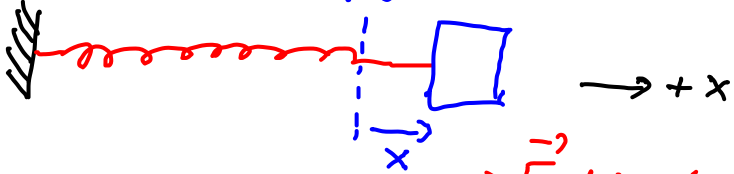
Recap

- **Springs:**

$\longleftarrow \vec{F}_{\text{spring on object}}$



$\longrightarrow \vec{F}_{\text{object on spring}}$

Hooke's "law" for an ideal spring:

$F_{\text{spring on obj.}} = -kx$

restoring force

$F_{\text{obj. on spring}} = +kx$

- Parallel springs: $k_{eff} = k_1 + k_2 + k_3 + \ldots$
- Series of springs: $\frac{1}{k_{eff}} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \ldots$

- **Solid on Solid Friction:**
  - force ∥ to interface between two surfaces that opposes relative motion

Case 1: Static friction force $\vec{f}_s$:

- no relative motion of surfaces in contact
- self-adjusts to prevent relative motion, up to maximum: $(f_s)_{max} = \mu_s N$

Recap

⇒ static friction:

$$f_s \le (f_s)_{max} = \mu_s N$$

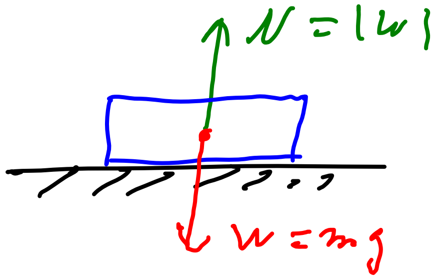
$\le$: self-adjust

μ_s: coefficient of static friction

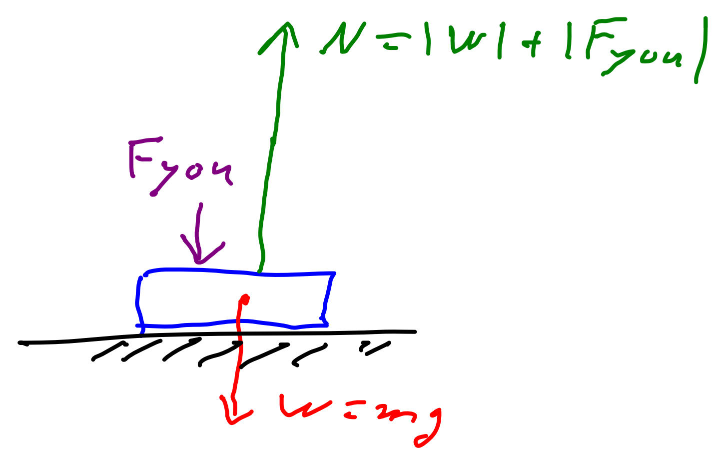
N ← normal force, = force $\perp$ to surface, pressing surfaces together

Note: $|N|$ is not necessarily equal to $|W|$!

Example:



$\sum \vec{F} = 0$



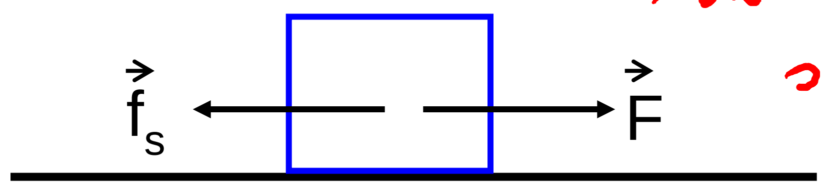
As the applied force F is increased, how does the static friction force f_s vary? (Assume F is less than that needed to make the block move.)

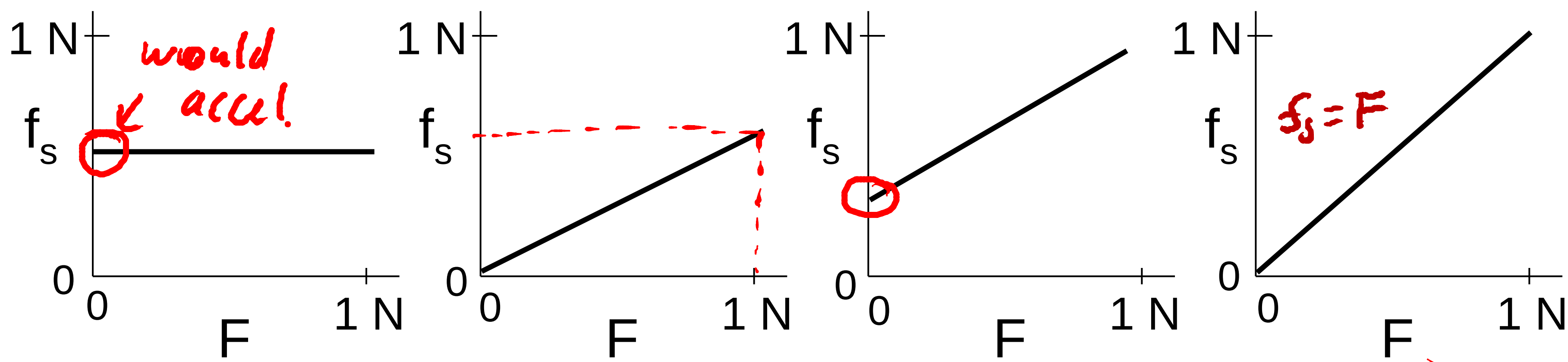
$\vec{a} = 0 \Rightarrow \Sigma \vec{F} = 0$ here

$\Rightarrow F = f_s$

self-adjusts!

Note: If $F > (f_s)_{max}$, surfaces will begin to slip!

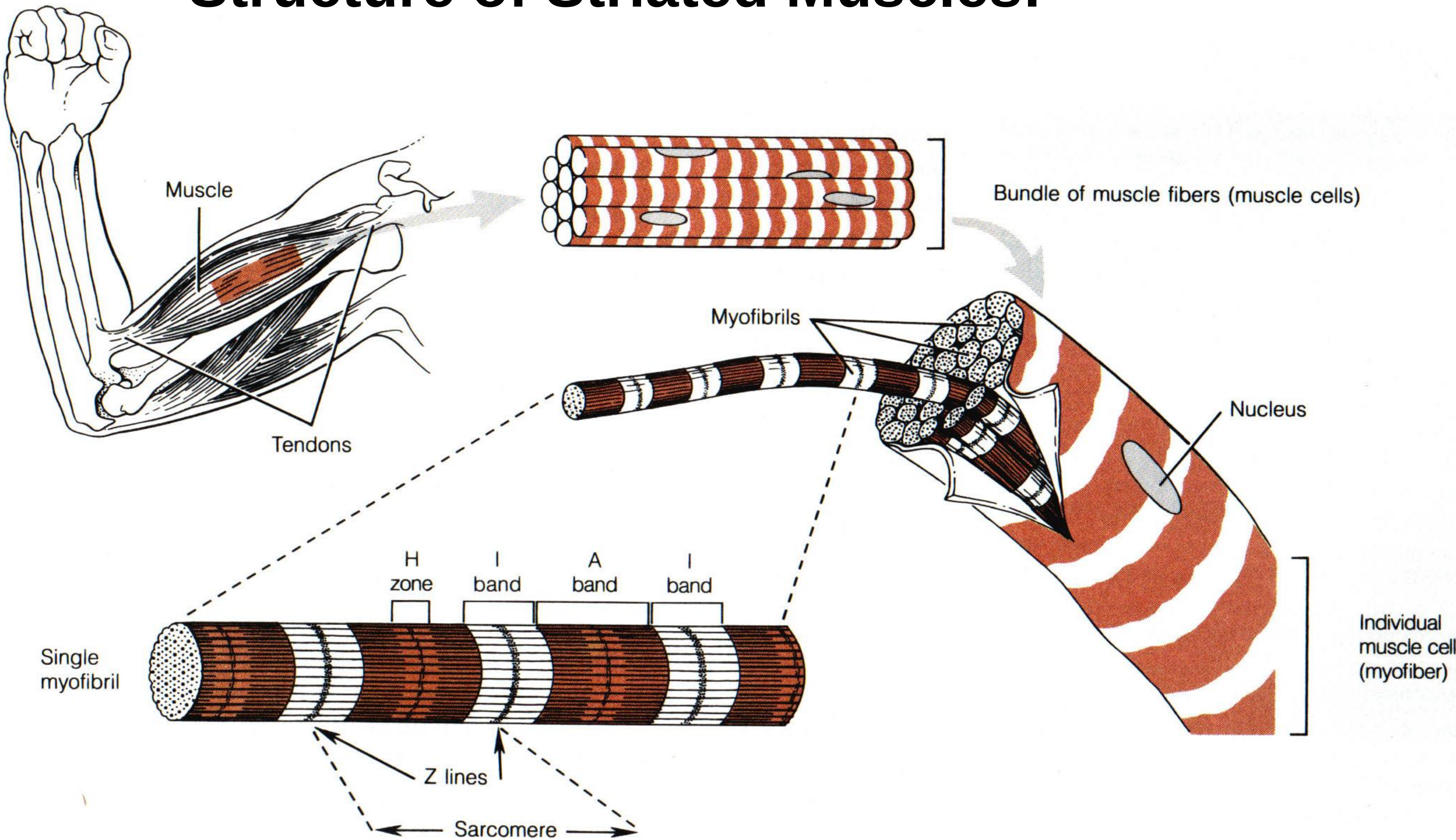




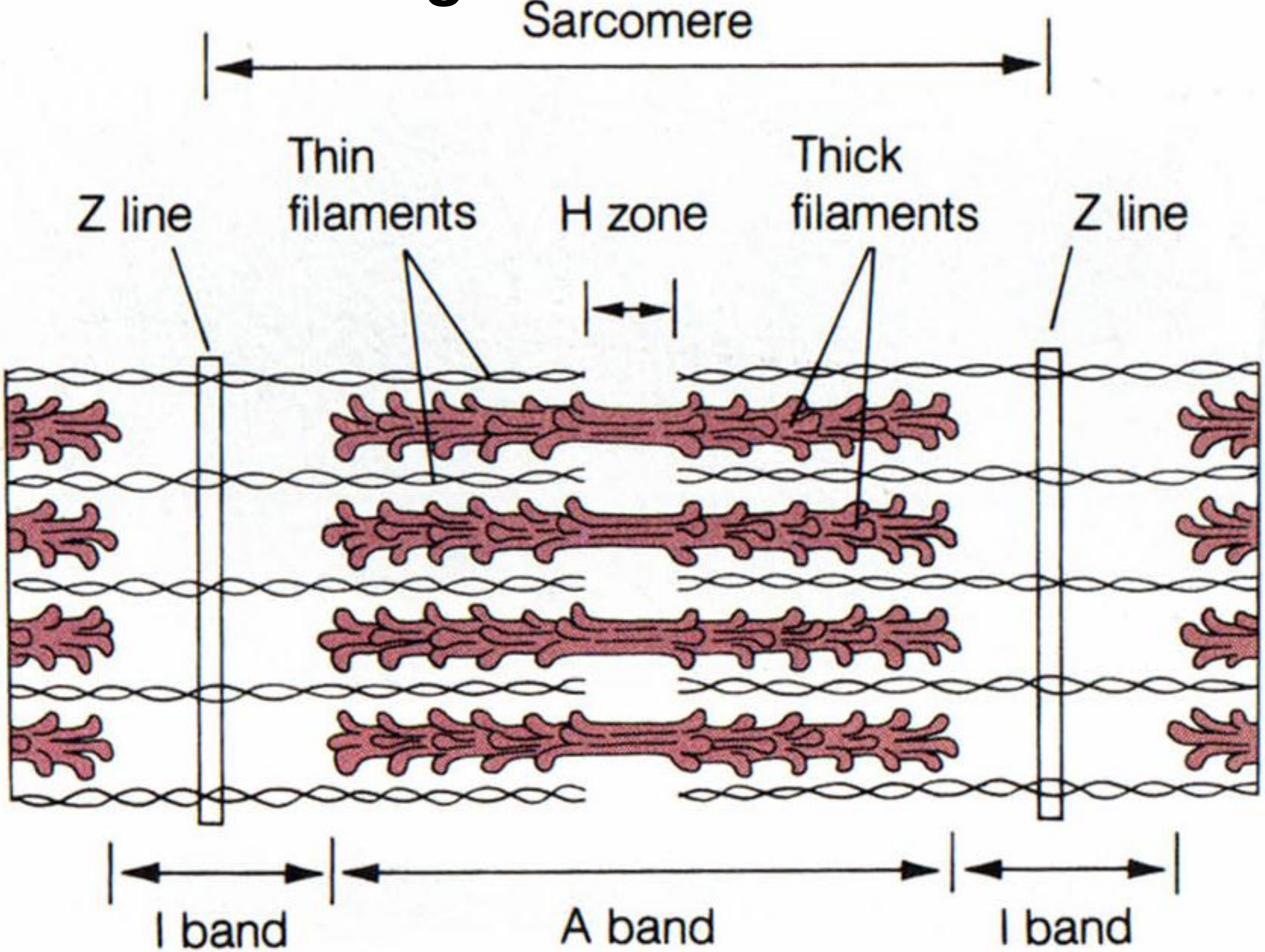
~~(A)~~ ~~(B)~~ ~~(C)~~ (D)

Series and Parallel Combinations in Muscle

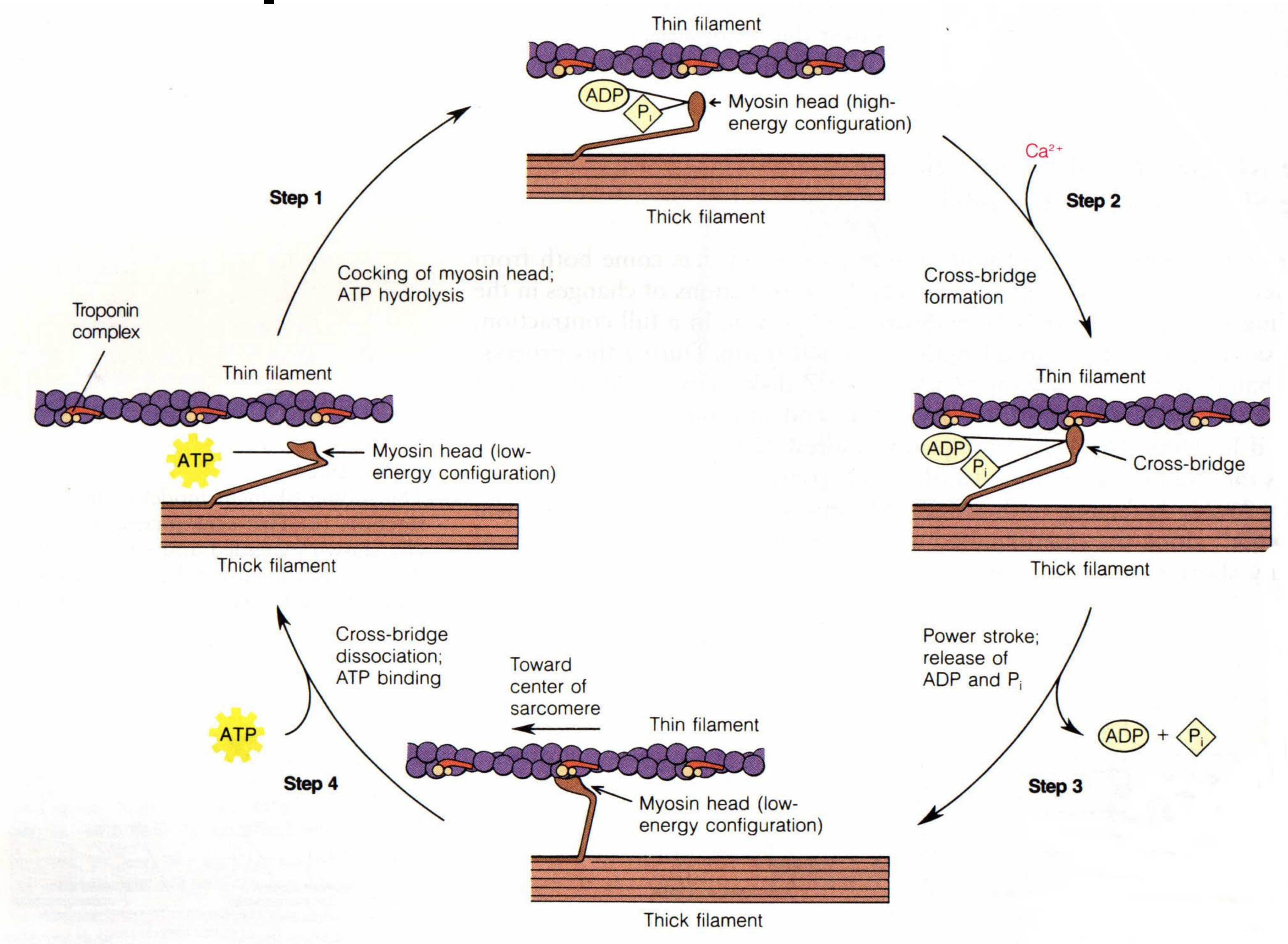
Structure of Striated Muscles:



Basic Building Block: The Sarcomere



Microscopic mechanism of muscle force production and contraction:



Some Numbers:

Sarcomere length:

fully extended: **2.3 μm**

fully contracted: **1.0 μm**

Force per myosin head: **~ 5 pN** = 5×10^{-12} N.

How to get a big motion/contraction?

- Connect M sarcomeres together ***in series*****:**

$\Delta x_{tot} = M \times (\Delta x$ of one sarcomere$)$

Muscle contracts by ~40% of its length.

How to get a big motion/contraction?

- Connect M sarcomeres together ***in series*:**

  $\Delta x_{tot} = M \times (\Delta x$ of one sarcomere$)$
  Muscle contracts by ~40% of its length.

How to get a big force?

- Connect N actin filaments together ***in parallel*:**

  $F_{tot} = N \times$ # of parallel filaments

How to get a big motion/contraction?

- Connect M sarcomeres together ***in series*:**

  Δx_{tot} = M × (Δx of one sarcomere)
  Muscle contracts by ~40% of its length.

How to get a big force?

- Connect N actin filaments together ***in parallel*:**

  F_{tot} = N × # of parallel filaments

For typical striated muscle,

$F_{max} \approx$ 30 N for each cm^2 of muscle cross-sectional area.

Today:

- **Kinetic friction**
- **What force acting on a car produces its acceleration?**

Case (2): Kinetic friction force $\vec{f}_K$ ("sliding" friction)

- relative motion of surfaces in contact (sliding)
- kinetic friction f_K ~ independent of F, a, relative velocity of surfaces
- good model:

$$f_K = \mu_K \cdot N$$

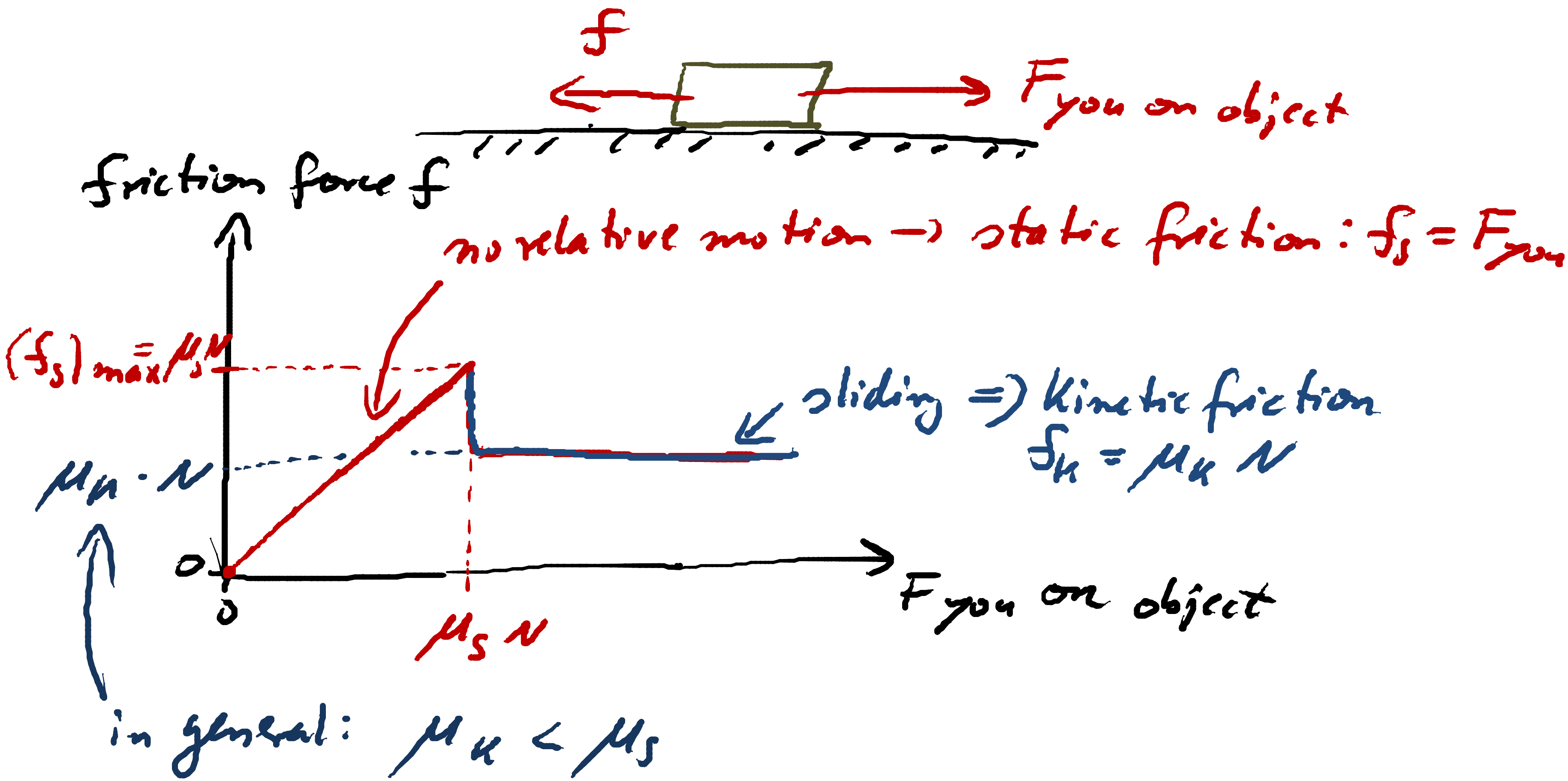
N ← magnitude of normal force, pressing surfaces together

μ_K ← coefficient of kinetic friction

in general: $\mu_K < \mu_S$

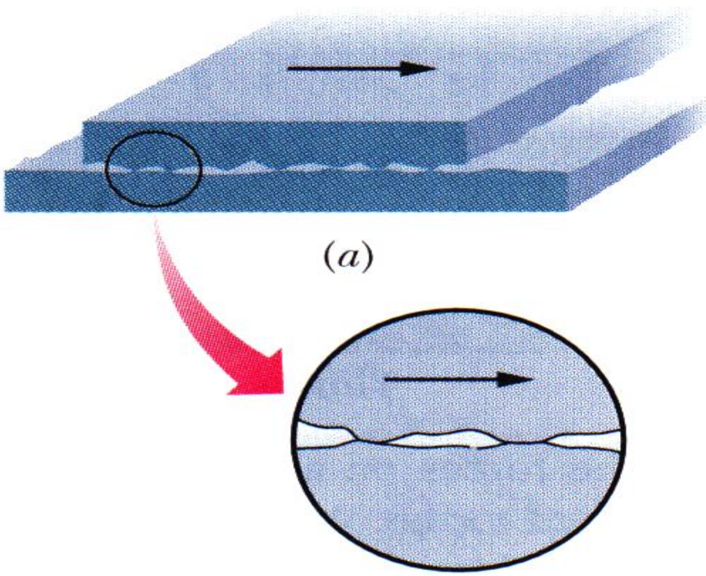
- friction force always opposes relative motion, but can act opposite to the direction of motion or in direction of motion!

Model for friction force f:



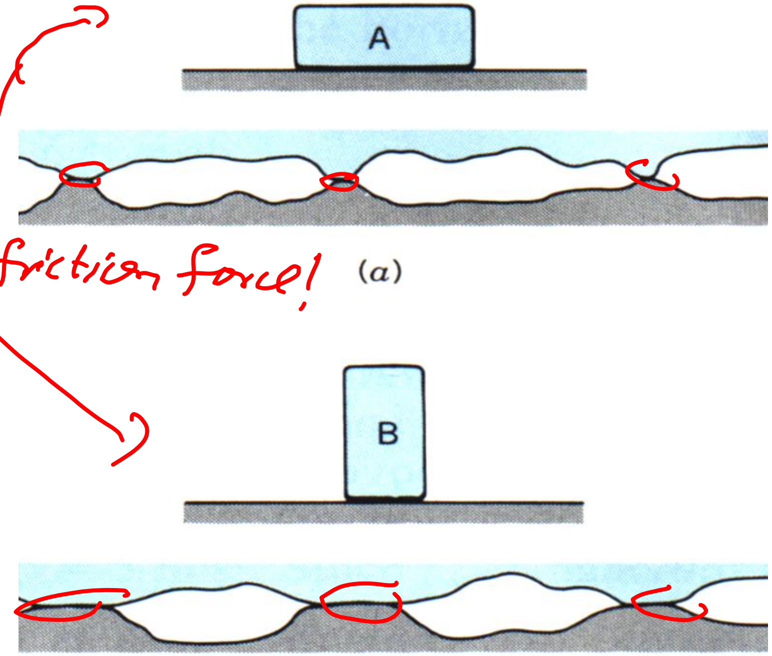
Microscopic Origin of Friction:

$(f_s)_{max} = \mu_s N$
$f_k = \mu_k N$ } indep. of surface area



(a)

(b)



(a)

Same friction force!

(b)

Coefficients of Friction[a]

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

[a] All values are approximate.

general: $\mu_s > \mu_k$

A car accelerates on a level road. What force acting on the car produces its acceleration?

$\vec{F}_{\text{acting on car}} = m\vec{a}_{\text{car}}$

car

in direction of motion!

internal force

no relative motion of road-tire surfaces in contact

$\Rightarrow$ static friction!

need force on car

~~A.~~ The force of the engine on the wheels

~~B.~~ The static friction force of the tires on the road

C. The static friction force of the road on the tires

~~D.~~ The kinetic friction force of the tires on the road

~~E.~~ The kinetic friction force of the road on the tires

The coefficients of static and kinetic friction between tires and the road don't vary significantly with the mass of a car.

How does the stopping distance Δ*x* of a car with mass *m* compare with that of a car with mass 2m? (Assume the cars have the same initial speed.)

Δ*x* (2*m*) / Δx (*m*) = ?

A. 1/4

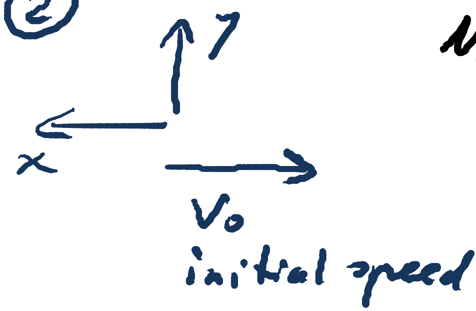
B. 1/2

C. 1

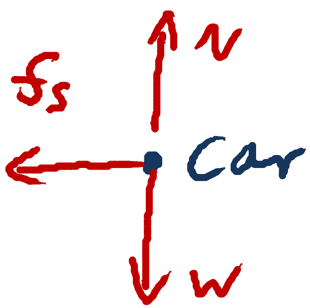
~~**D.**~~ 2

E. 4

2



3 FBD:



NII: $\Sigma F_y = m a_y = 0$

$= N - W = mg$

$\Rightarrow N = W = mg$

$\Sigma F_x = m a_x = f_s \le (f_s)_{max}$

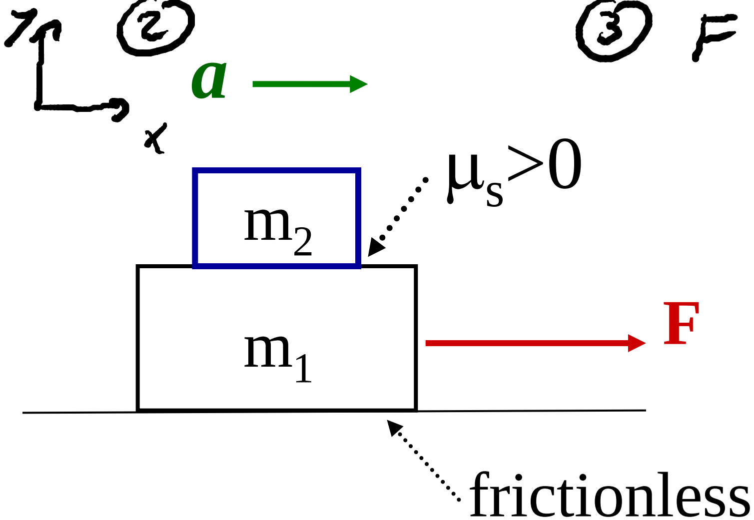
$$\Rightarrow (a_x)_{max} = \frac{(f_s)_{max}}{m} = \frac{\mu_s N}{m} = \frac{\mu_s m g}{m}$$

$$\Rightarrow \boxed{(a_x)_{max} = \mu_s g}$$ indep. of mass

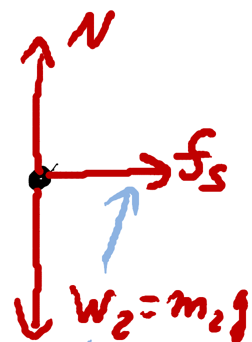
$\Rightarrow$ Δx indep. of m_{car}!

What is the maximum acceleration a that F can produce and still have the two blocks move together?

②



③ FBD of m_2:



friction force in direction of motion!

a_{max} = ?

A. g

~~B.~~ $\mu_s\, m_2\, g$ units!

~~C.~~ $\mu_s\,(m_1 + m_2)\, g$

D. $\mu_s\, g$

E. Insufficient information

N II: $\Sigma F_y = m_2 a_y$

$= 0 = N - W_2 \Rightarrow N = W_2 = m_2 g$

$\Sigma F_x = m_2 a_x = m_2 a = f_s \le (f_s)_{max}$

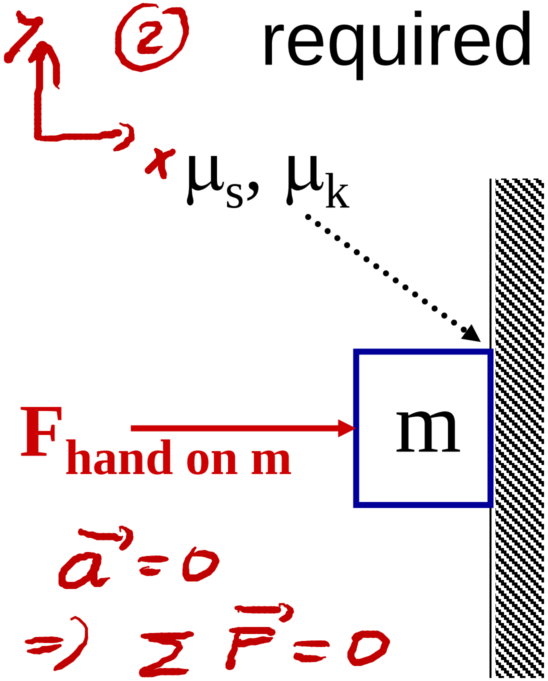
$\Rightarrow m_2 (a)_{max} = (f_s)_{max} = \mu_s N = \mu_s m_2 g$

$\Rightarrow \boxed{(a)_{max} = \mu_s g}$

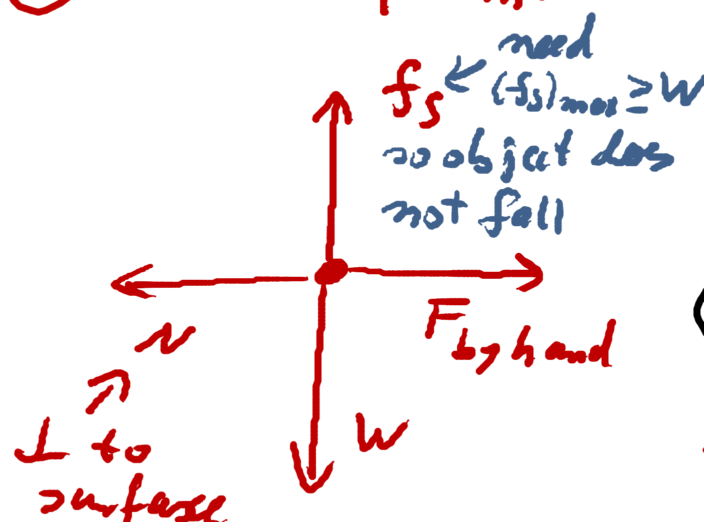
static friction force on m_2 generates accel of m_2

What is the minimum magnitude of $F_{hand\ on\ m}$ required so that the block doesn't fall?

②



③ FBD of m:



$\vec{a} = 0$

$\Rightarrow \Sigma \vec{F} = 0$

F_{min} = ?

A. mg

B. μ_s mg

C. mg / μ_s

~~D.~~ μ_k mg

~~E.~~ mg / μ_k

$$\Sigma F_x = m a_x = 0 = F_{hand} - N$$

$$\Rightarrow N = F_{hand\ on\ mass}$$

$$\Sigma F_y = m a_y = 0 = f_s - W = f_s - mg$$

$$\Rightarrow mg = f_s \le (f_s)_{max} = \mu_s N = \mu_s \cdot F_{by\ hand}$$

$$\Rightarrow F_{min} = mg/\mu_s$$