Lecture 4

Friction

and

Newton's 3rd law

Pre-reading: KJF §4.8

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"
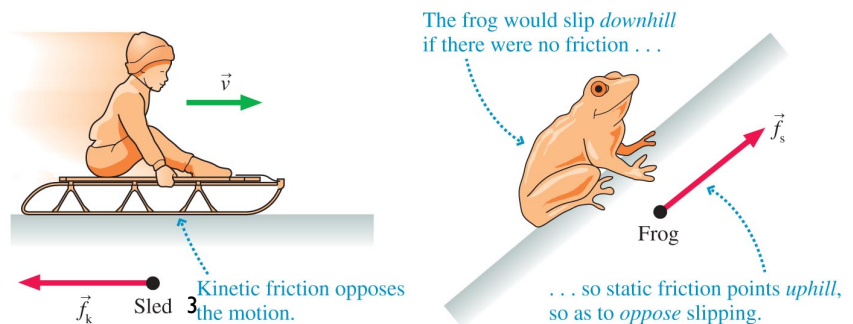
Proportional to normal force

Always acts in the direction opposite to the slippage direction

Two surfaces in contact

Very few points are actually in contact.
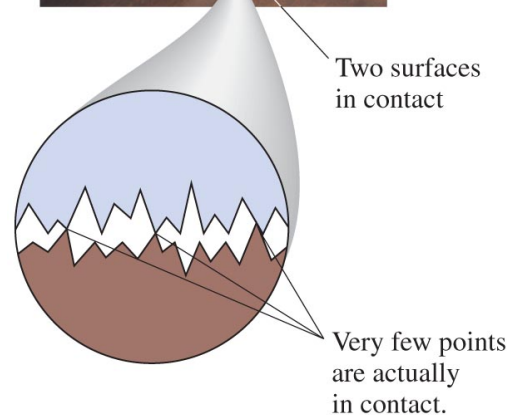
Three kinds of friction:

- *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

The frog would slip *downhill* if there were no friction . . .

$\vec{v}$

$\vec{f}_s$

Frog

Kinetic friction opposes the motion.

$\vec{f}_k$ Sled **3**

. . . so static friction points *uphill*, so as to *oppose* slipping.

Coefficient of Friction μ

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

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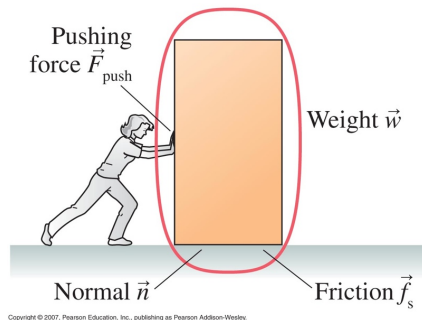- Doesn't depend on size of contact area

Usually:

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

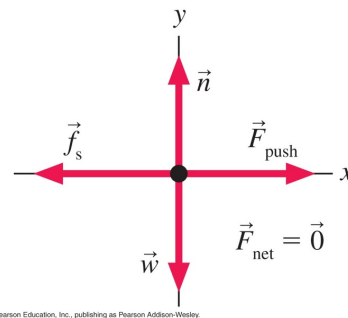*Microscopic theory of friction very complex - cannot yet theoretically predict μ values*

Properties of friction

(a) Force identification

Pushing force $\vec{F}_{push}$

Weight $\vec{w}$

Normal $\vec{n}$ Friction $\vec{f}_s$

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(b) Free-body diagram

y

$\vec{n}$

$\vec{f}_s$ $\vec{F}_{push}$

x

$\vec{w}$

$\vec{F}_{net} = \vec{0}$

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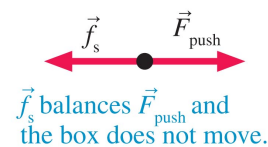
$$\underline{F}_s = -\underline{F}_p$$

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

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

(a) Pushing gently: friction pushes back gently.

$\vec{f}_s$ $\vec{F}_{push}$

$\vec{f}_s$ balances $\vec{F}_{push}$ and the box does not move.

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(b) Pushing harder: friction pushes back harder.

$\vec{f}_s$ $\vec{F}_{push}$

$\vec{f}_s$ grows as $\vec{F}_{push}$ increases, but they still cancel and the box remains at rest.

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(c) Pushing harder still: $\vec{f}_s$ is now pushing back as hard as it can.
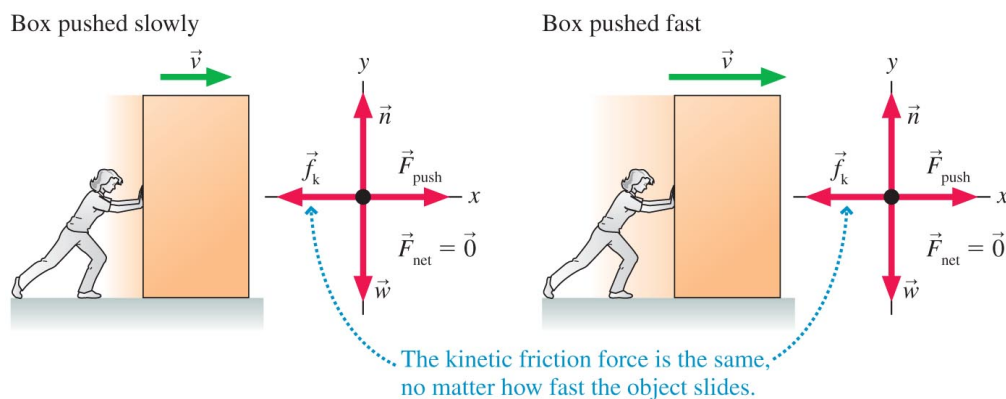

$\vec{f}_s$ $\vec{F}_{push}$

$f_{s\,max}$
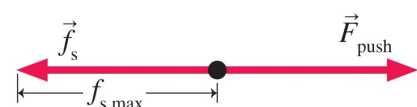
Now the magnitude of f_s has reached its maximum value $f_{s\,max}$. If $\vec{F}_{push}$ gets any bigger, the forces will *not* cancel and the box will start to move.

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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

$$F_k = \mu_k \, N$$

Box pushed slowly

$\vec{v}$

y

$\vec{n}$

$\vec{f}_k$ $\vec{F}_{push}$ x

$\vec{F}_{net} = \vec{0}$

$\vec{w}$

Box pushed fast

$\vec{v}$

y

$\vec{n}$

$\vec{f}_k$ $\vec{F}_{push}$ x

$\vec{F}_{net} = \vec{0}$

$\vec{w}$

The kinetic friction force is the same, no matter how fast the object slides.

Direction of kinetic friction

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

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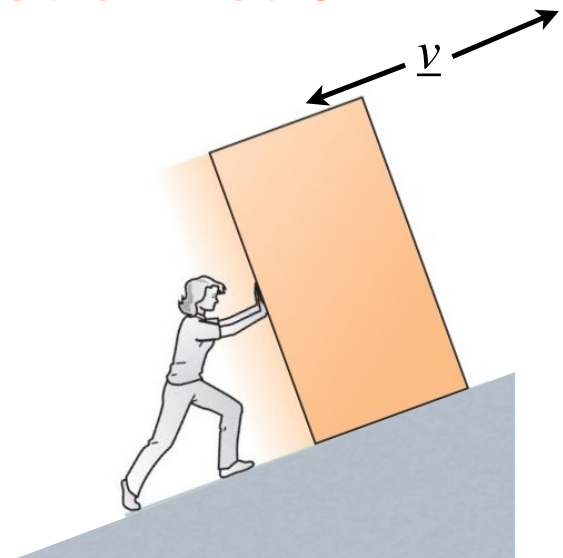
What if the box slid *down* the hill, even though you were still pushing it?

Properties of Friction

Case B
$F_{S(max)} = \mu_S N$

Case A
$F_S = F_P$

Case C
$F_k = \mu_k N$

Friction force

Parallel applied force; F_P
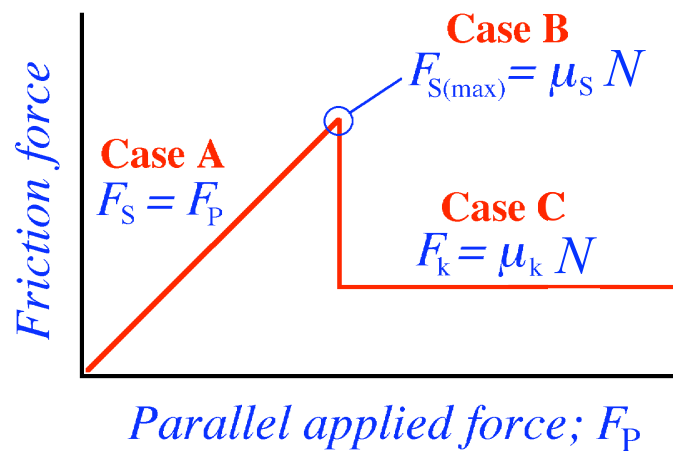
This graph is an idealisation. In softer, stickier materials like rubber, the transition from static to kinetic is not so sharp
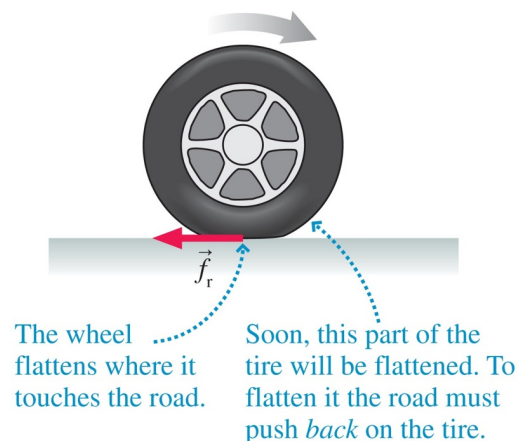
Rolling friction

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)*

$\vec{f}_r$

The wheel flattens where it touches the road.

Soon, this part of the tire will be flattened. To flatten it the road must push *back* on the tire.

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Problem

The coefficient of static friction between teflon and scrambled eggs is about 0.04.

What is the smallest angle from the horizontal that will cause the eggs to slide across the bottom of a teflon-coated pan?
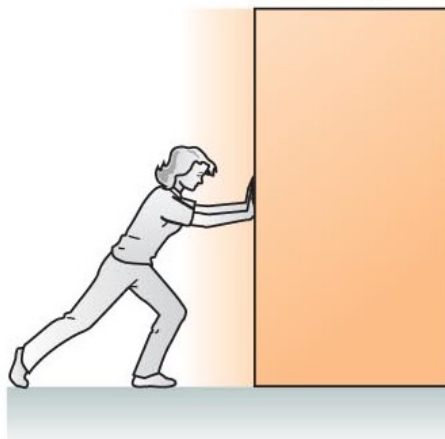
[2°]
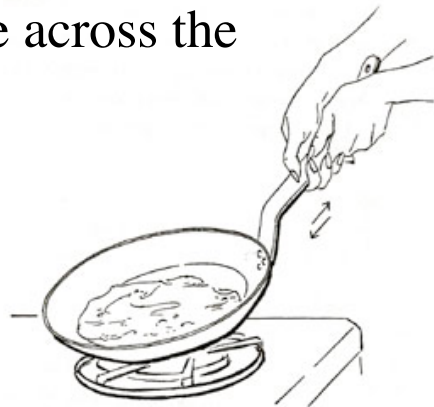
Problem 2

You push a 100.0 kg box along the ground with constant horizontal force 600.0 N. For box on ground $\mu_k = 0.100$

Find the acceleration.

[5.02 ms^{-2}]

NEWTON'S THIRD LAW

KJF §4.3, 5.5

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

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

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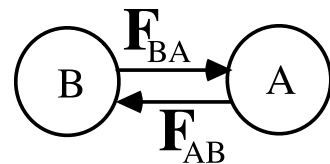
- If a body is accelerating, there must be a force on it.

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Newton's Third Law

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

or

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

So, why does anything move at all?
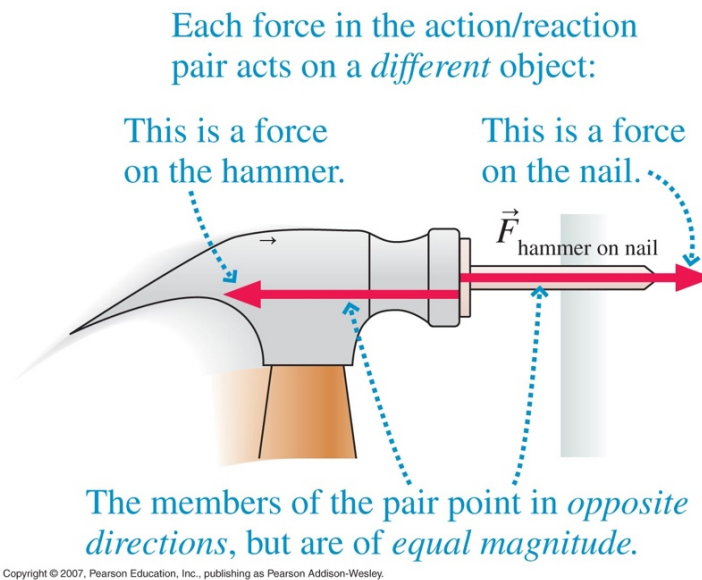
Remember:
Although all forces are paired, the Action (force) and the Reaction (force) are NOT exerted on the same object.
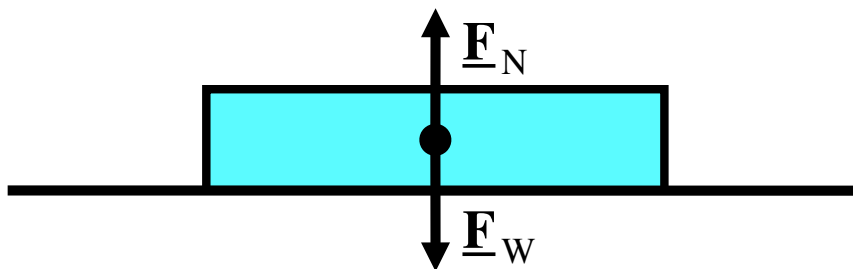
- The action/reaction forces act on *different* objects

- The action/reaction forces point in *opposite* directions and are *equal* in magnitude

Each force in the action/reaction pair acts on a *different* object:

This is a force on the hammer.

This is a force on the nail.

$\vec{F}_{\text{hammer on nail}}$

The members of the pair point in *opposite directions*, but are of *equal magnitude*.

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Example: Book on table
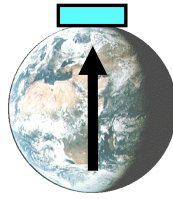
$\underline{\mathbf{F}}_N$

$\underline{\mathbf{F}}_W$

Choose our "system": the book

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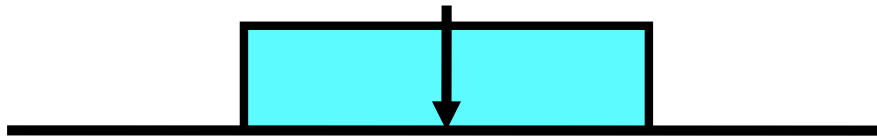(1) Force from attraction to earth – Weight
(2) Force from table – Normal Force

action-reaction pair?

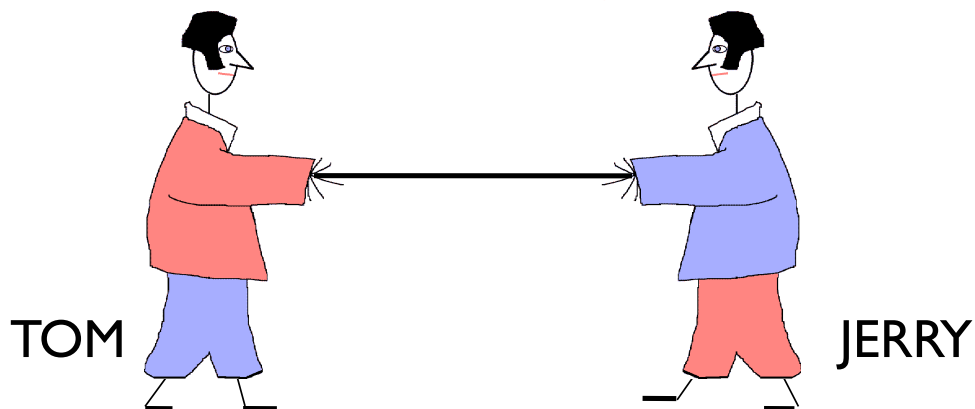*NO! These are not an action-reaction pair even though they are equal and opposite*

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

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

Problem: Tug of War

TOM

JERRY

- 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.

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

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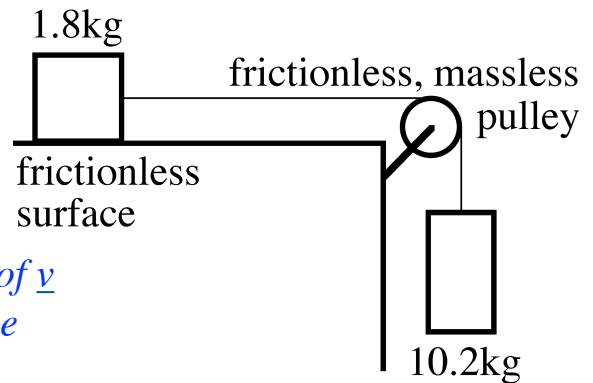
a) the rope is moving with constant speed of 2.0 ms^{-1}, and

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}.

$$[68 \text{N}, 73 \text{N}]$$

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

1.8kg

frictionless, massless
pulley

frictionless
surface

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

10.2kg

*inextensible, with negligible mass & stiffness

NEXT LECTURE

ILD on Newton's third law