Lecture 4

Newton’s 3rd law
and
Friction

Newtons First Law
or Law of Inertia

If no net external force is applied to an object, its velocity will remain constant ("inert").

OR

A body cannot change its state of motion without outside influence.

Newton's Second Law

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

where $\underline{F}_{net}$ is the resultant or "net" force on a body (N), m is its mass (kg), and $\underline{a}$ is acceleration (ms^{-2}).

Consequences:

- If sum of all forces on a body does not add to zero, then acceleration occurs; and
- If a body is accelerating, there must be a force on it.

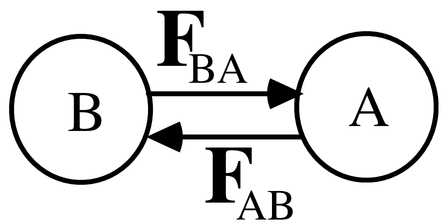
KJF §4.6

Newton's Third Law

For every action (force) there is an equal and opposite reaction (counter-force)

or

$$\underline{F}_{\mathrm{BA}} = -\underline{F}_{\mathrm{AB}}$$

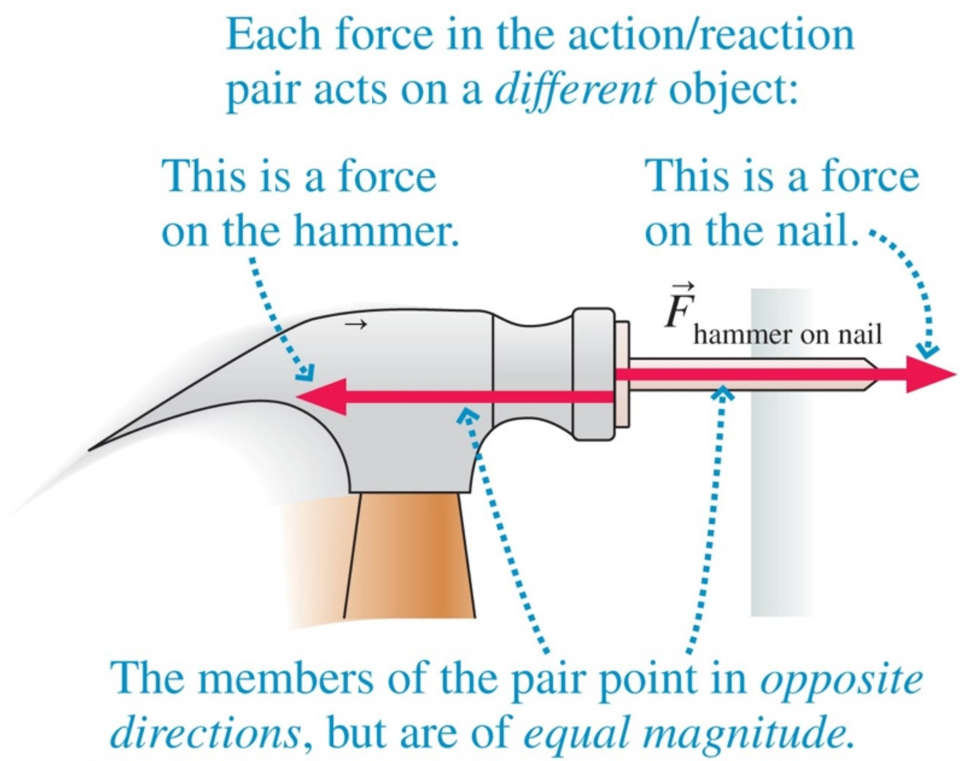


So, why does anything move at all?

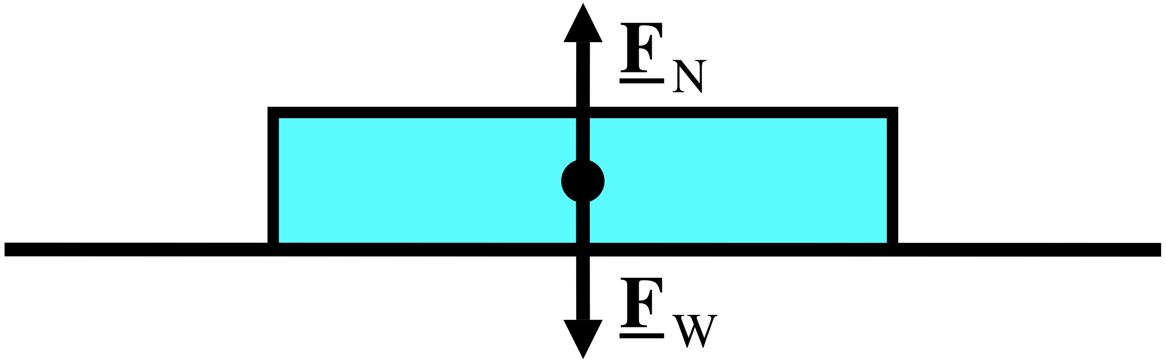
Remember:
Although all forces are paired, the Action (force) and the Reaction (force) are NOT exerted on the same object.

KJF §4.8

- The action/reaction forces act on *different* objects
- The action/reaction forces point in *opposite* directions and are *equal* in magnitude



Example: Book on table

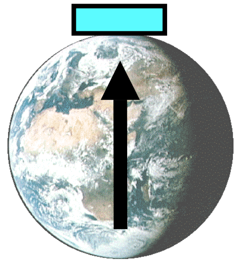


Choose our "system": the book

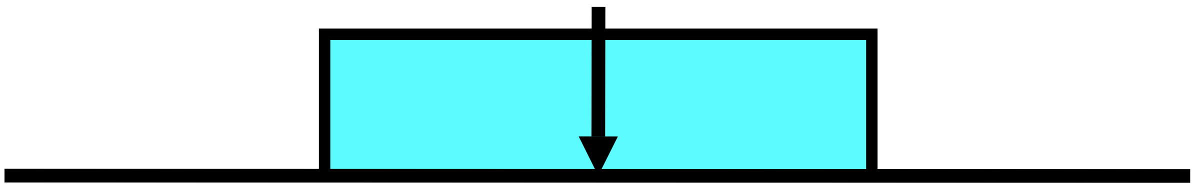
Forces ON the book are
(1) Force from attraction to earth – Weight
(2) Force from table – Normal Force

action-reaction pair?

NO! These are not an action-reaction pair even though they are equal and opposite



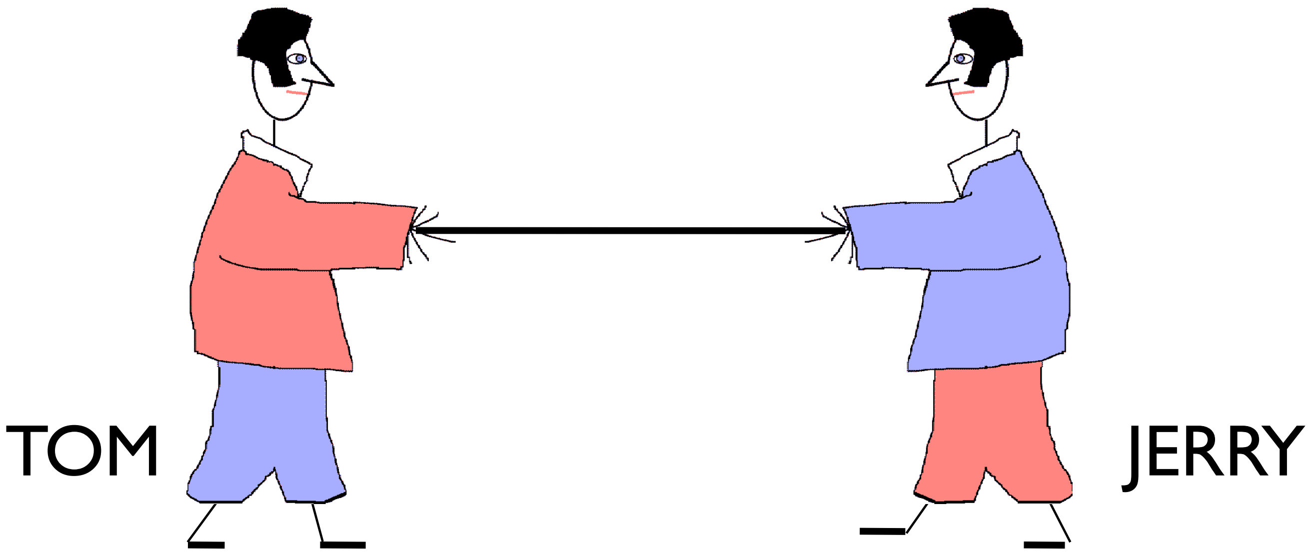
- Reaction to (1) is the force of gravitational attraction **BY** book on earth



- Reaction to (2) is the force **BY** book on table

Hecht §4.4

Problem: Tug of War



- Draw in forces acting ON Tom
- Draw in forces acting ON Jerry
- Draw in forces acting ON the rod
- Identify action/reaction pairs

Problem

A worker drags a crate across a factory floor by pulling on a rope tied to the crate. The worker exerts a force of 450 N on the rope, which is inclined at 38° to the horizontal, and the floor exerts a horizontal friction of 125 N that opposes the motion. You can assume the crate doesn't leave the ground.

a) Calculate the acceleration of the crate (mass = 310 kg).

b) Calculate the normal force by the floor on the crate.

[0.74 ms^{-2}, 2.7 kN]

Another Problem

A 50 kg skier is pulled up a frictionless ski slope that makes an angle of 8° with the horizontal, by holding onto a ski rope that moves parallel to the slope. Determine the magnitude of the force of the rope on the skier at an instant when:

a) the rope is moving with constant speed of 2.0 ms^{-1}, and

b) the rope is moving with a speed of 2.0 ms^{-1}, but that speed is increasing at a rate of 0.10 ms^{-2}.

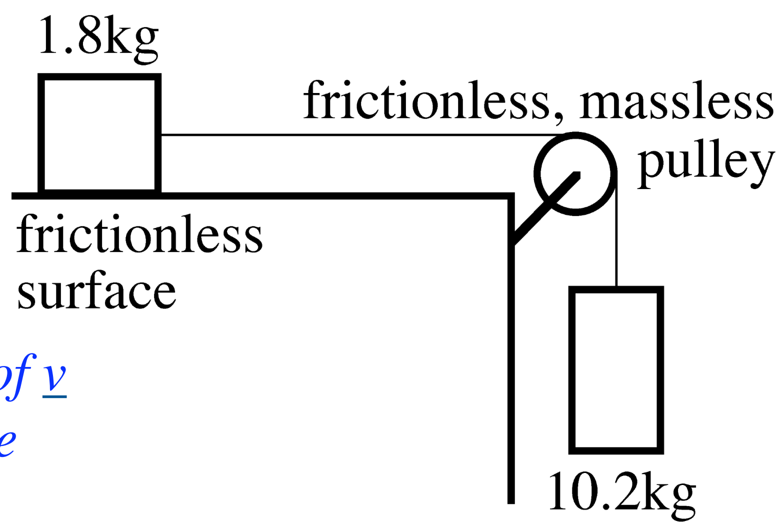
[68N, 73N]

And yet more..

A problem with pulley, weights and string:

a) Find the magnitude of acceleration of the blocks

b) Find the tension in the string

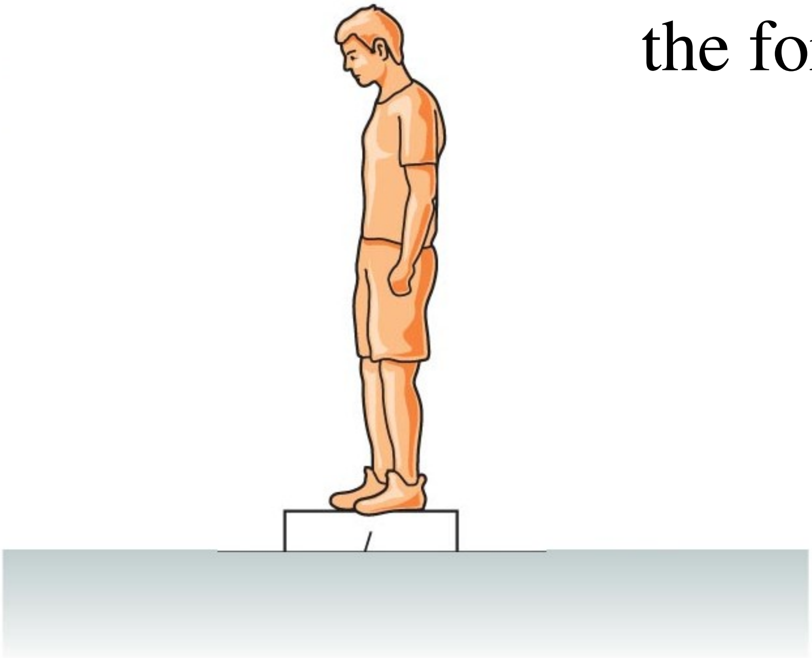


Note; for an ideal string the magnitudes of v & a (along the string direction) are the same at both ends*

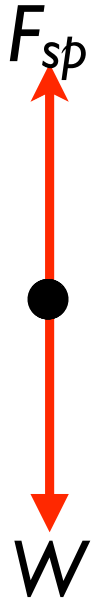
**inextensible, with negligible mass & stiffness*

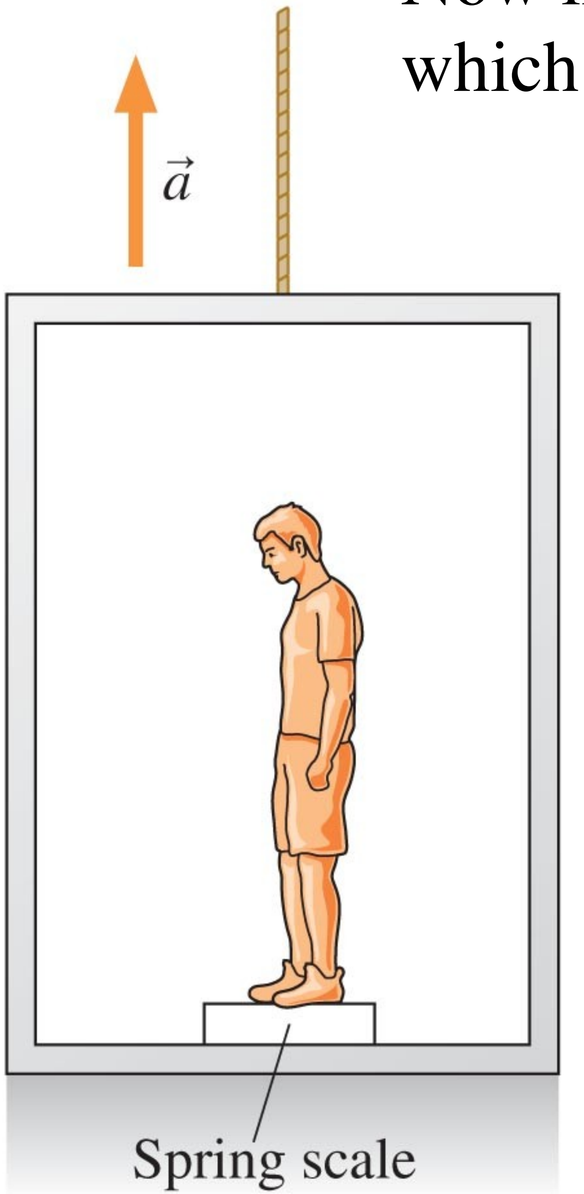
Apparent weight

Consider a man standing on a spring scale



The only forces acting on the man are the weight force and the force of the spring.





Now imagine he weighs himself in a lift which is accelerating upwards.

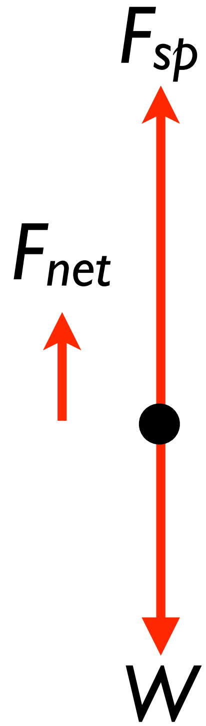
Since he is accelerating, there must be a net force

$$F_{net} = F_{sp} - W = ma_y$$

or

$$F_{sp} = W + ma_y$$

i.e. the scale reads heavier.



Apparent weight is given by the magnitude of the normal force.

FRICTION

KJF §4.3, 5.5

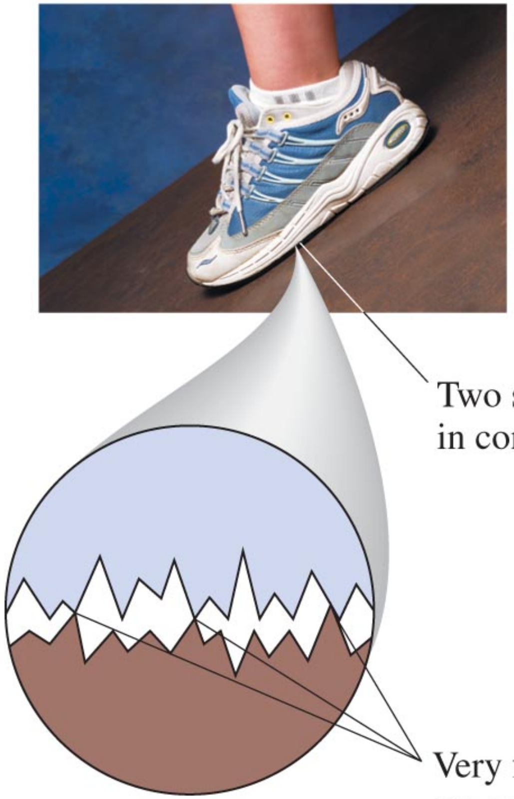
Frictional Forces

Friction is a force exerted by a surface. The frictional force is always *parallel* to the surface

Due to roughness of both surfaces & microscopic "cold welding"

Proportional to normal force

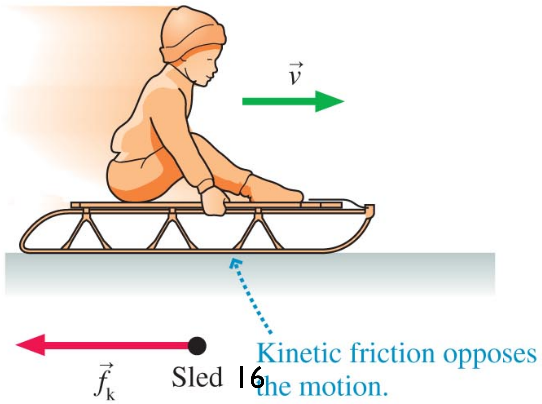
Always acts in the direction opposite to the slippage direction

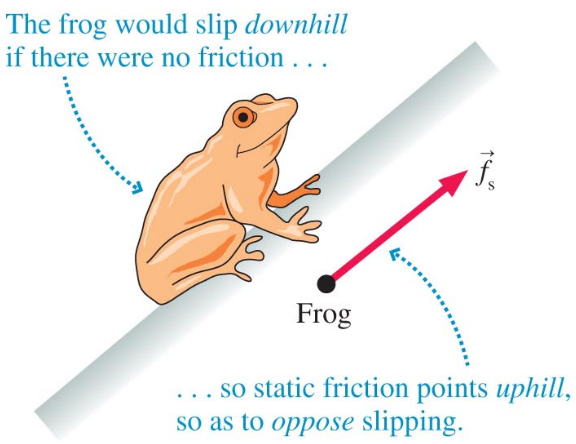


KJF §4.3, 5.5

Three kinds of friction:

- *Static friction*: acts to prevent motion, so points opposite to the direction the object would move in the absence of friction
- *Kinetic friction*: appears when an object slides across a surface; points opposite to the direction of motion
- *Rolling friction*: one surface rolling over another





Coefficient of Friction μ

μ is a measure of strength of friction.
Scalar. No units - dimensionless

- Depends on BOTH surfaces
- Doesn't depend on size of contact area

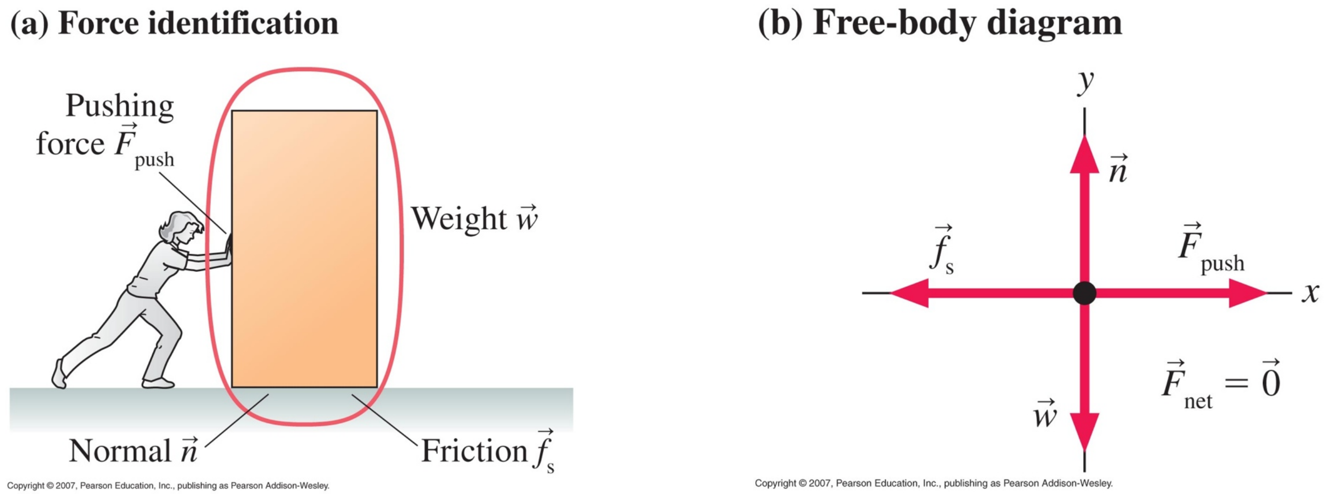
Usually:

$$\mu_s > \mu_k > \mu_r$$

Microscopic theory of friction very complex - cannot yet theoretically predict μ values

KJF §5.5

Properties of friction



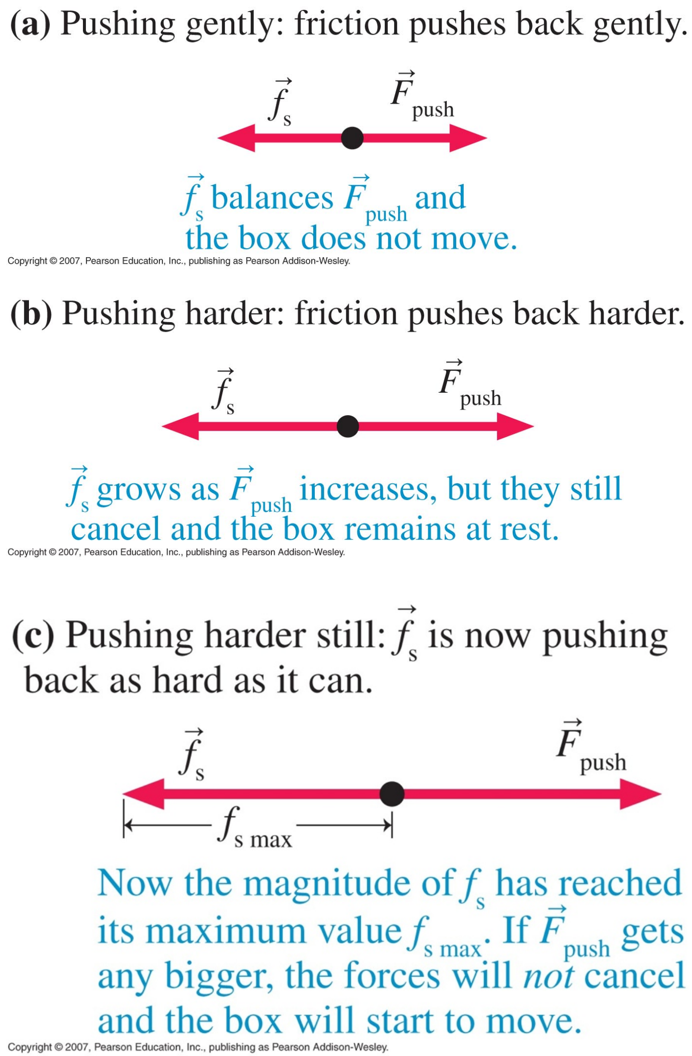
A. Consider a person pushing a box on a horizontal surface with force $\underline{F}_p$. If the box does not move (*static friction*), then

$$\underline{F}_s = -\underline{F}_p$$

i.e. the static frictional force $\underline{F}_s$ adjusts itself to be exactly equal and opposite to $\underline{F}_p$

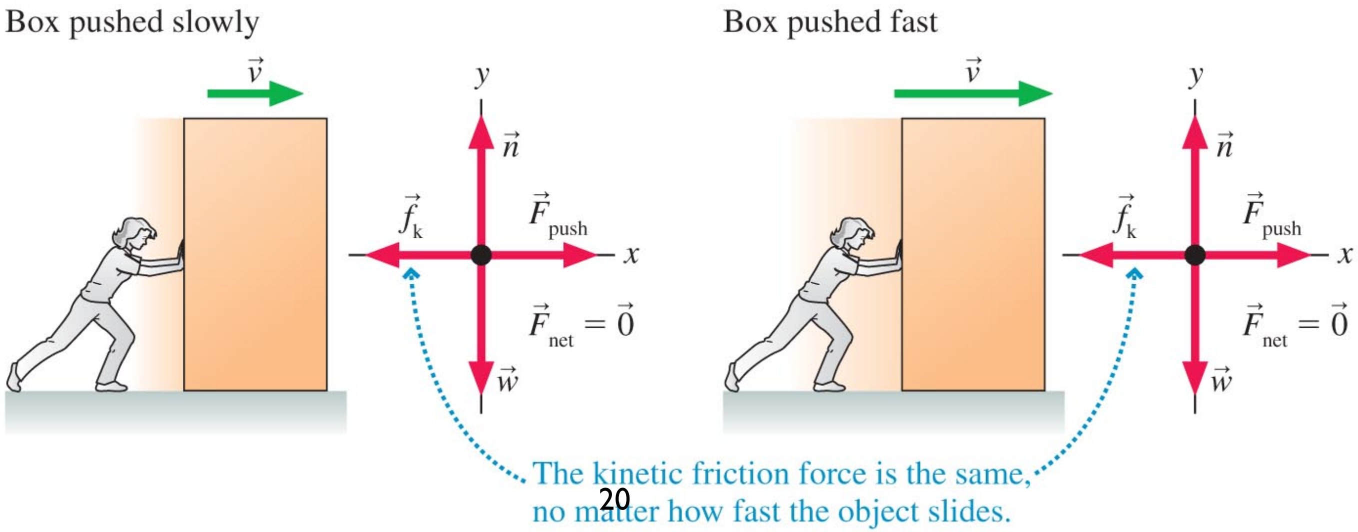
B. As you increase the pushing force, eventually the object will slip and start to move. The *maximum* static friction force has magnitude

$$F_{s(max)} = \mu_s N$$



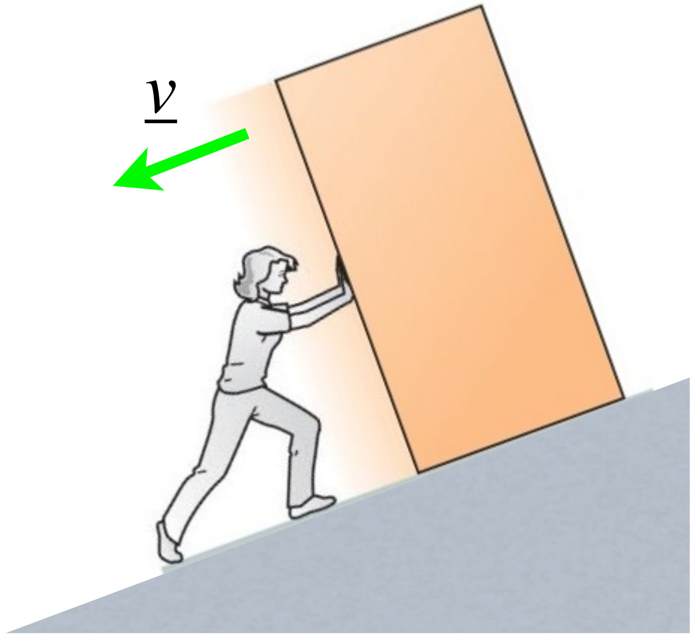
C. Once the box starts to slide, the static friction force is replaced by a kinetic (or sliding) friction force. The direction is opposite to the motion, and the magnitude is constant

$$F_k = \mu_k N$$



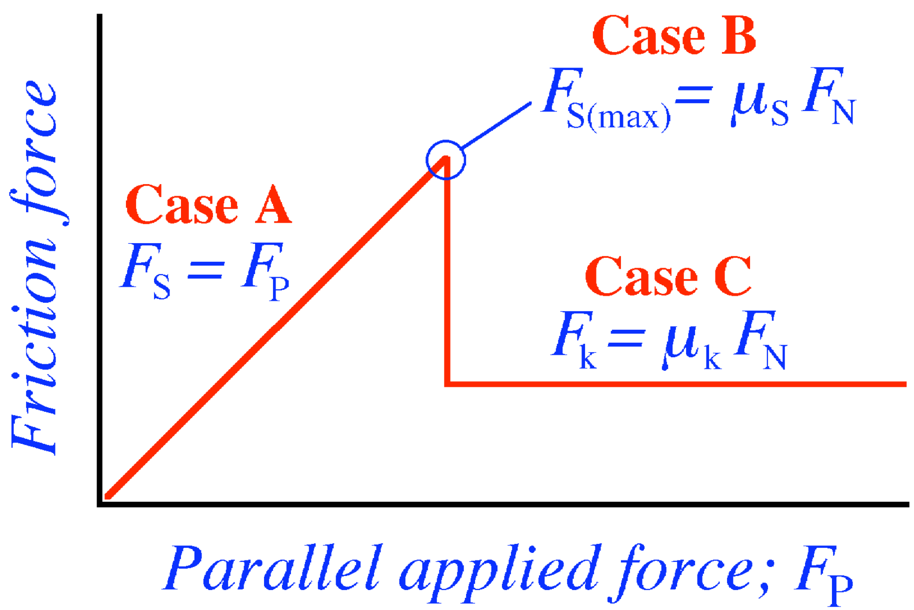
Direction of kinetic friction

You are pushing a box uphill.
Which direction does the friction point?
Draw a free-body diagram.



What if the box slid *down* the hill, even though you were still pushing it?

Properties of Friction



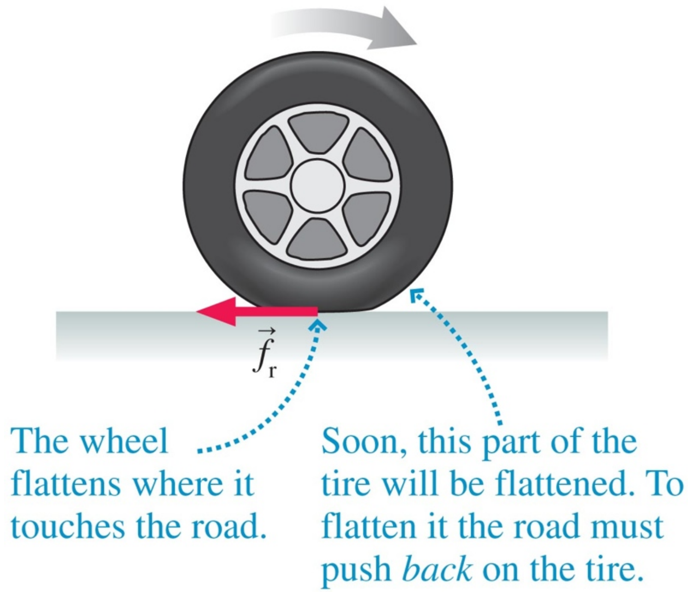
This graph is an idealisation. In softer, stickier materials like rubber, the transition from static to kinetic is not so sharp

Rolling friction

Wheel is compressed by road as it rolls.
This results in a horizontal component of force that resists motion.

Behaves very similarly to kinetic friction (but much smaller); Roughly constant, proportional to normal force

$$F_r = \mu_r N$$



Don't confuse static friction in tyres with rolling friction. (Static friction keeps tyres gripping the road)