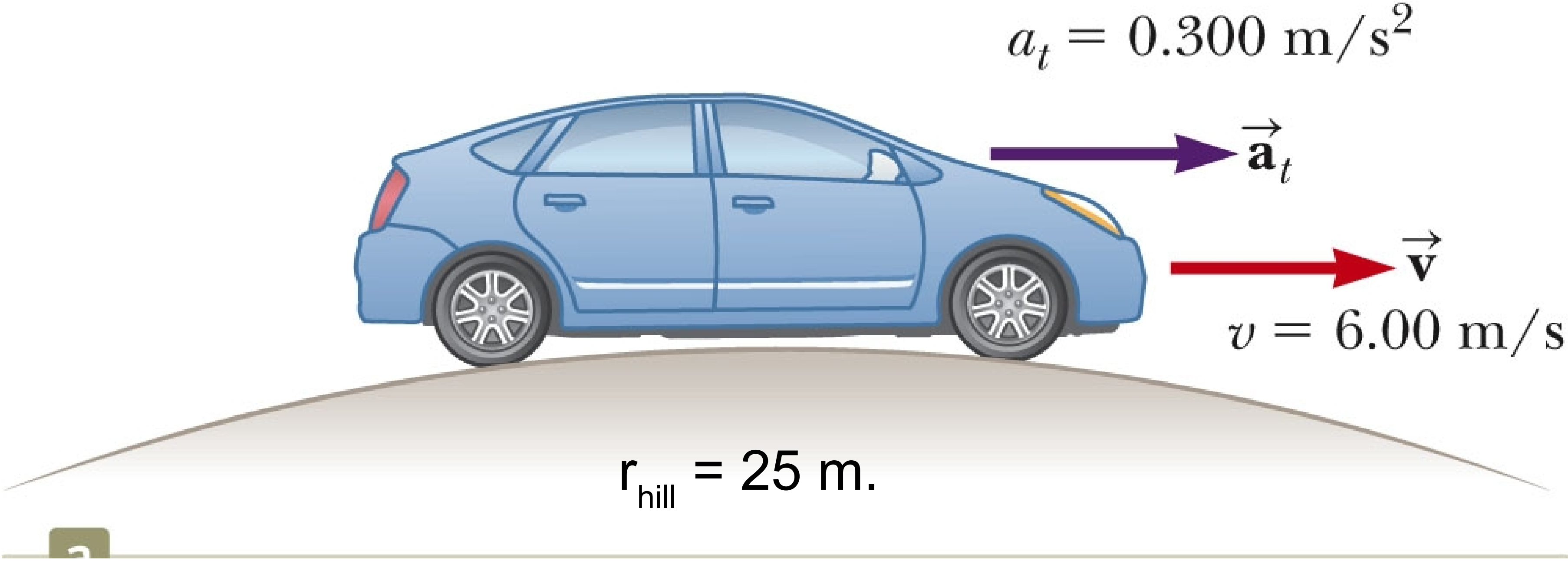
$$\vec{a} = a_t\,\hat{\theta} - a_r\,\hat{r}$$

$$\boldsymbol{a}_{tot} = 0.3\,\hat{\theta} - 1.44\,\hat{r}$$




b

Fig. 4.17, p. 89




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 Fg = Fc

$$mg = mv^2/r$$
$$(gr)^{1/2} = v$$
$$(9.8*25)^{1/2} = v$$
$$v = 15.7 \text{ m/s} \quad (35 \text{ mph})$$

**Fig. 4.17, p. 89**