# Outline for Day W4,D2

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. Due Fri
Read 3.9 (rel motion)

## Notes: Lab this week: "Acceleration of Gravity"

"NEW STUFF" has new PPT, YouTube (FOR), exam-like problems for Ch. 3, rel. motion problems.

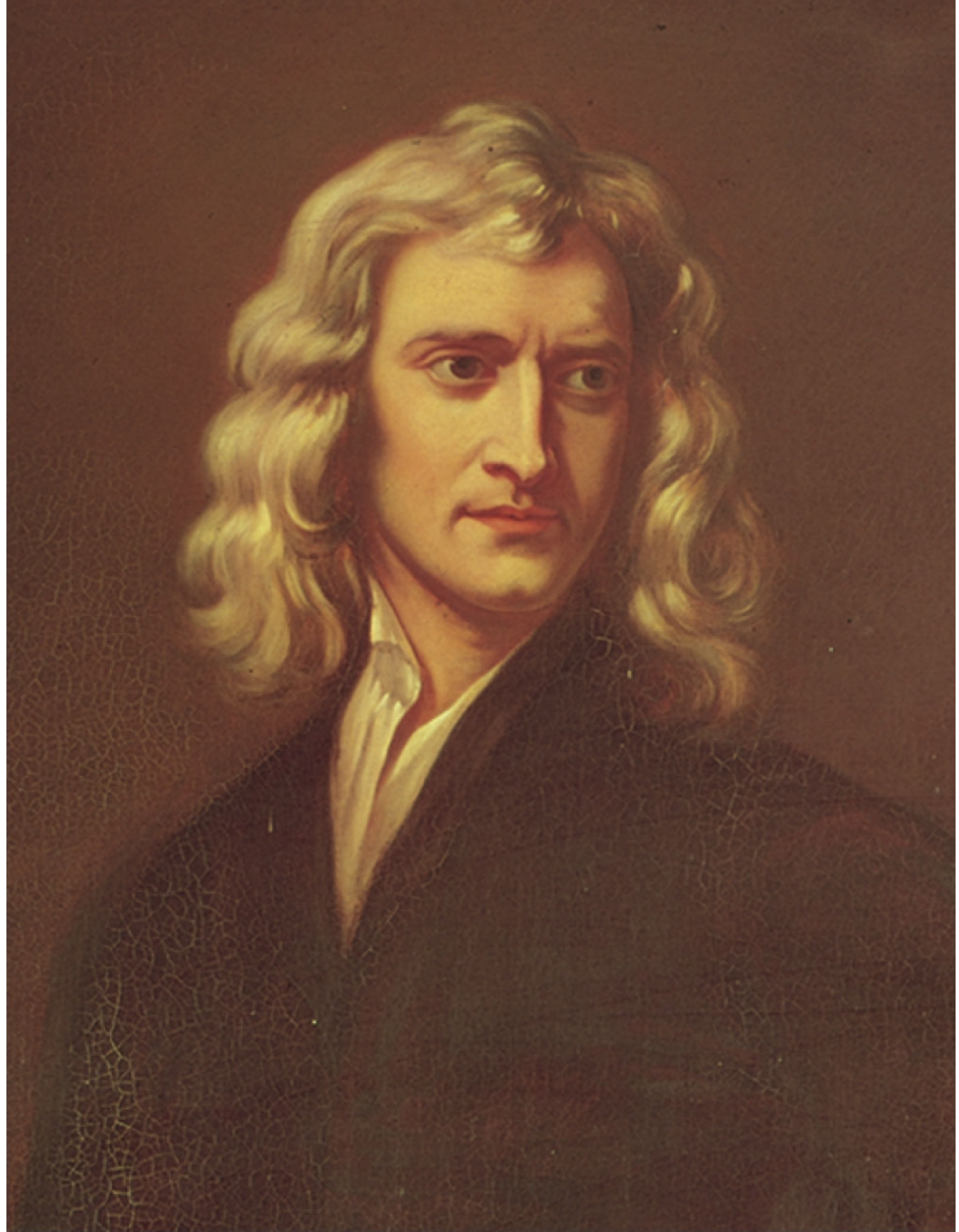
Exam I follows Chapter 5 material.

## Week 4-6 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

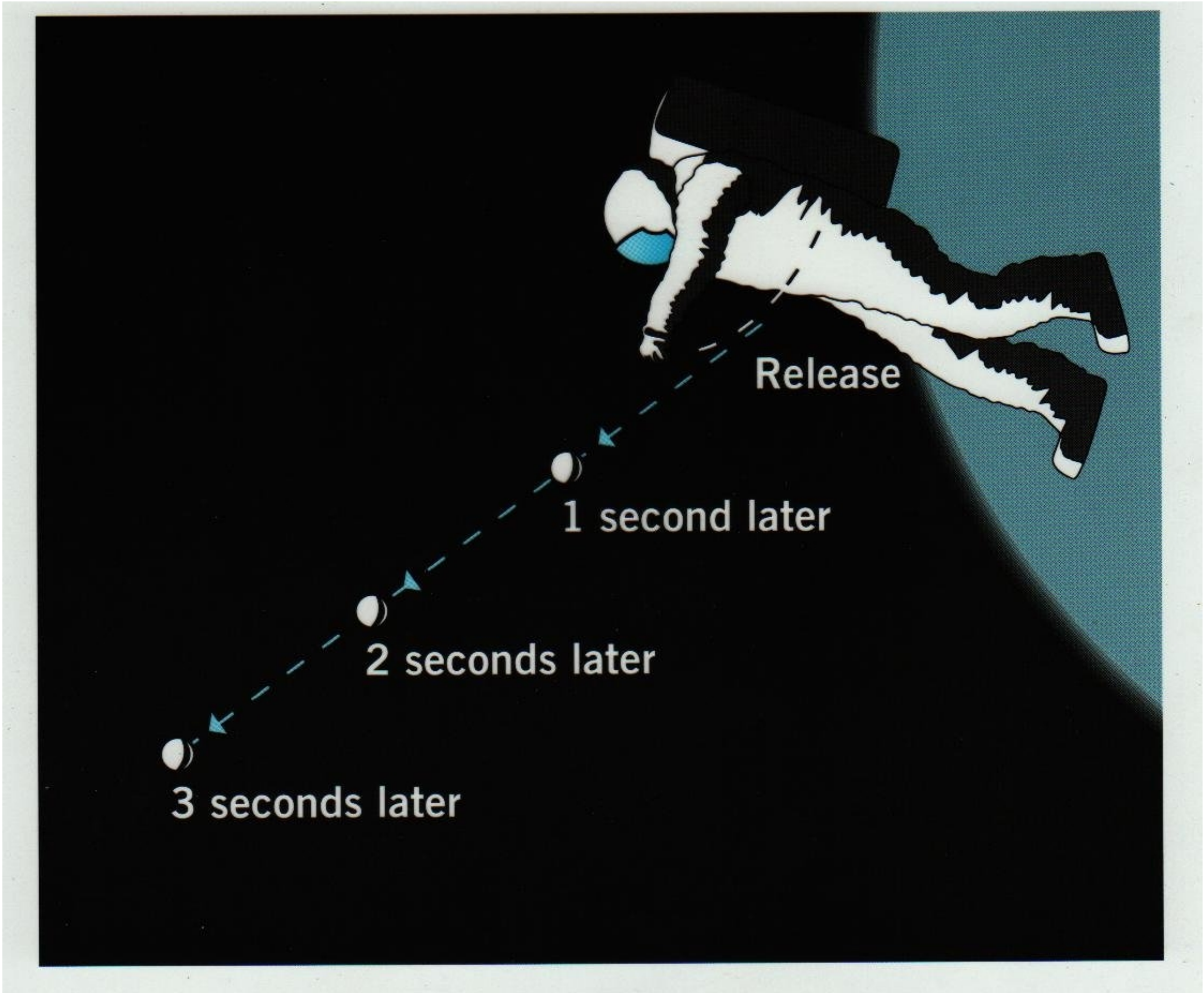
Newton's 1st law = inertial frames of reference exist such that an object will move with a constant velocity if no forces act upon it.

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

Overthrows Aristotle and medieval ideas:

“natural state” is at rest

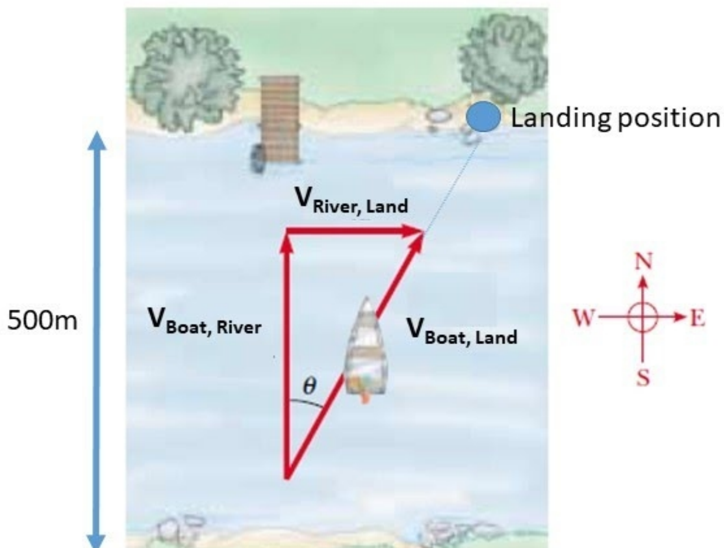
“impetus” pushes an arrow along



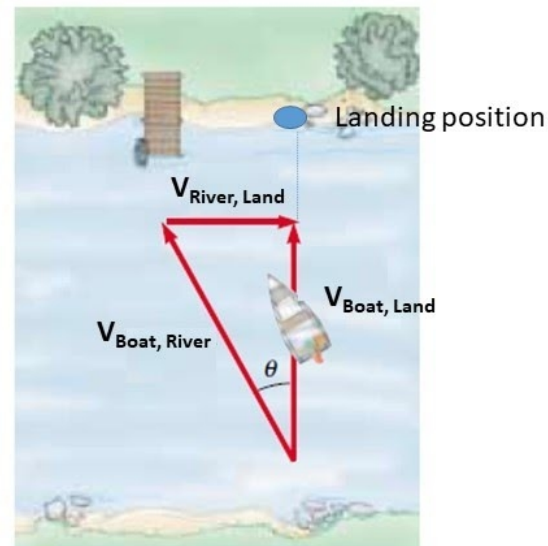
# Frames of reference and relative motion

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 $\mathbf{v}_{BL}$.

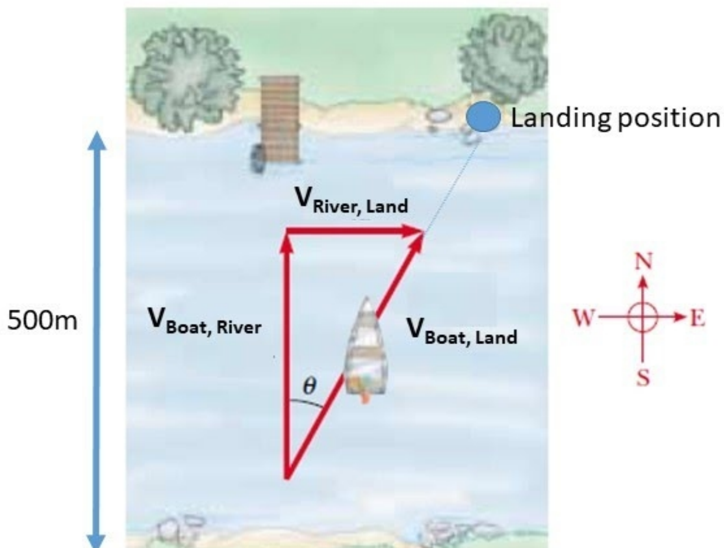
Find $\mathbf{v}_{BL}$. $\mathbf{v}_{BL} = \mathbf{v}_{BR} + \mathbf{v}_{RL} = 8\hat{\jmath} + 3\hat{\imath}$ , $|\mathbf{v}_{BL}|$=8.54 m/s, θ=20.6°

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

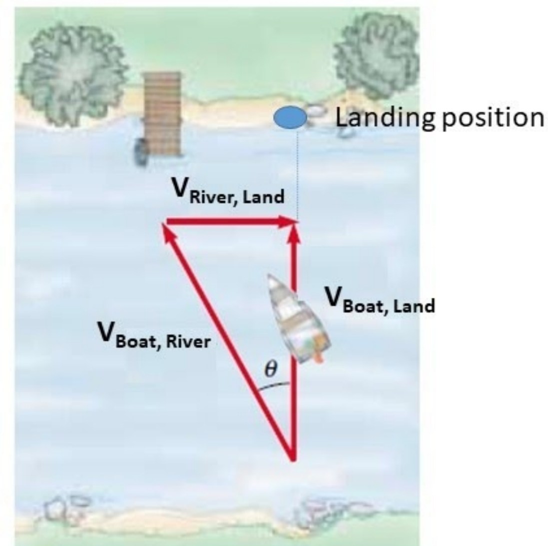
# Frames of reference and relative motion

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).

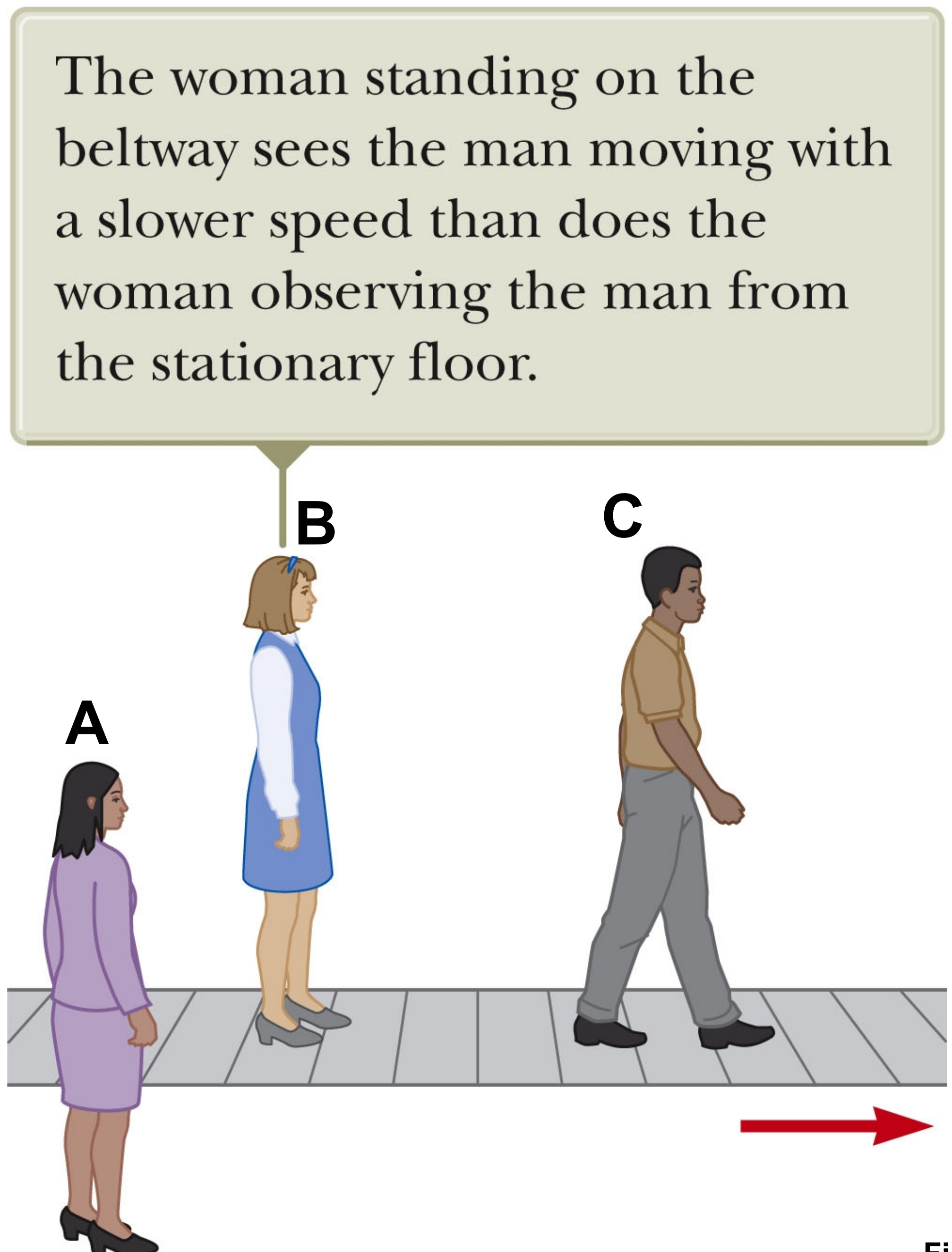
Given $\mathbf{v}_{RL}$ = 3 m/s E, $|\mathbf{v}_{BR}|$ = 8 m/s.

**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



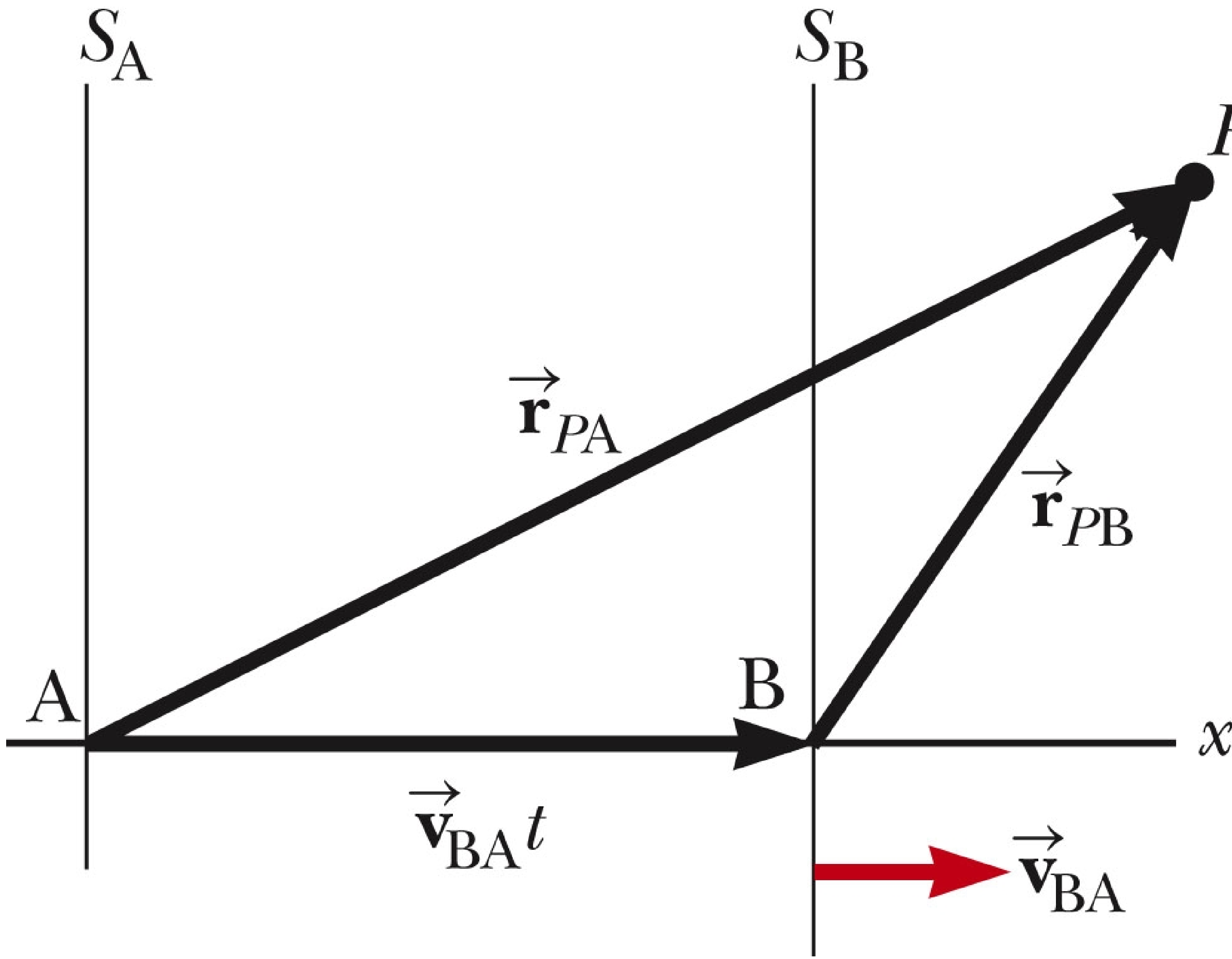

Each person is in a different inertial frame-of-reference!

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) Standing 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.

# Outline for Day W4,D3

Relativity
Types of Forces
Newton's $2^{nd}$ and $3^{rd}$ laws.
Weight vs Mass

# Homework

Ch. 4 P. 1-5,7,12-14,28,33,42,45,47,48
MisQ 1-11 (odd), Read Sec 4.1-4.8, 3.9. Do by Mon
Watch "frames of reference"

# Notes:

"NEW STUFF" has key for "exam-like questions" Ch 1-3.
Engineering tutoring is 7-9 pm on Wednesdays, JLK 203.
Exam I follows Chapter 5 material.

# Inertial Frames of reference (cont.)

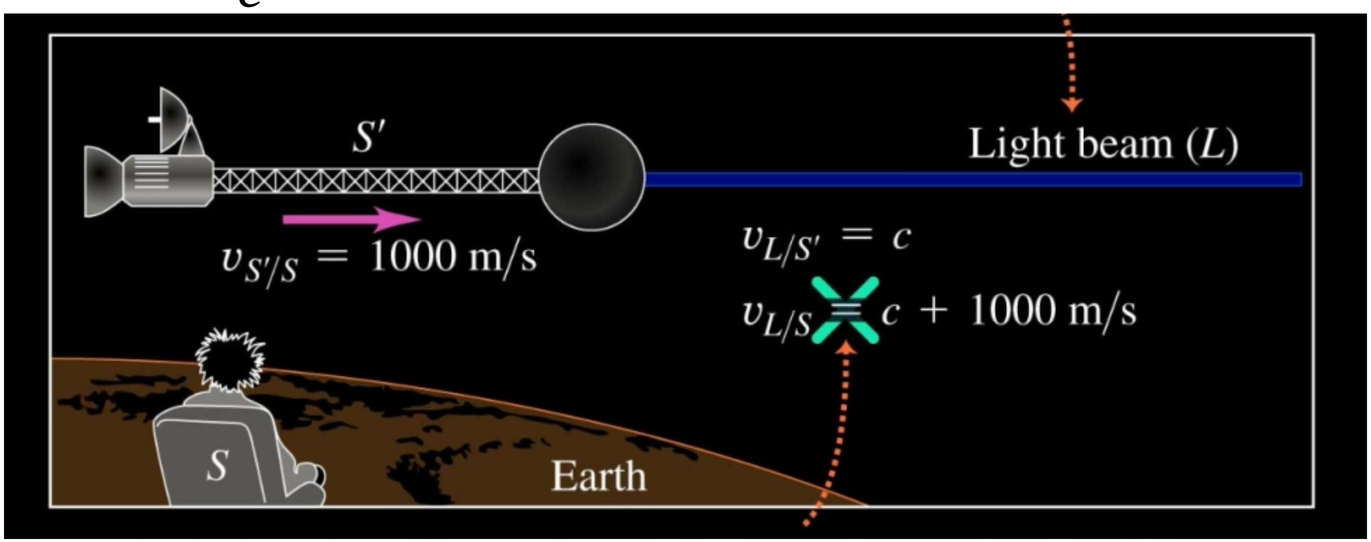
Velocity transformation (from Galilean relativity):

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

Velocity transformation (from Special Relativity):

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

(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)

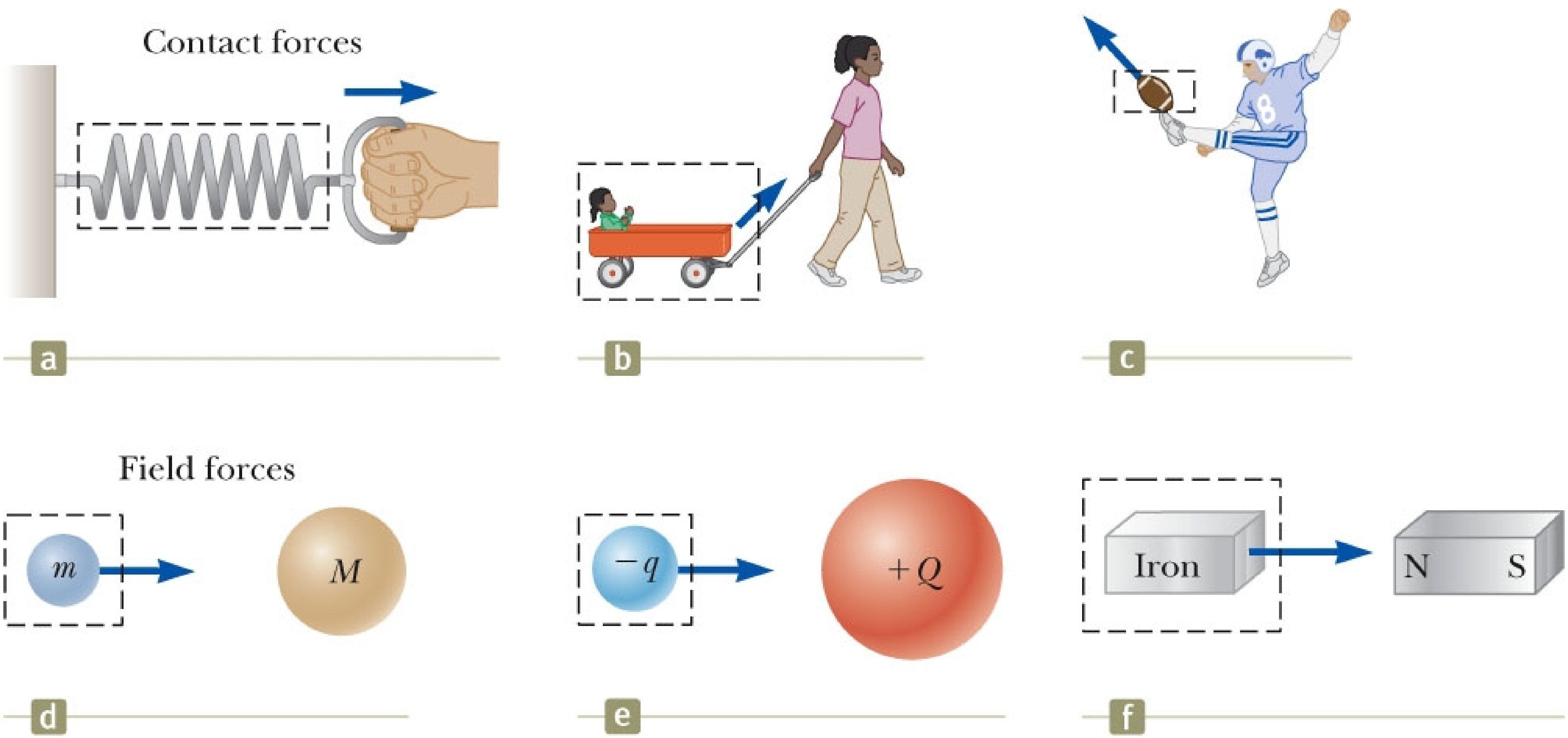
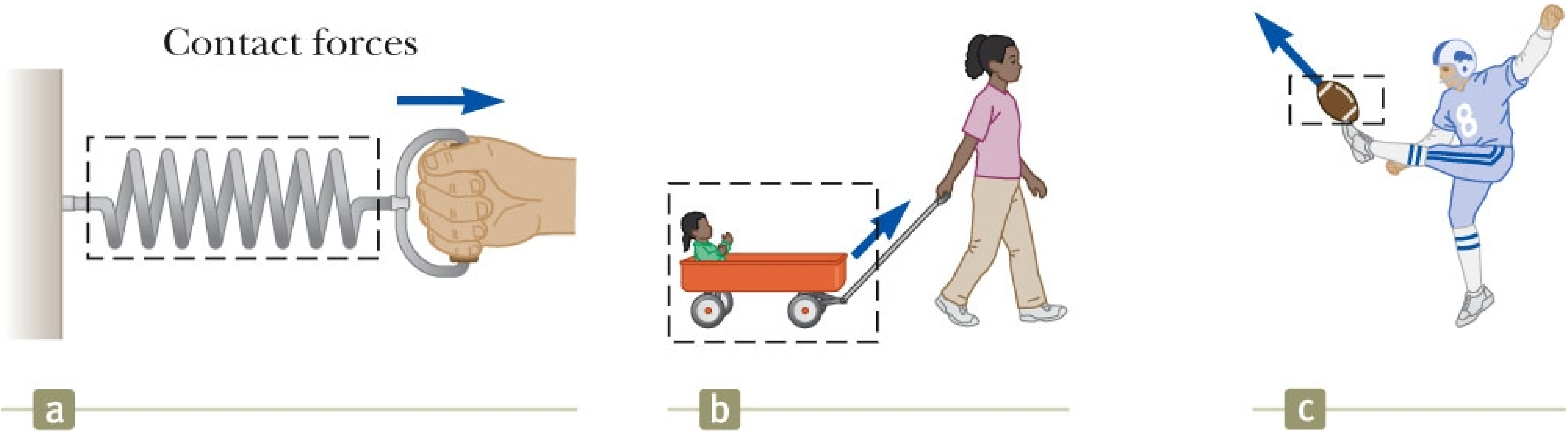



Fig. 5.1, p. 104

# Types of forces

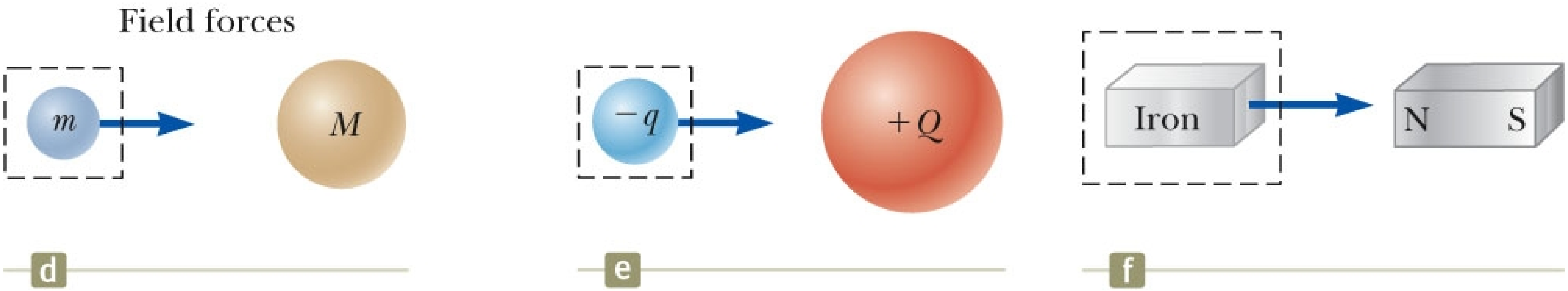



contact forces

- 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

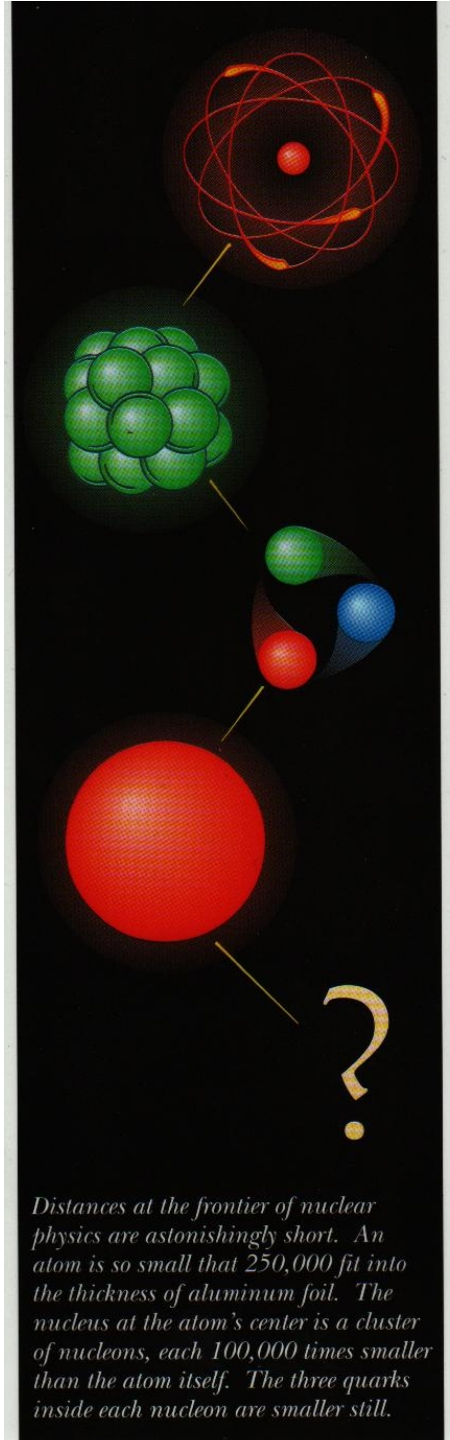
# The 4 Fundamental forces

Gravity

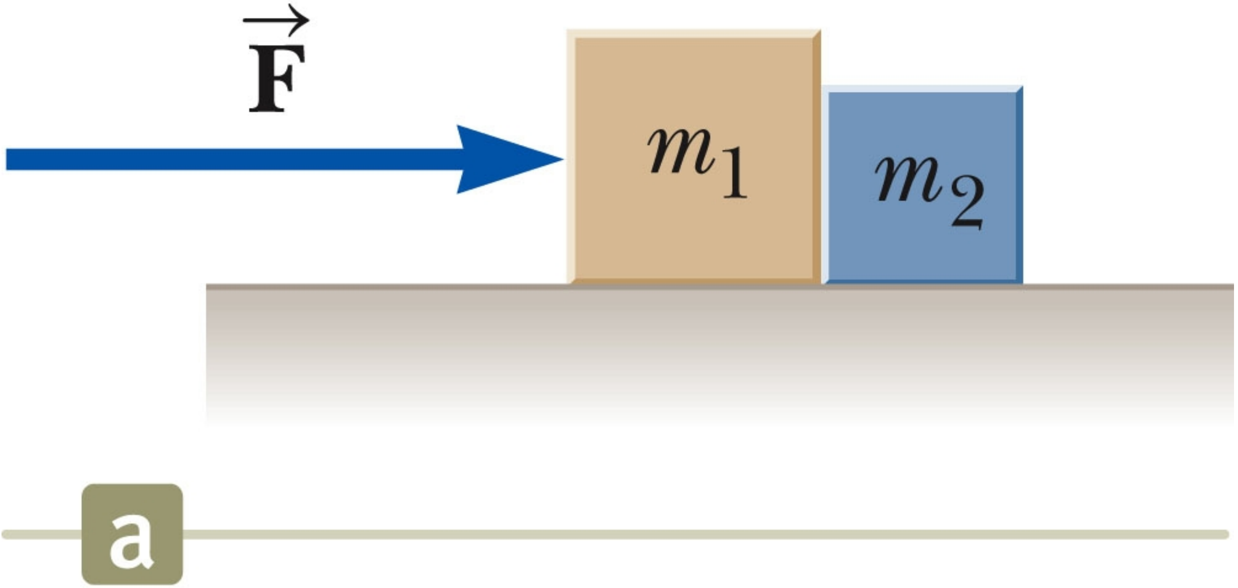
Electromagnetic Force

Nuclear Strong Force – holds nuclei together

Nuclear Weak force – decay of n and p



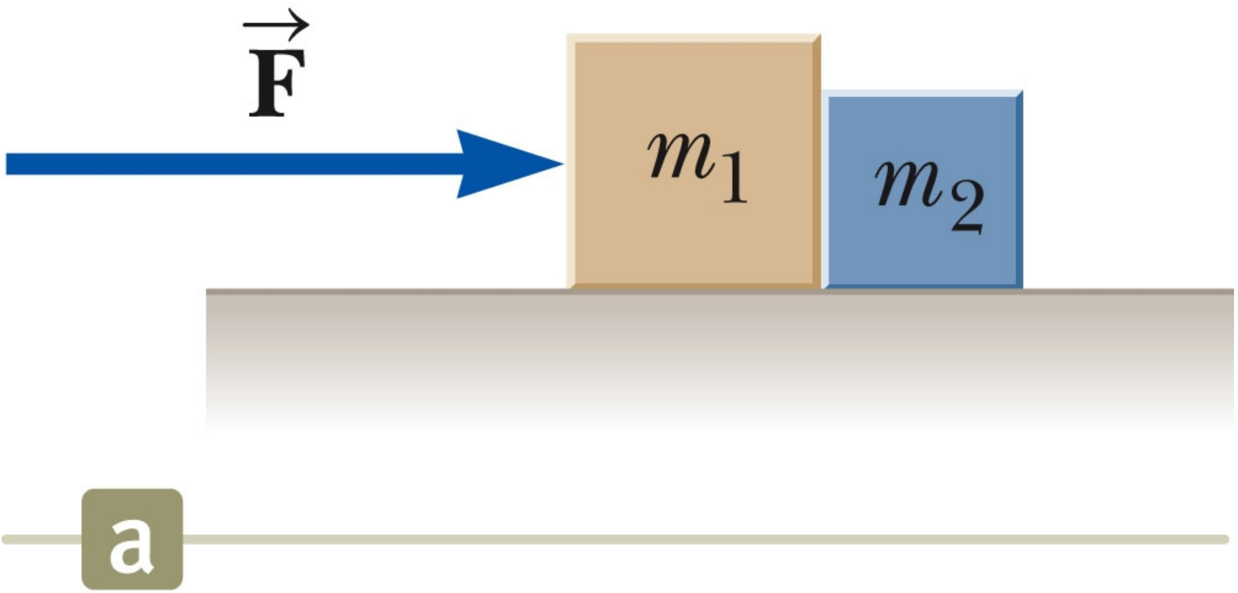
Newton's 2nd law = the acceleration of an object is proportional to the net force and inversely proportional to the mass.




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

If same force acts on m1, m2, and m1+m2, the accelerations are different.

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 **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?

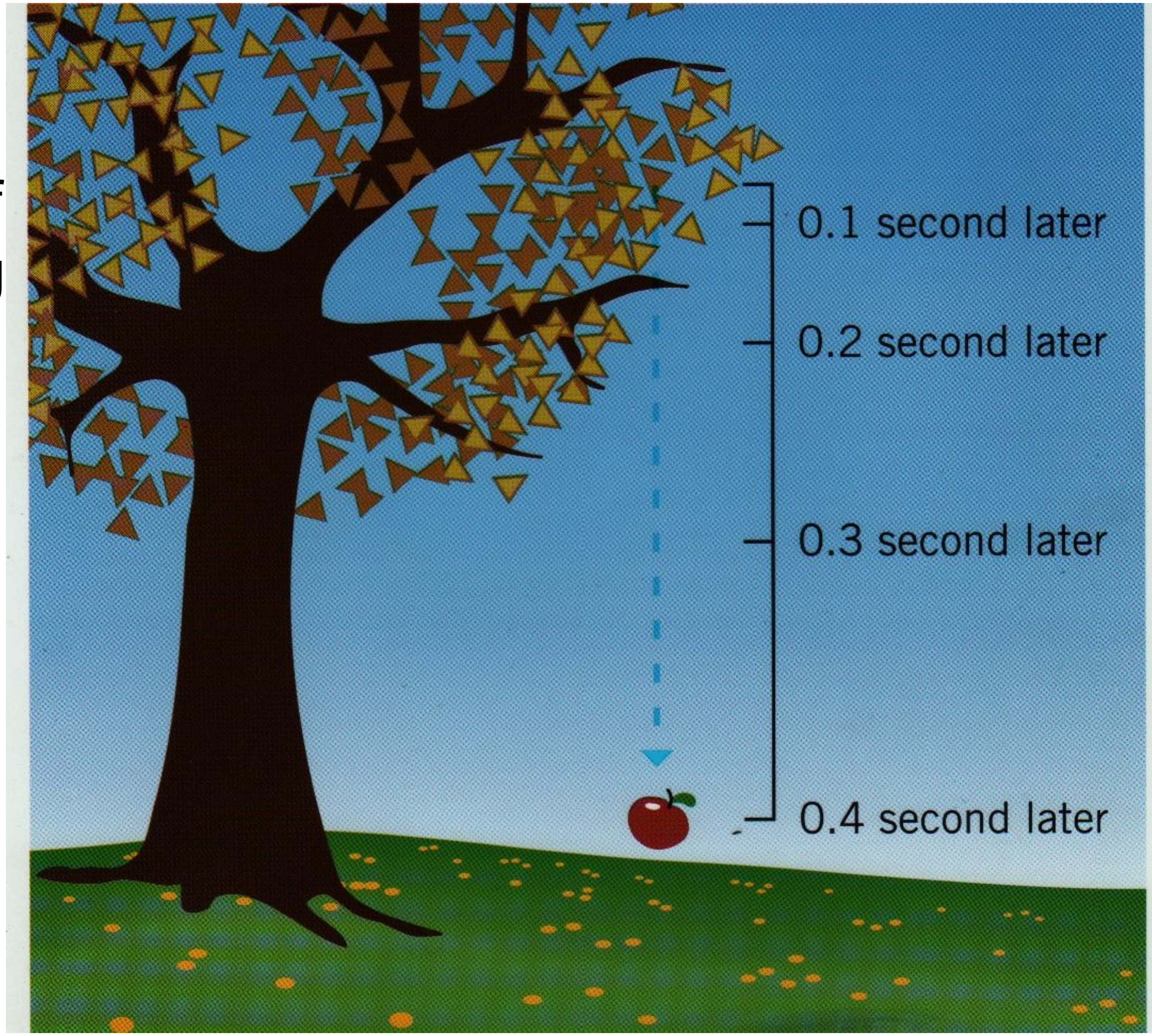
Yes: $F_{net} = F_g$ if only gravity acts. Then $a = F_g/m = mg/m = g$

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

$$W=F_g$$

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



# Outline for Day W5,D1

Newton's $2^{nd}$ and $3^{rd}$ laws.
Weight vs Mass
Problem solving approach
Example problems

## Homework

Ch. 4 P. 1-5,7,12-14,28,33,42,45,47,48
MisQ 1-11 (odd), Read Sec 4.1-4.8, 3.9. Do for today

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

## Notes:

"NEW STUFF" has key for Ch 4 hwk, and new example problems on force (with key).

Exam I either next Wed (2/26) or Fri (2/28).

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

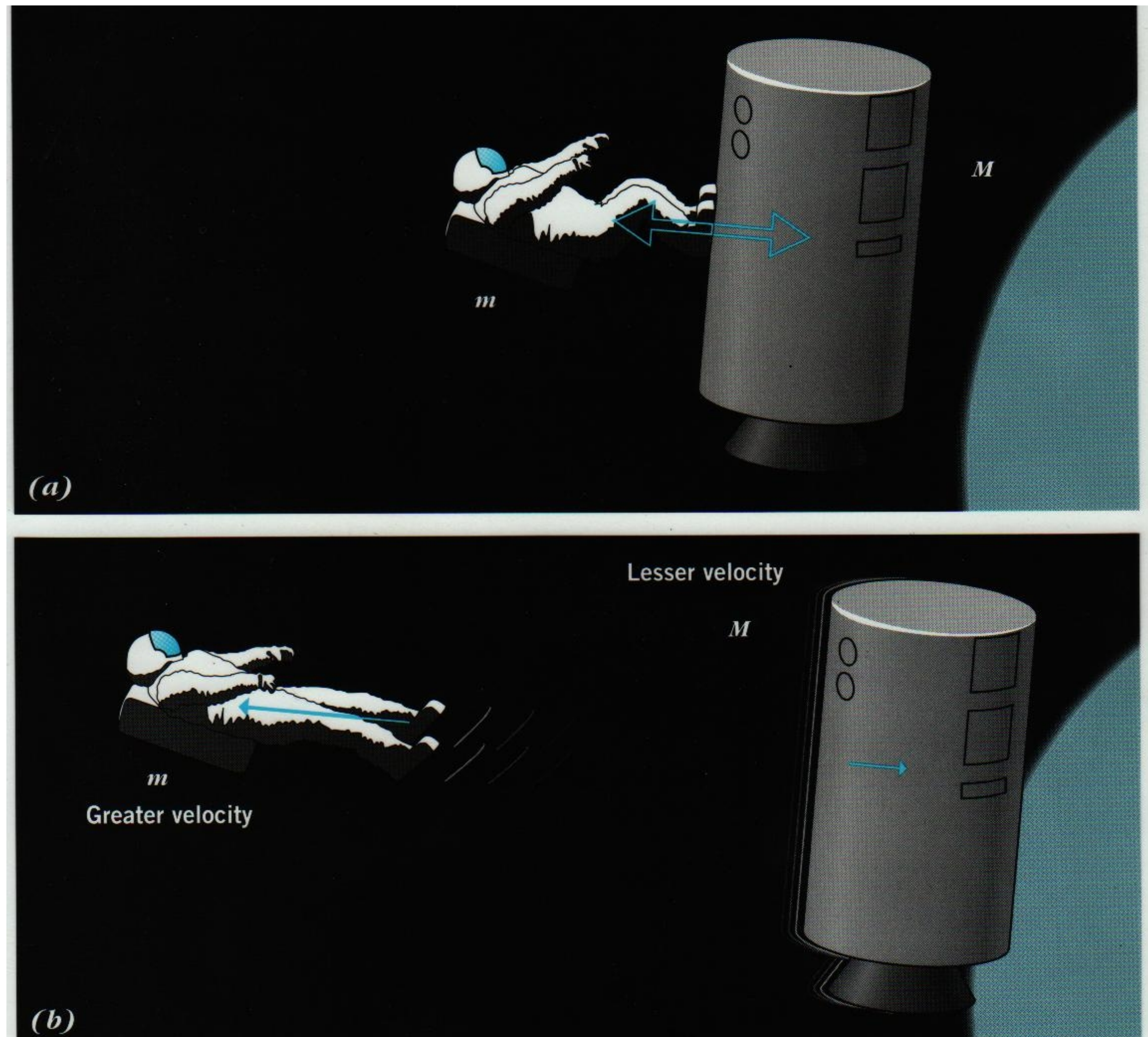
And so $F_{avg} = ma_{avg} = -3134\text{ N}$

(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."

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



Newton's 3rd 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 $\mathbf{a}_2$?

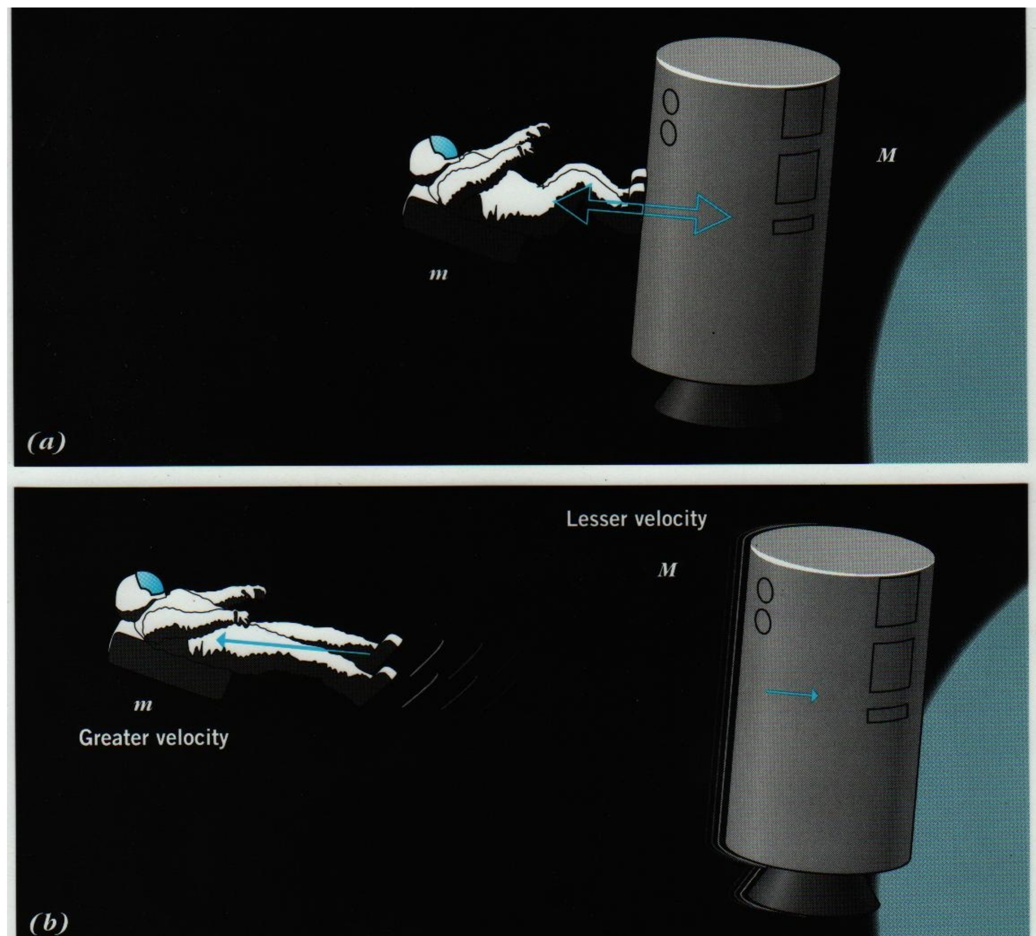
$\mathbf{a}_2 = \mathbf{F}_{21} / m_2$

$\mathbf{a}_2$=1000/700=1.43m/s$^2$î

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

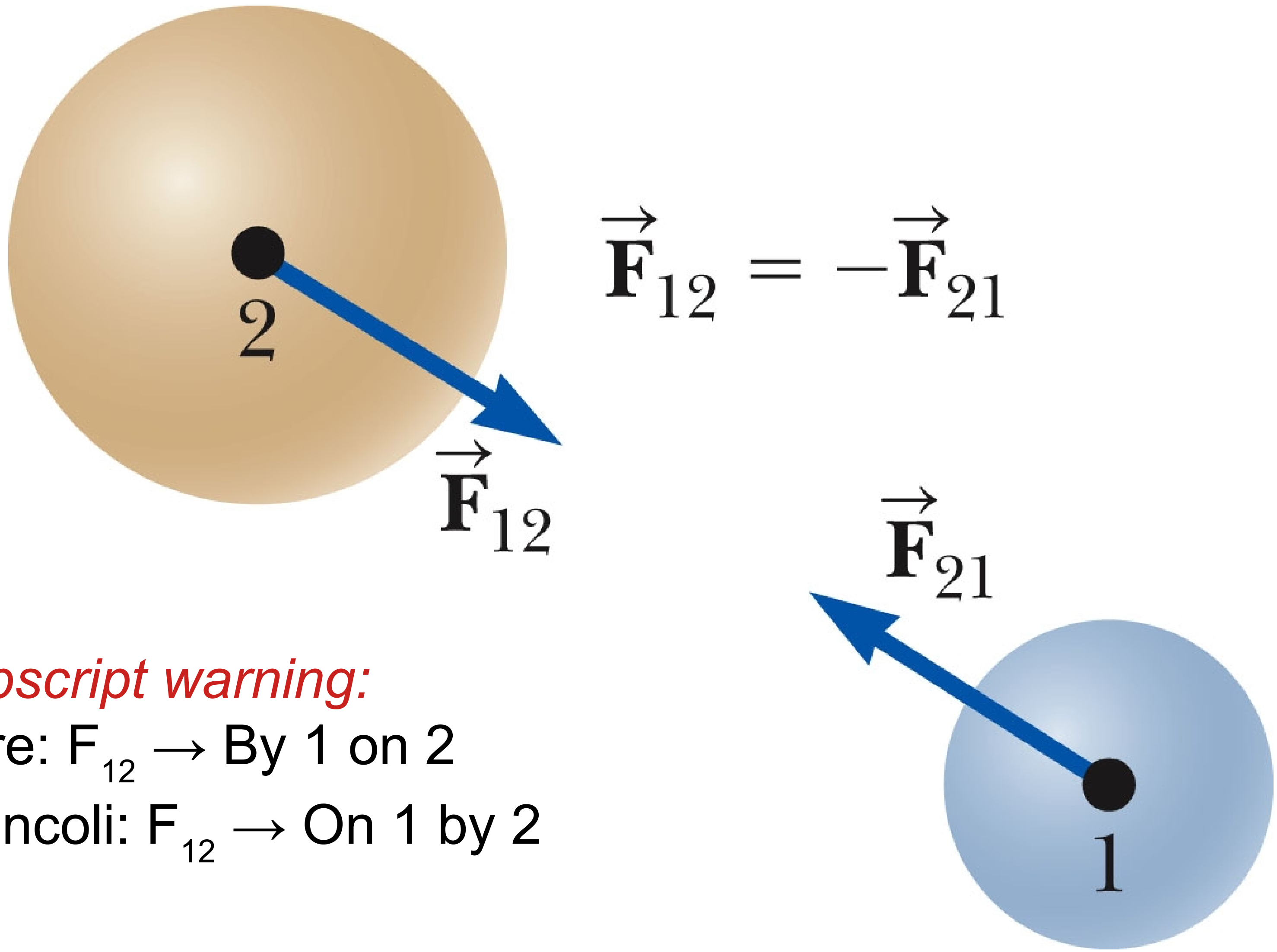
$\mathbf{a}_1$=-1000/70=-14.3m/s$^2$î

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.




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

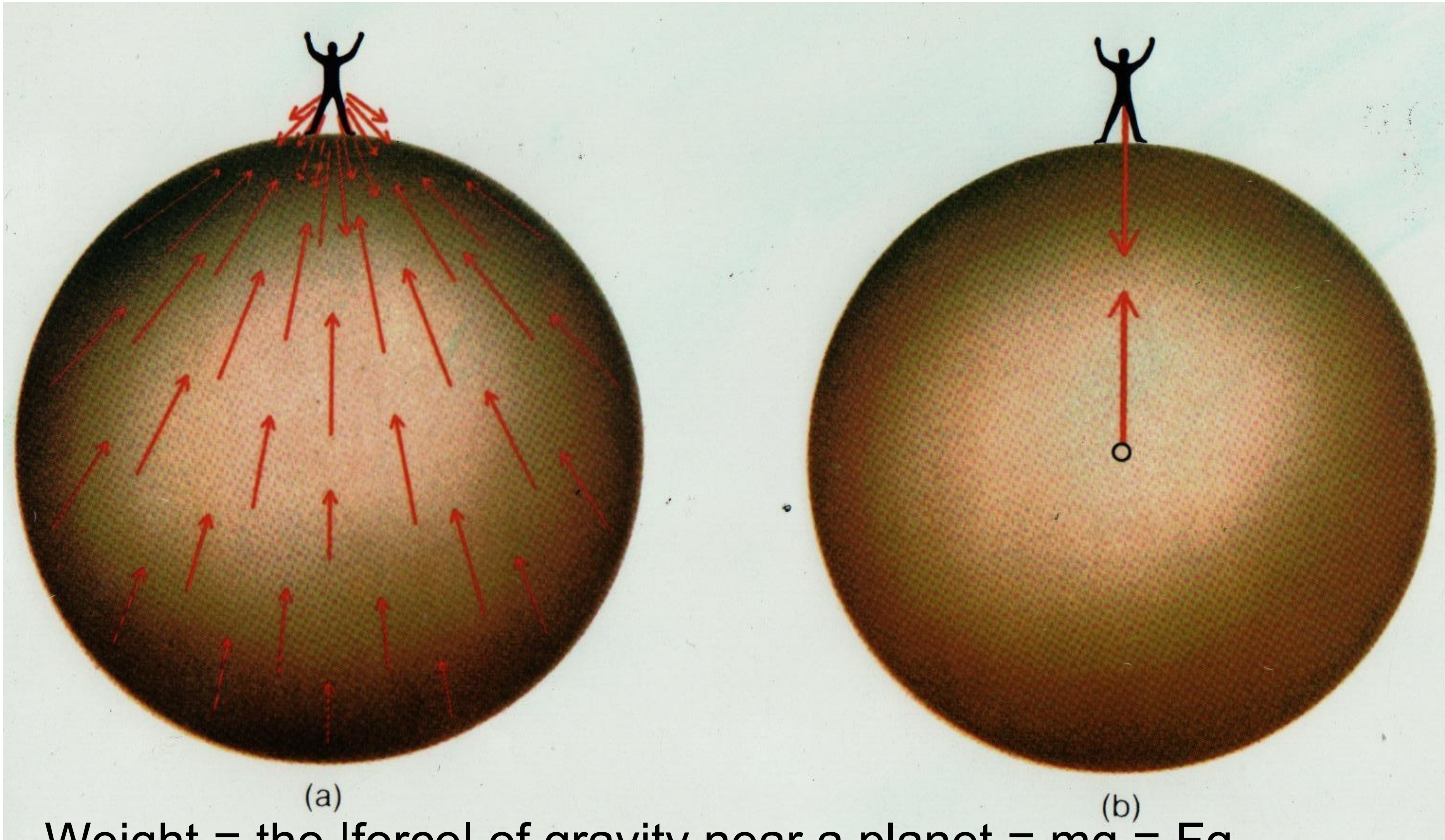
*Subscript warning:*

Here: $F_{12}$ → By 1 on 2

Giancoli: $F_{12}$ → On 1 by 2

Fig. 5.5, p. 111

# 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**

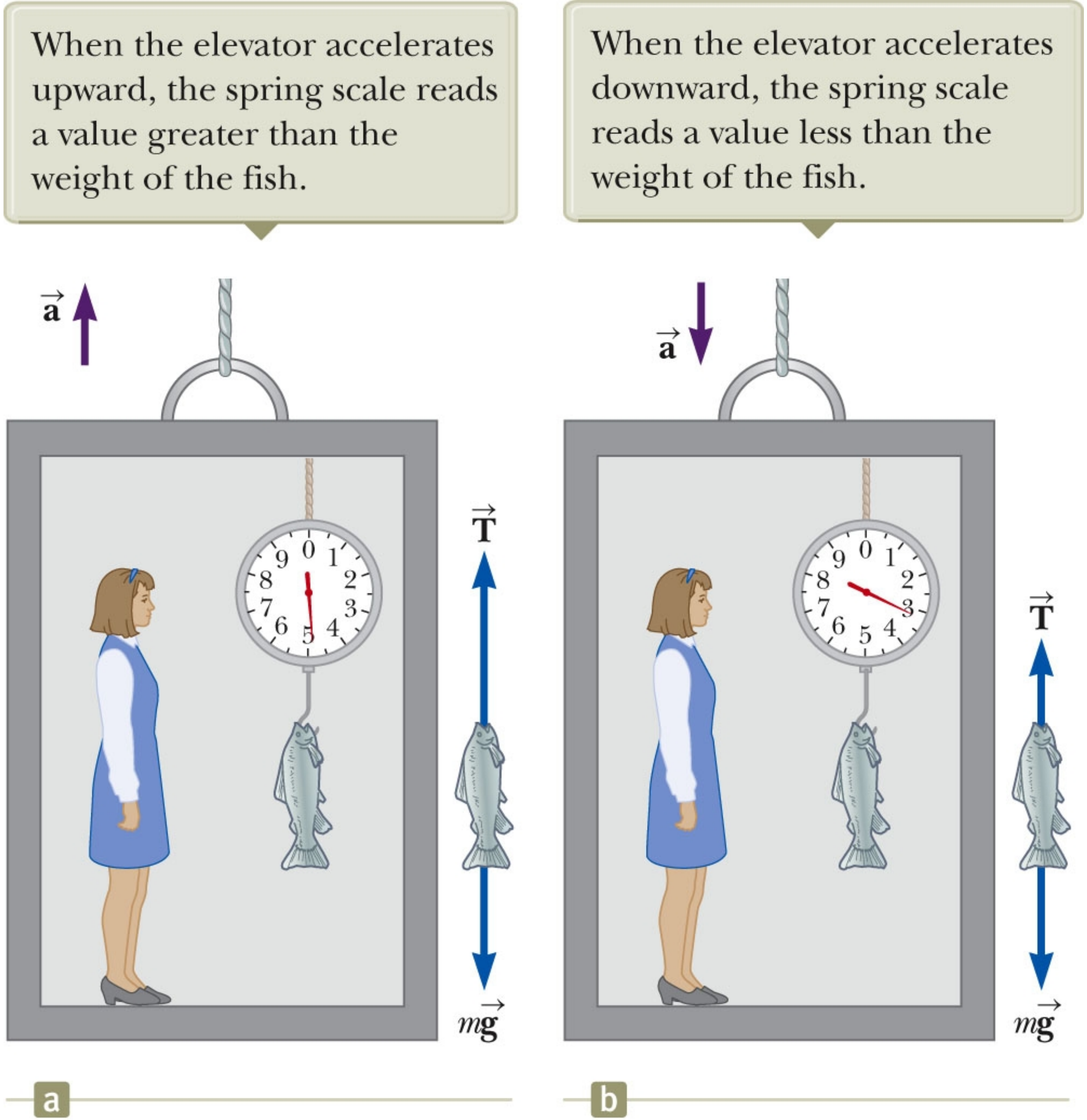

When the elevator accelerates upward, the spring scale reads a value greater than the weight of the fish.
When the elevator accelerates downward, the spring scale reads a value less than the weight of the fish.
$\vec{a}$
$\vec{T}$
$m\vec{g}$
$\vec{a}$
$\vec{T}$
$m\vec{g}$
a
b

Fig. 5.13, p. 119

# Outline for Day W5,D2

General problem solving approach
Elevator problems
Example problems: stationary box, hockey puck,
frictionless incline, traffic lights, Atwood's machine
Friction: kinetic and static

# Homework

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

# Notes:

"NEW STUFF" has key for Ch 4 hwk, and new example problems on force (with key).

Exam I next Fri (2/28).

# The Application of Newton's Laws

Problem solving method

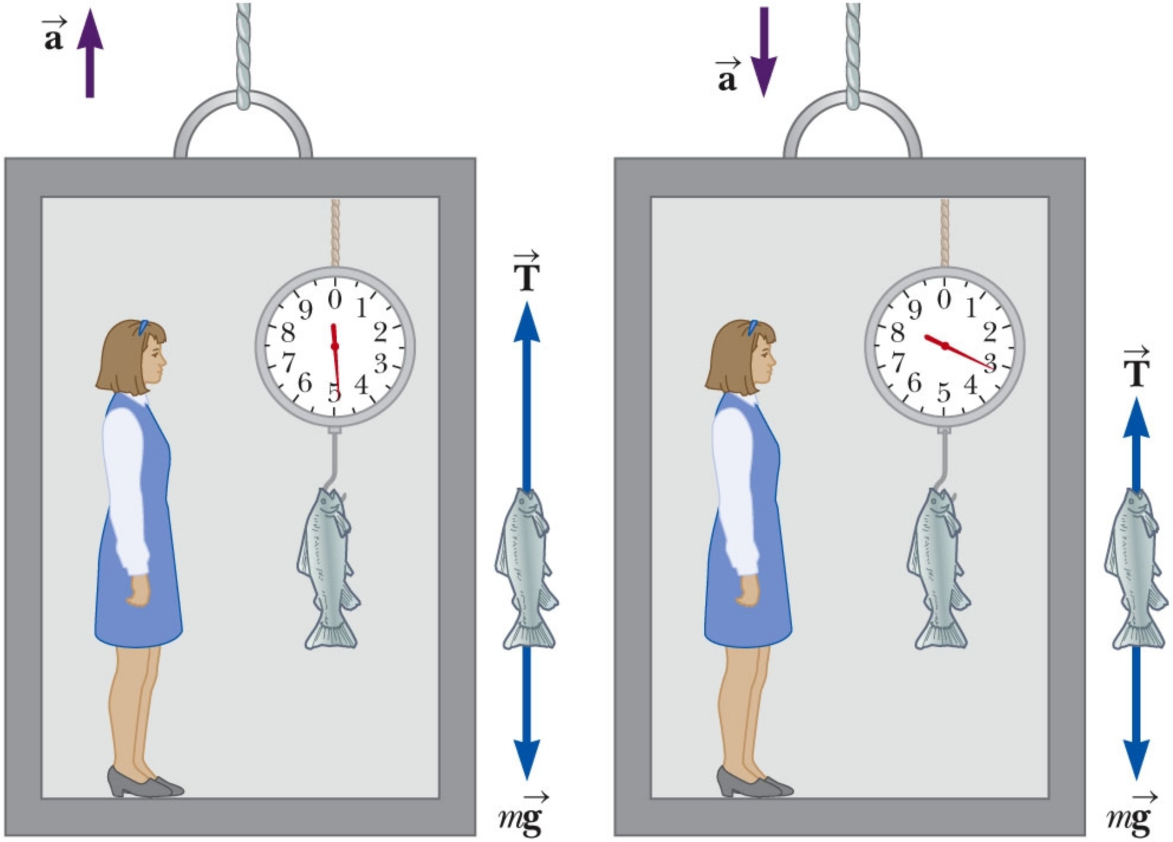
1. Conceptualize
   - What is problem asking for?
   - Write down knowns and unknowns.
   - Draw picture.
2. Categorize
   - Equilibrium problem – object stationary (or constant velocity)
   - Newton's $2^{nd}$ law problem – object accelerates
3. Analyze
   - Isolate object of interest and draw forces 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!

Example)

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 $\hat{j}$

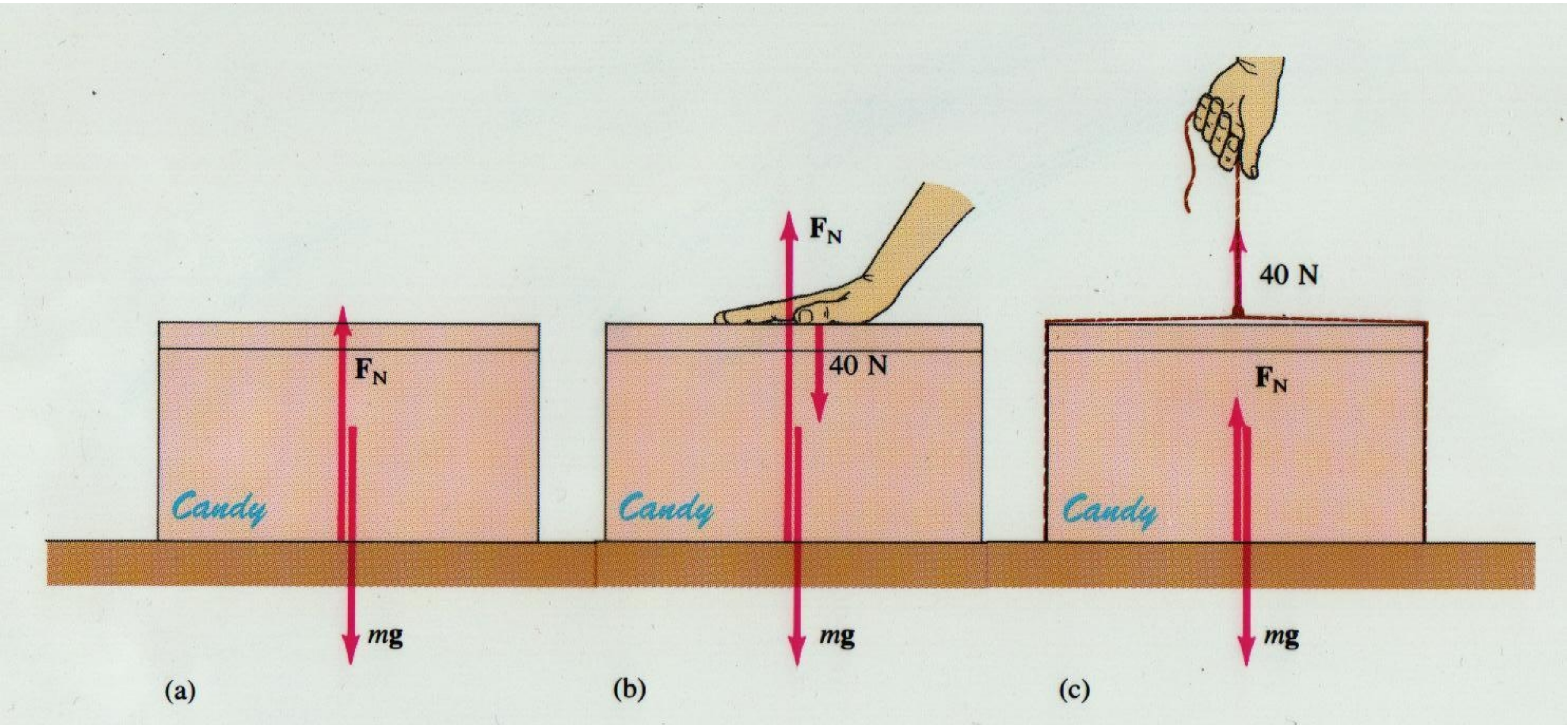
c) $a = -3\ m/s^2\ \hat{j}$

Fig. 5.13, p. 119

# The Application of Newton's Laws

## Box on table

Find the normal force in each case if m=1 kg and the box remains stationary. (Use $g=10\ m/s^2$)

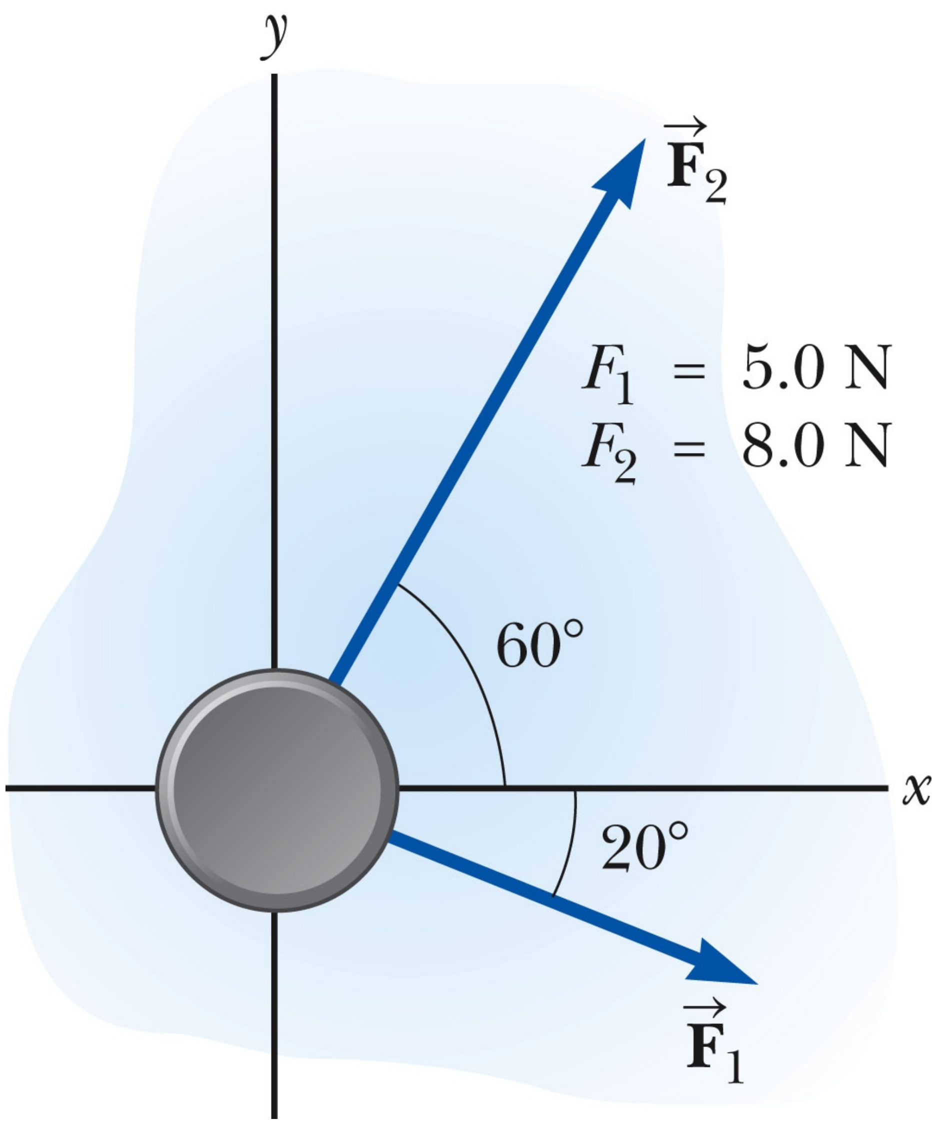



***Note: if m=5 kg, you get a more realistic normal force in (c).***

# 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

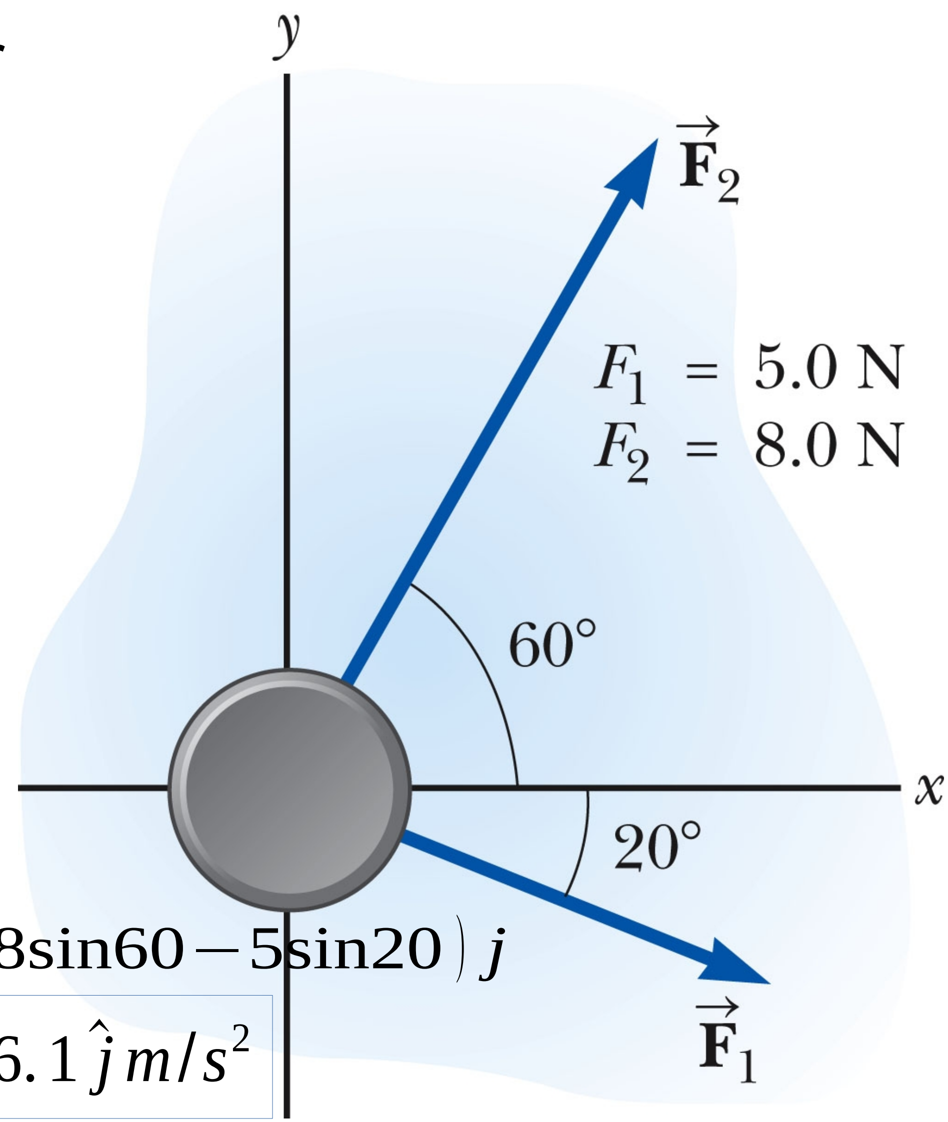
## Puck on frictionless ice

Find the acceleration vector for the 0.2 kg hockey puck.

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

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

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




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

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

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

# Outline for Day W5,D3

Example problems: hockey puck,
frictionless incline, traffic lights, Atwood's machine
Friction: kinetic and static

# Homework

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

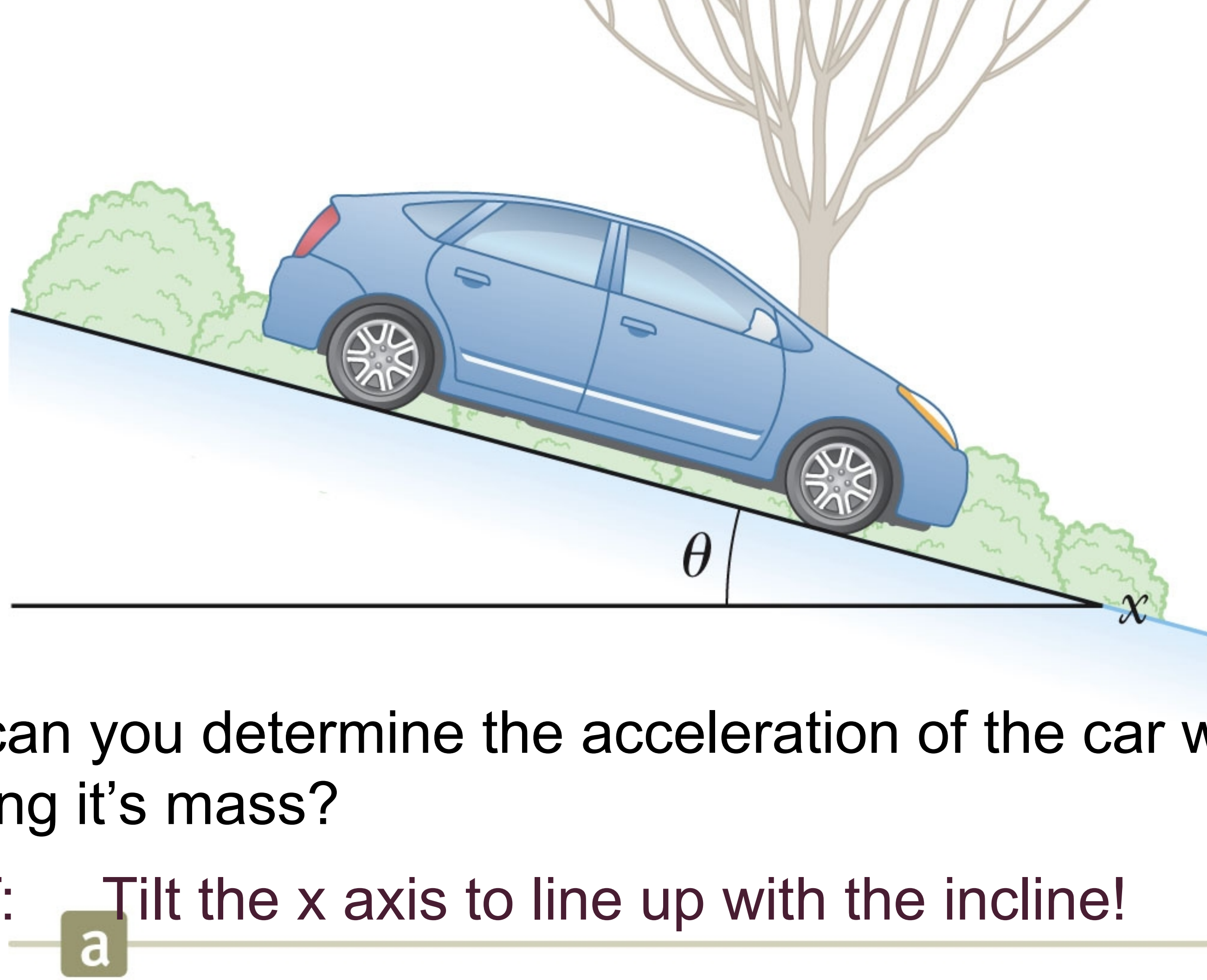
# Notes:

"NEW STUFF" has key for Ch 4 hwk, and new example problems on force (with key).

Exam I next Fri (2/28).

# Car on frictionless incline

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



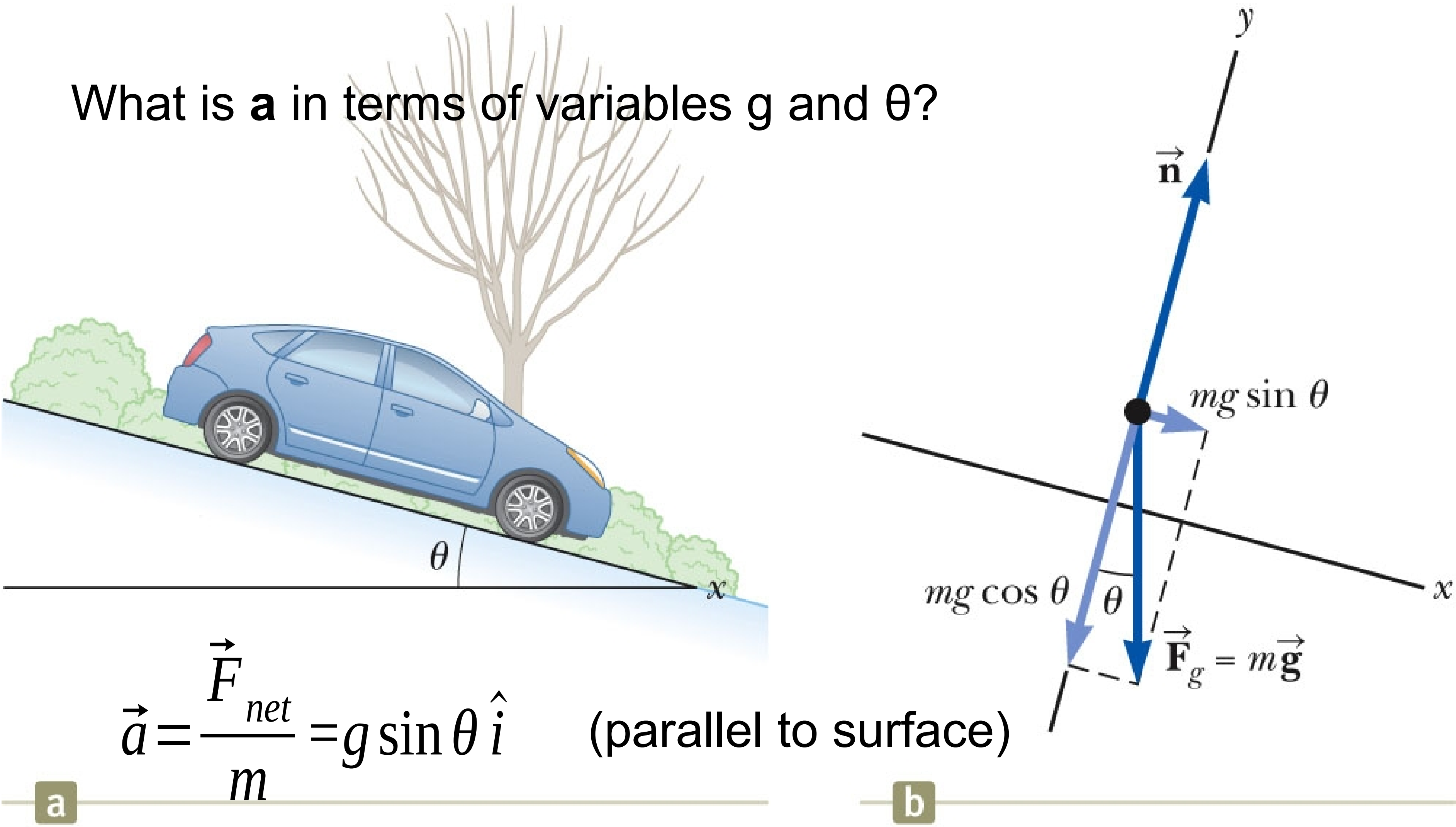

How can you determine the acceleration of the car without knowing it’s mass?

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?

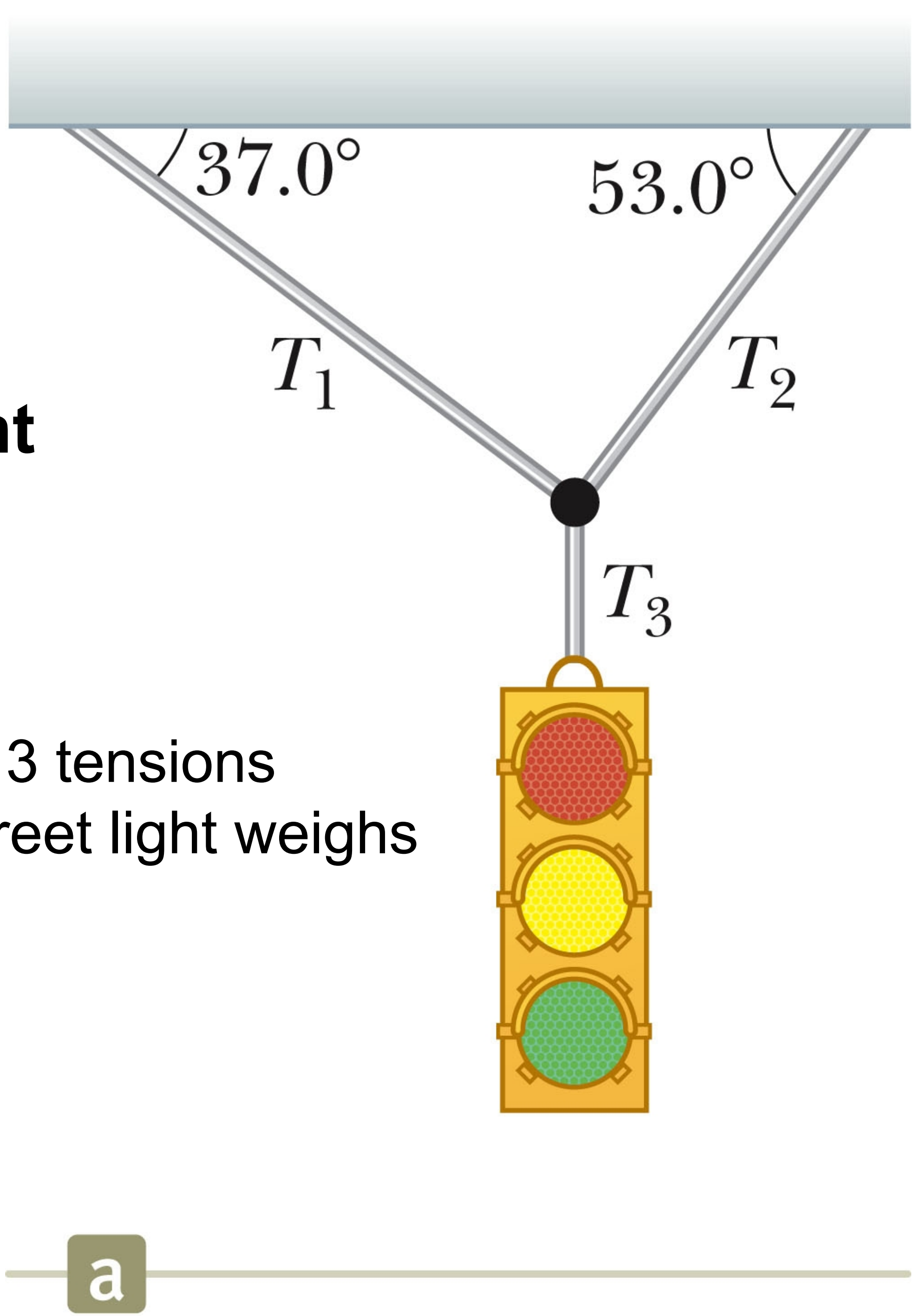



$$\vec{a} = \frac{\vec{F}_{net}}{m} = g \sin\theta\, \hat{i}$$ (parallel to surface)

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

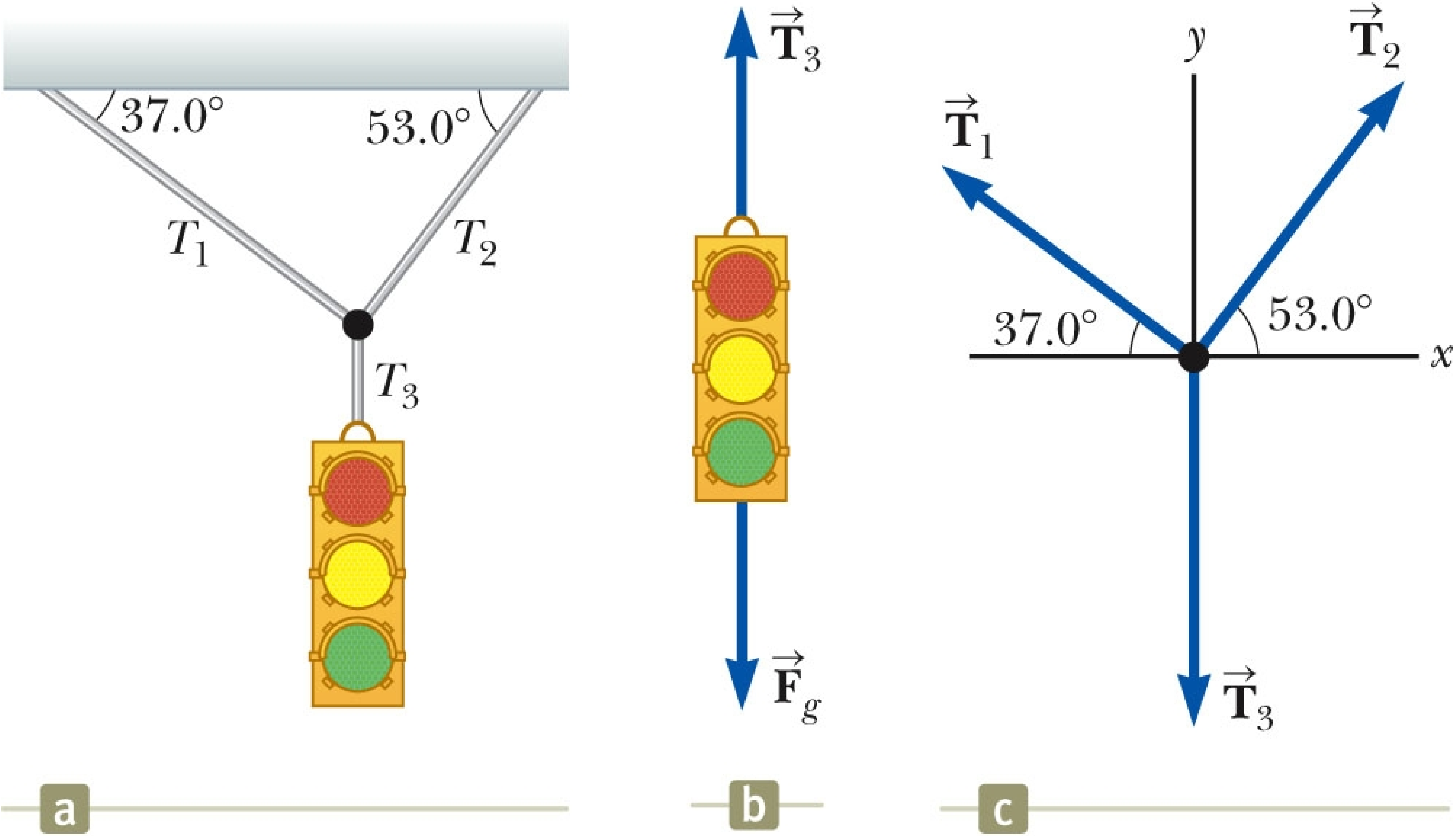
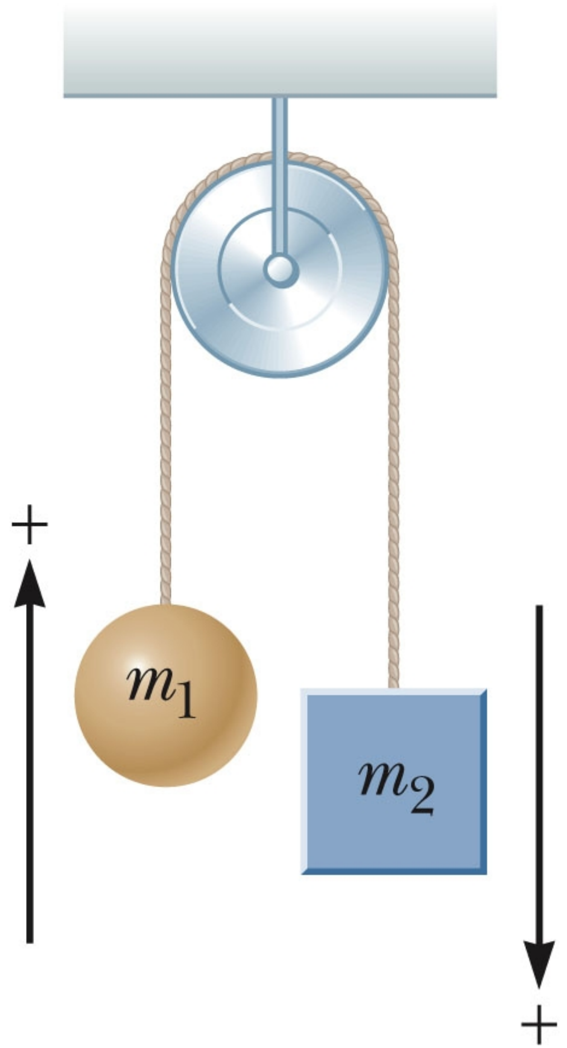
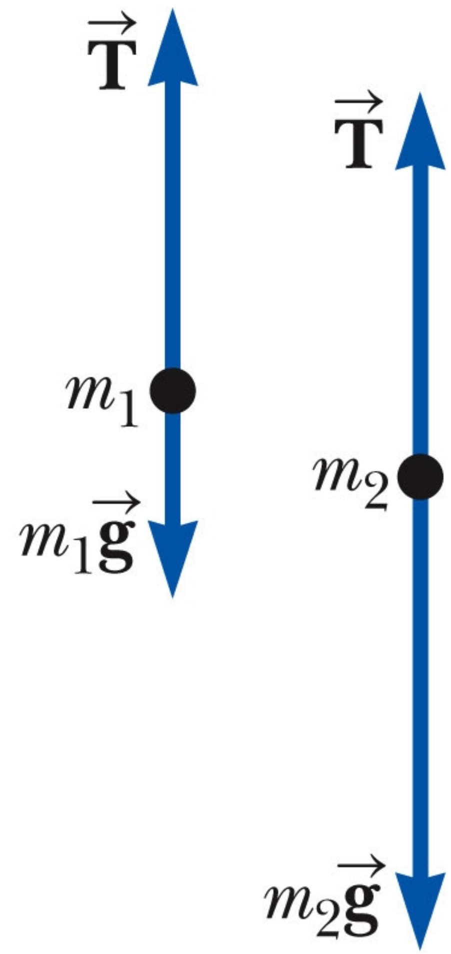



Fig. 5.10, p. 114

# Atwood's Machine




Find acceleration of either mass, given $m_1$ and $m_2$.




a b

Fig. 5.14, p. 120

# 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. (maybe not?)

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
* $f_s$ = Fapplied until Fapplied reaches $f_{s,max}$, then slippage occurs.

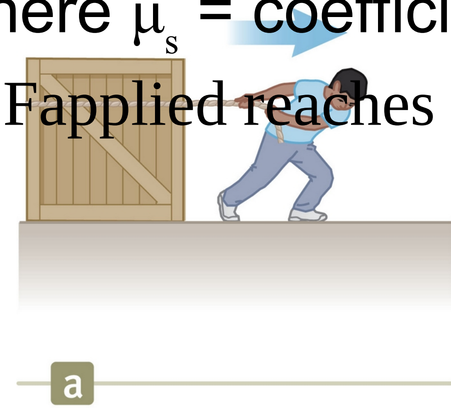
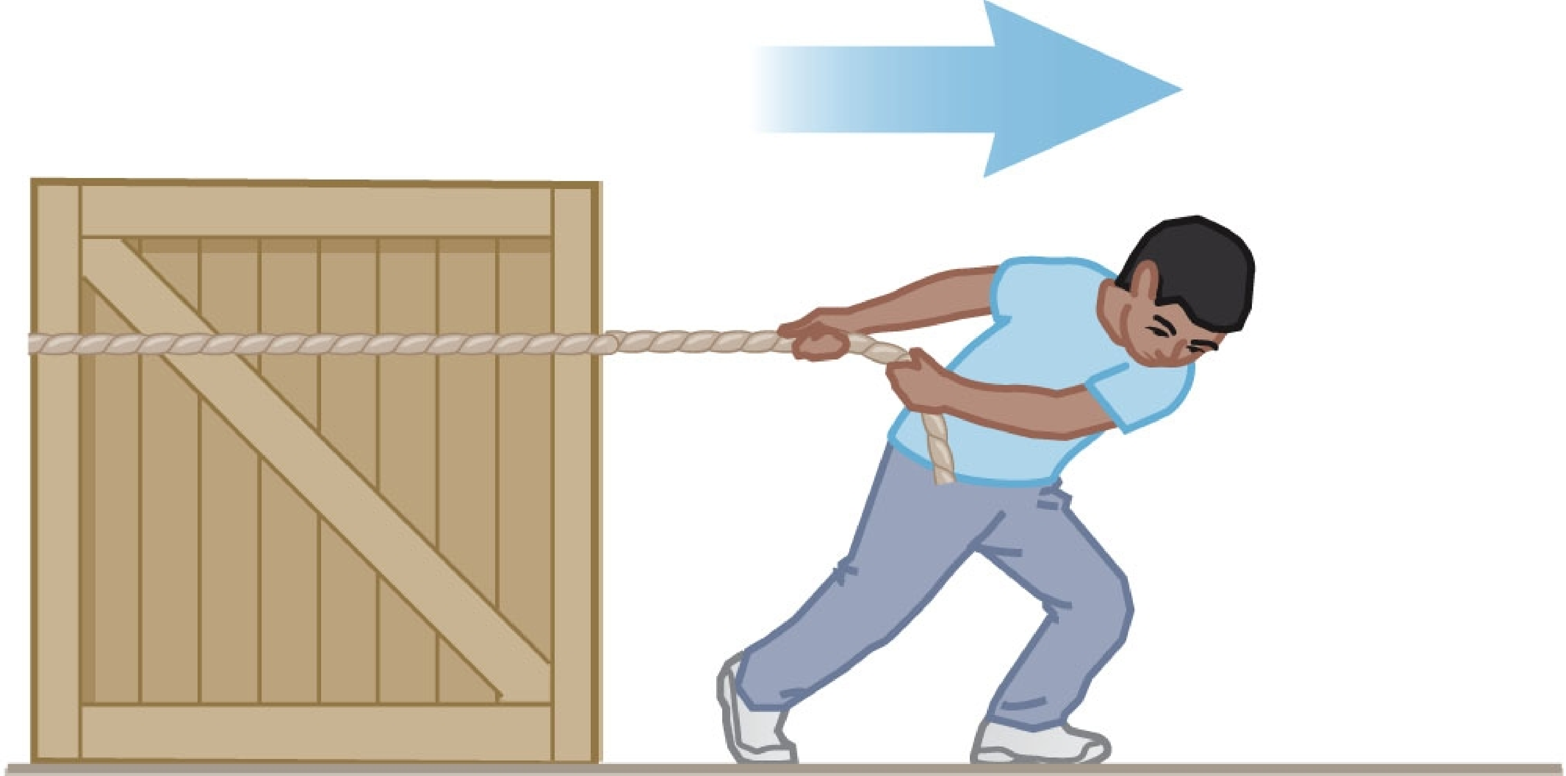



Fig. 5.8, p. 113



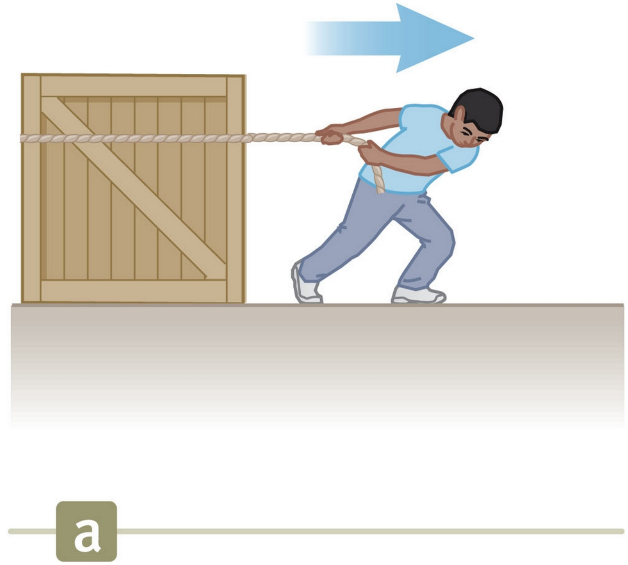
Wood on wood has $\mu_s$ ~ 0.4, and $\mu_k$~0.2.

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

Ans: F_boy=fs,max = $\mu_s$ $F_N$ = $\mu_s$ 90*9.8 = 353 N

a

5.8, p. 113




Which force is missing from this FBD?

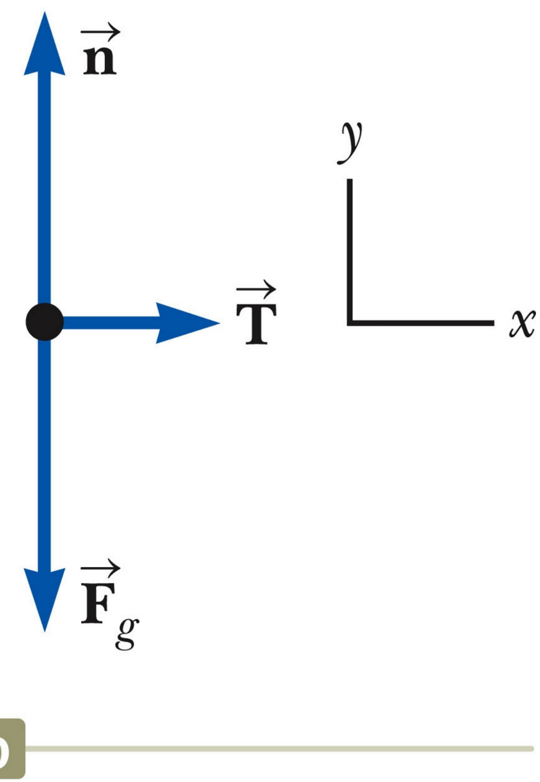
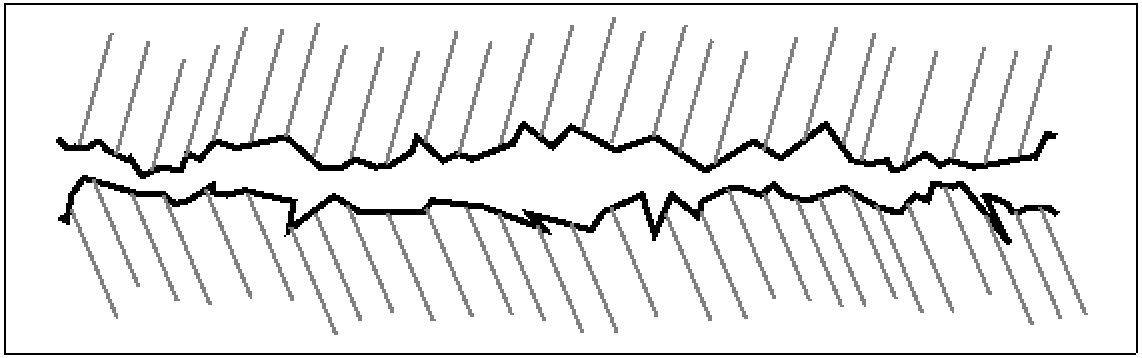
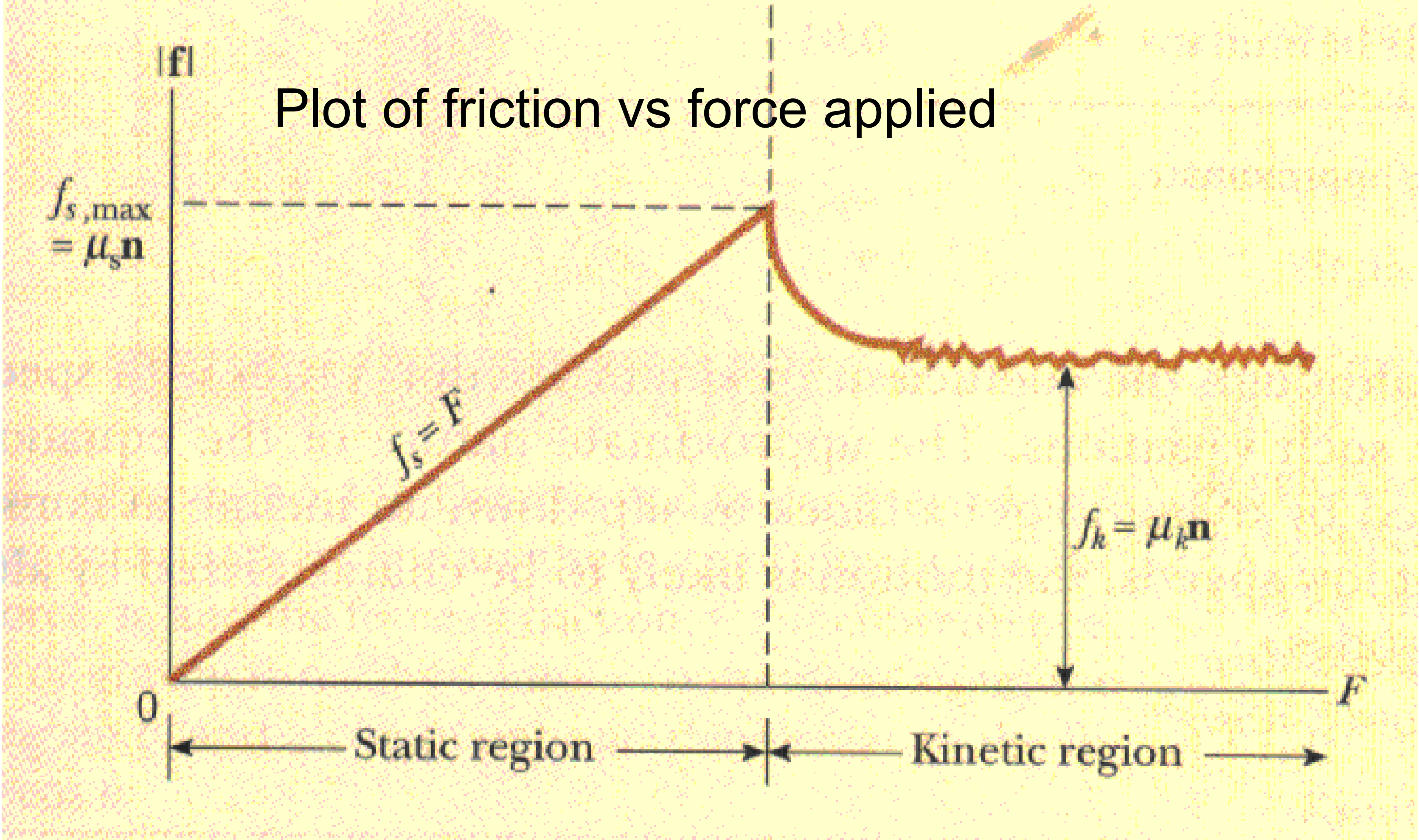



Fig. 5.8, p. 113

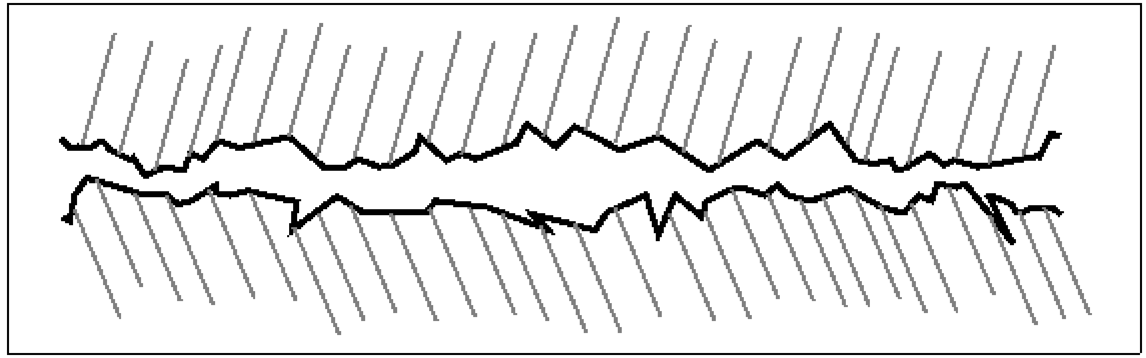
Close-up of
surfaces.

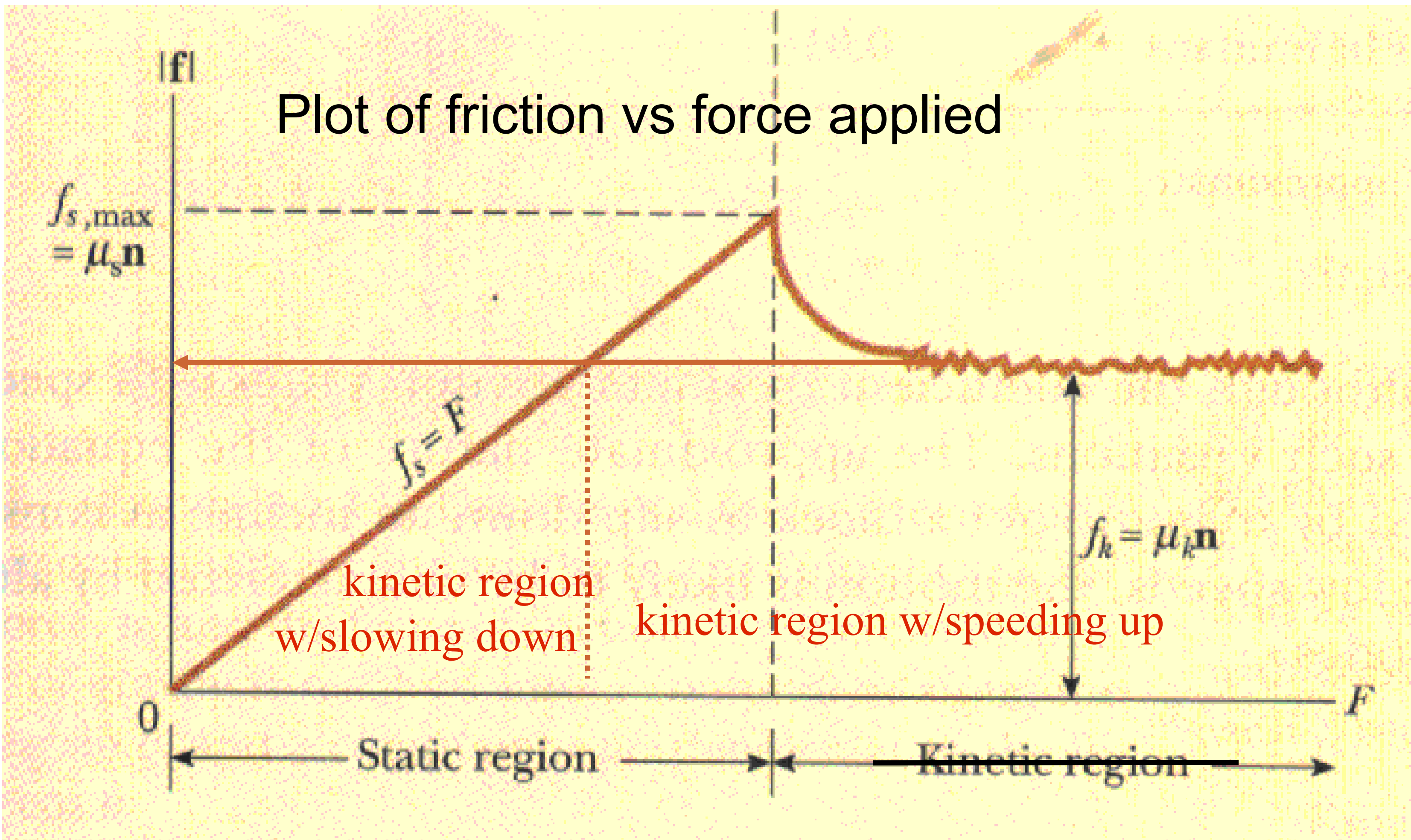





Plot of friction vs force applied

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.

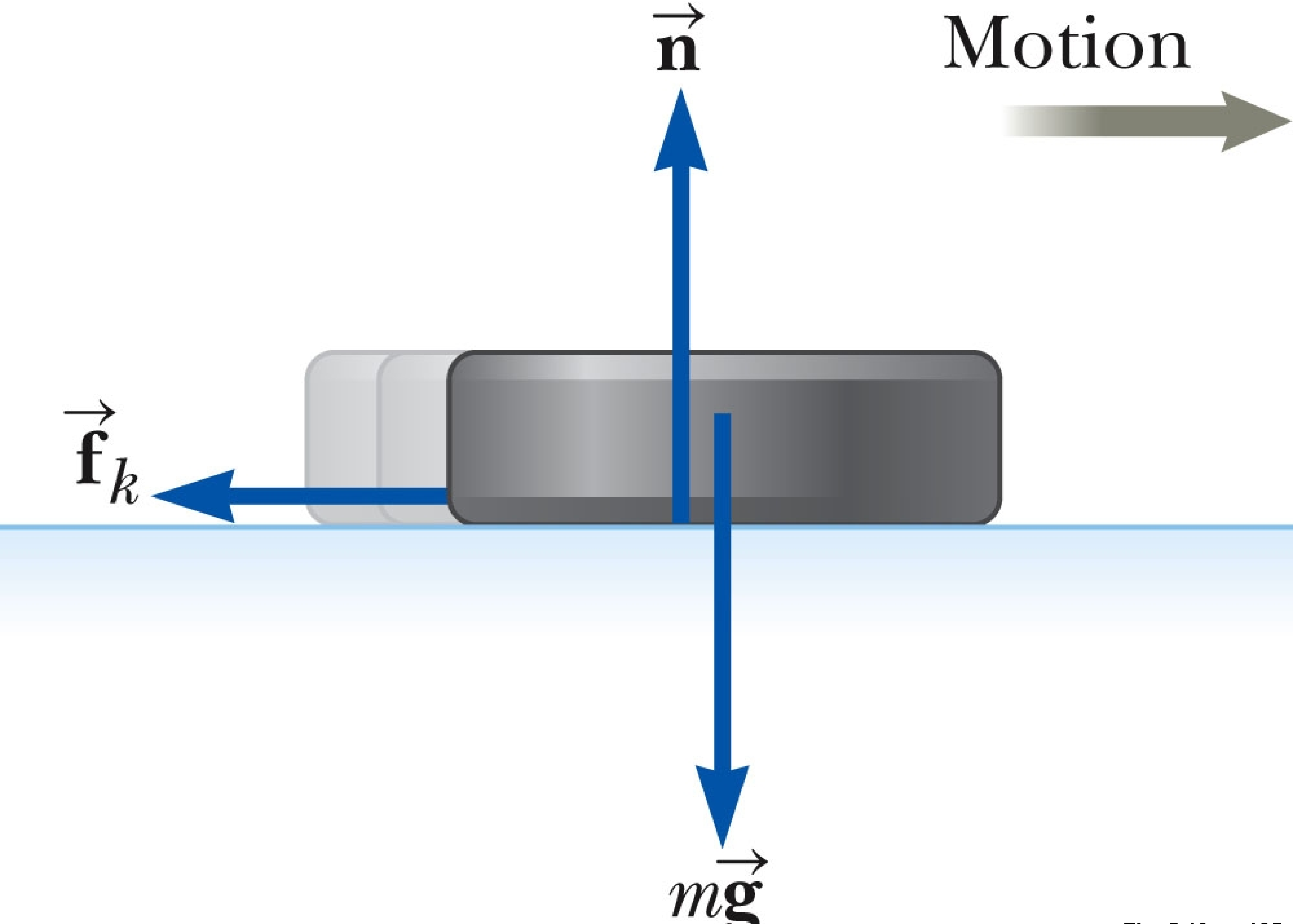
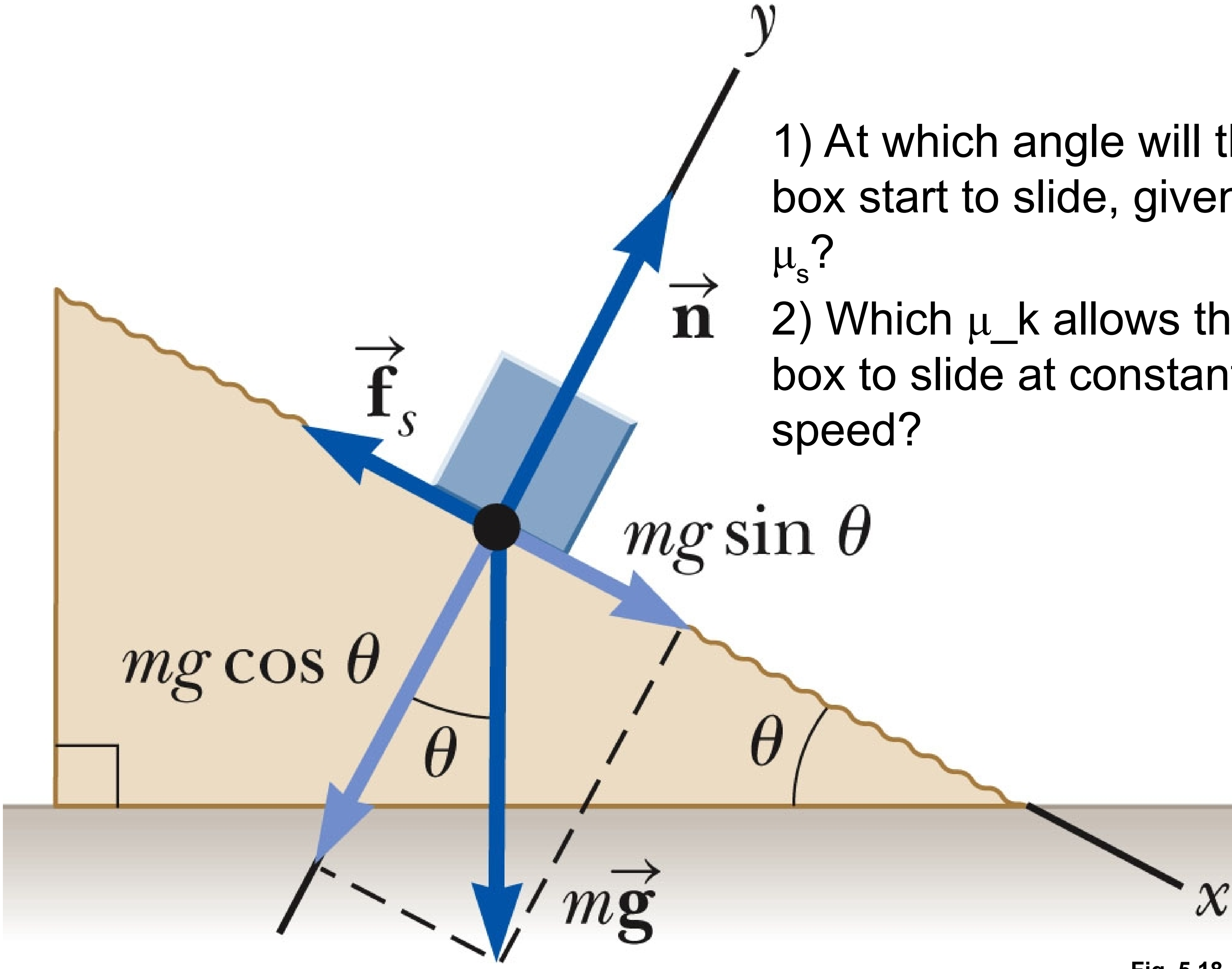



Fig. 5.19, p. 125

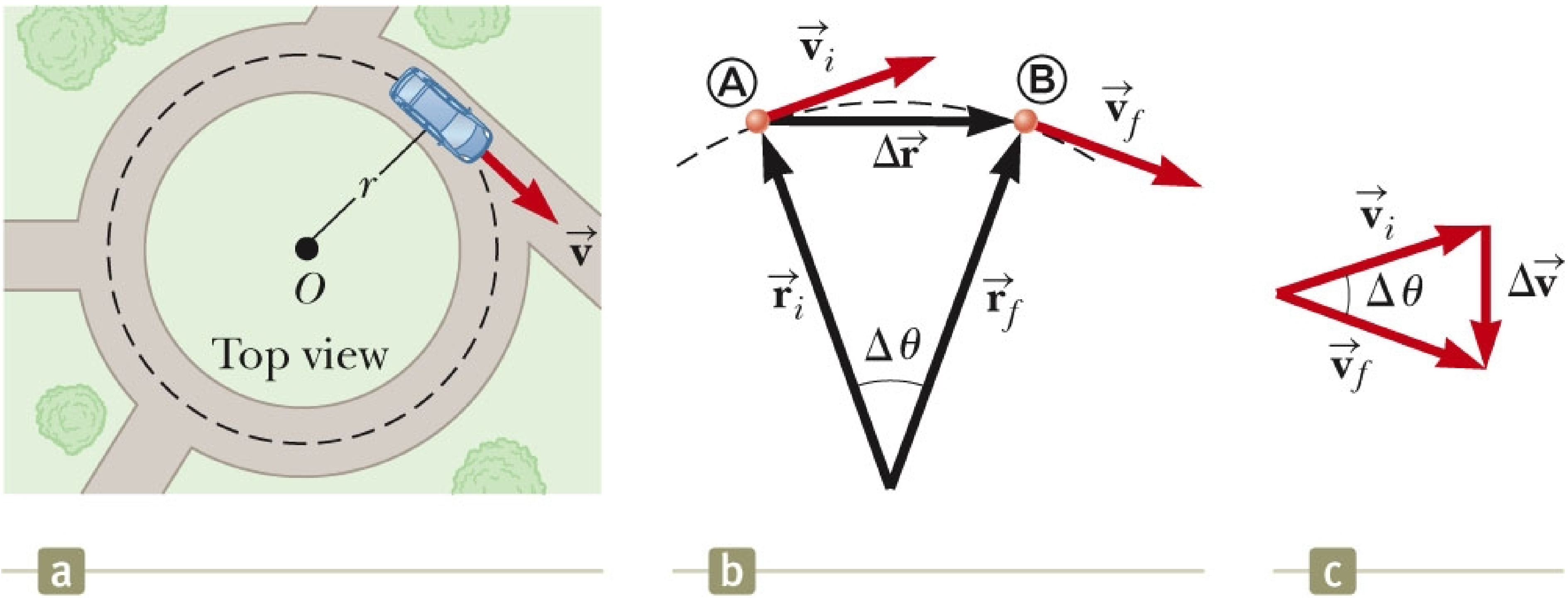



1) At which angle will the box start to slide, given $\mu_s$?

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.




Time to make one cycle = period = T = circumf/speed

Fig. 4.15, p. 86

# Total acceleration – sum of tangential and centripetal components

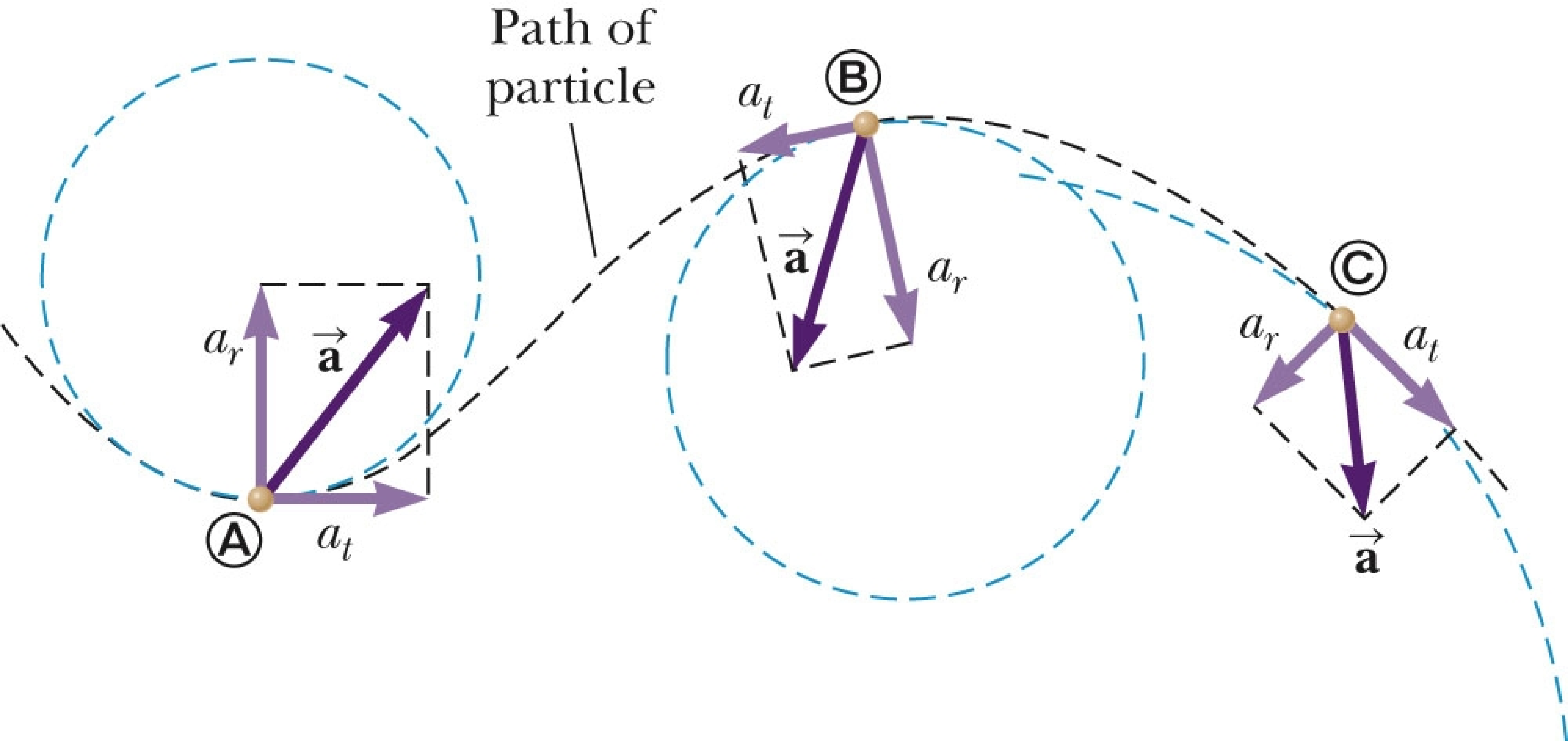
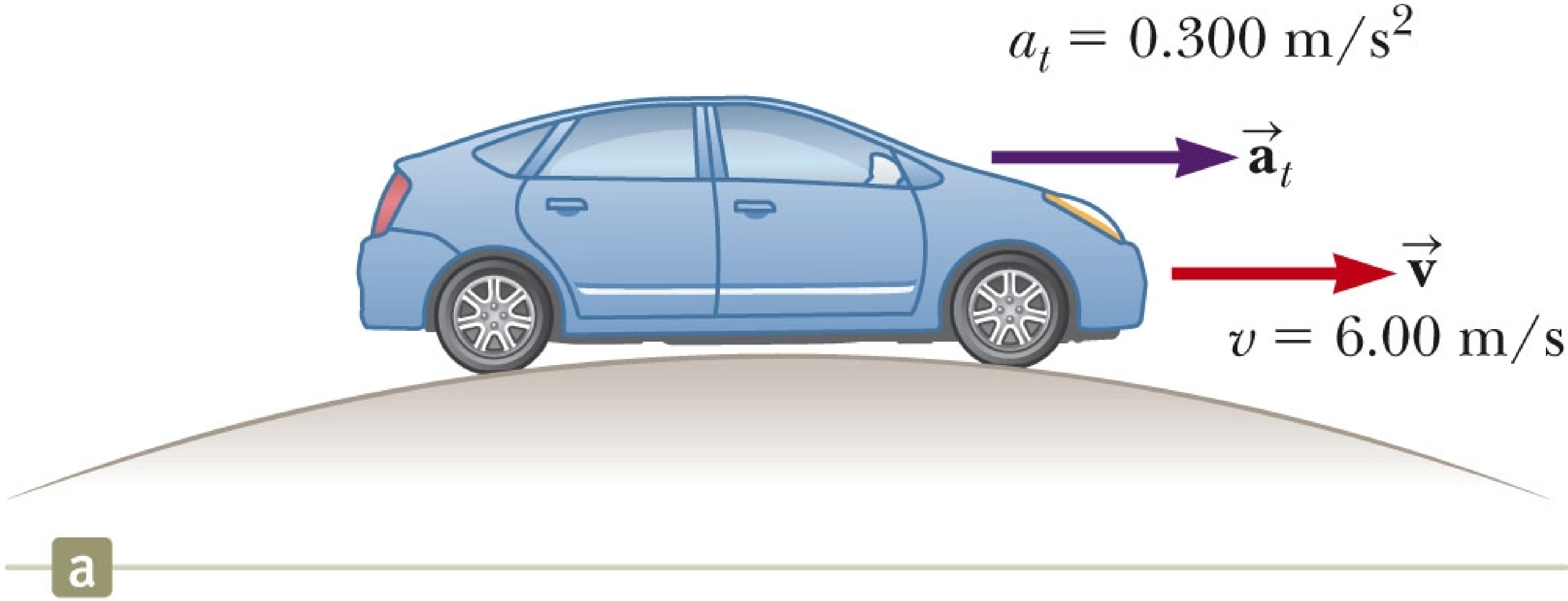



Fig. 4.16, p. 88


$a_t = 0.300 \text{ m/s}^2$
$\vec{\mathbf{a}}_t$
$\vec{\mathbf{v}}$
$v = 6.00 \text{ m/s}$
a

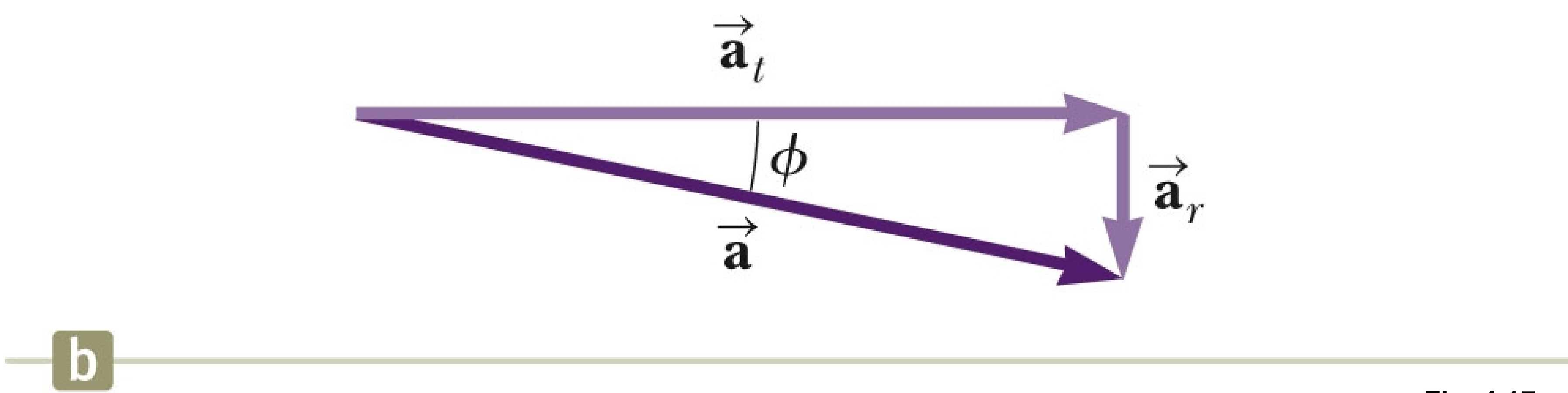

$\vec{\mathbf{a}}_t$
$\phi$
$\vec{\mathbf{a}}_r$
$\vec{\mathbf{a}}$
b

Fig. 4.17, p. 89