Friction, Springs and Scales

Where shoes make a difference

Day 6:
Friction
Springs

Reminders:
Homework 3 due Monday
No HW or new reading next week!
Review lecture Tuesday – email topics to me ASAP
HW sessions: Thurs & Monday
Friday if you email benjamin.simonds@colorado.edu
And Wed with NF if y'all wish…

Summary

Last time

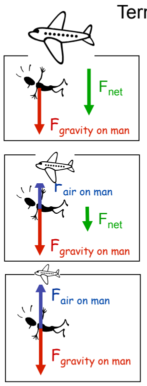
- Net force
  - Terminal velocity
  - (- Car Crashes)

Today

- All about force of friction
  - How big is it?
  - What causes it
- All about springs
  - How is spring force related to extension of spring
  - How to make a spring scale

(- Car Crashes)

Terminal velocity summary

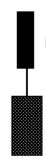


1. Just left plane: Velocity zero, so air resistance zero
   $F_{net} = F_{grav}$
   a = 9.8 m/s^2 downwards
2. Short time after leaving plane: Velocity > 0 so now air resistance partially cancels force of gravity
   $0 < F_{net} < F_{grav}$ downwards
   $0 < a < 9.8$ m/s^2 downwards
3. Some time later: Terminal velocity
   Air resistance exactly cancels force of gravity
   You can't fall faster than this
   $F_{net} = 0$
   a = 0

Starting to Investigate Friction: begin with weight

Block has a *mass* of 2.5 kg,
It weighs approx. how many N? (How much force needed to lift it?)
a. 2.5 b. 25 c. 1.5/2.5 d. (1.5/2.5) x 9.8

Answer: b



Newton and Real Life

- Newton (and physicists since) say that an object in motion stays in motion until acted on by a Force
- (this is what F = ma means)

http://phet.colorado.edu/en/simulation/ramp-forces-and-motion

Newton and Real Life

- So why do objects stop when I slide them across the desk?
- What does this mean?
  F= ma !!!
- The must be a force pushing it backward…

So what do I have to do in order to keep an object moving at constant speed normally?

Friction important for everything that moves (e.g. everything interesting)

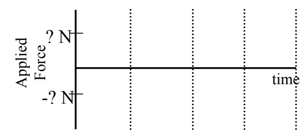
- Moving boxes of books or building pyramids
- Engines and cars
- Generating power
- Walking and running
- Driving
- lighting fires when trapped on desert island
- ...

Today
What does it depend on?
Where does it come from?

example of not-so-perfect scientific model (contrast with Newton's laws)

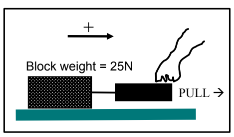
Investigating friction

Friction between table and block.
Predict graph of force which we must apply by pulling on sensor in order to move block along table at a **constant speed** … prediction should include force from **before** starting to pull until block is moving at constant speed across the table. (Make guess as to specific value as well as shape.)

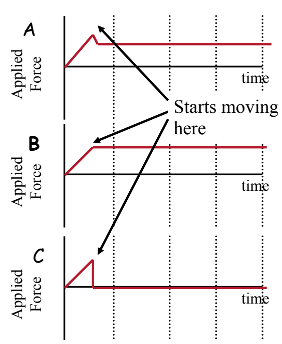


Hint: think about your real life moving a heavy object across the floor

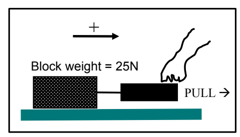
Investigating friction



Friction between table and block.
Predict graph of force which we must apply by pulling on string in order to move block along table at a constant speed … prediction should include force from before starting to pull until block is moving at constant speed across the table.



Investigating friction



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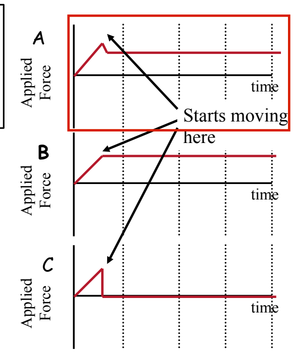
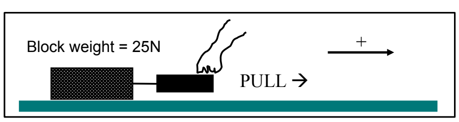
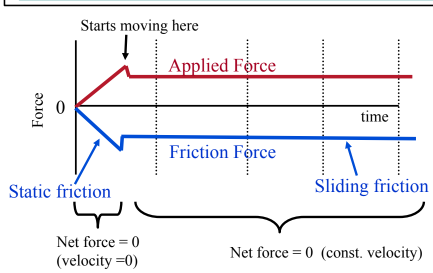
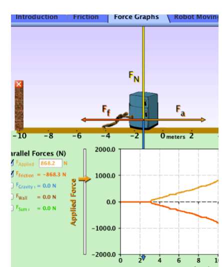






Note: Max static friction force > Sliding friction force (see later)

Test this . . .



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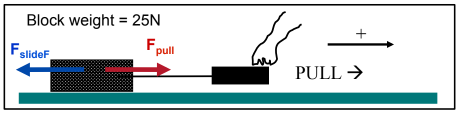
Sliding (kinetic) friction

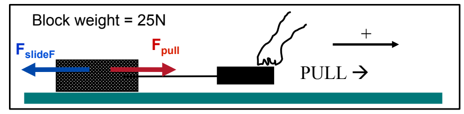


Balancing sliding friction:

How much force is required to keep it moving along table at constant speed if weight of block = mg = 25 N ?

a. Weight x 0.3, b. Weight x 0.7, c. Weight x 1.5 d. Weight x 5

Sliding (kinetic) friction



Balancing sliding friction:

How much force is required to keep it moving along table at constant speed if weight of block = mg = 25 N ?

a. Weight x 0.3, b. Weight x 0.7, c. Weight x 1.5 d. Weight x 5

- Sliding friction force between object and smoothish floor surface typically ~ 0.3 weight of object
- Makes sense – easier to slide a box across a wood floor than lift it

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Been dealing with friction your whole life.
What is your mental model for it?
(relationships you expect it to depend on)

With group, write down on piece of paper:

things that friction depends on—makes less or more	things that friction does not depend on– makes no difference
____________	____________
____________	____________
____________	____________
____________	____________

all answers right– is how *you* thought about it

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collected items

matter
1. Type of surface
2. Weight
3. Surface Area (in contact)
4. Shape of the object & surface
5. Speed
6. Force of gravity
7. Slope
8. Applied external force (Pushing) – type of surface
9. Air pressure
10. Orientation of object

doesn't' matter
1. Liquids (don't have friction)
2. Angle of surface / slope
3. Velocity
4. Color
5. Direction

poll on a few to see opinions

Sliding (kinetic) friction

Increase the mass of the block from 2.5kg to 5 kg,
what pulling force (approx) is needed to keep block moving at a constant speed?

a. 0 N, b. 4N c. 15N d. 49N c. 100N

Answer is c.
Larger mass, larger weight force, larger sliding friction force ….

F_{slideF} ~ 0.3 ×weight = 0.3 × mg = 0.3 × 50N

The heavier the box, the more force it takes to push it across the floor.

It takes a pulling force of ~7N to keep the block moving in a straight line across the table at a constant speed of 0.2 m/s.
Now I double the speed to a steady 0.4 m/s. What constant pulling force is required now?

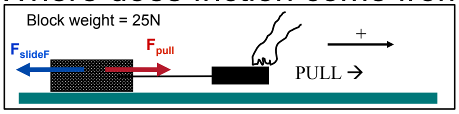
a. 0N b. less than 7N c. about 7N d. more than 7N

Answer is c

Sliding friction force does not change much as speed increases.

Takes about as much force to go at slow constant velocity as high constant velocity. (unless fast enough that air resistance important.)

Where does friction come from?

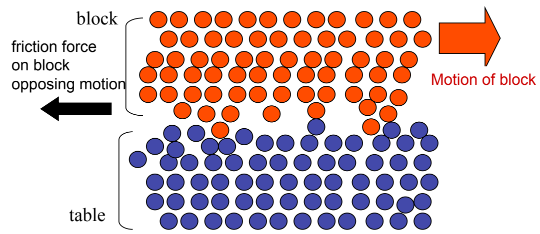


The size of the friction force depends on

a) How rough /smooth the surfaces are
b) The atomic make up of materials that are interacting
c) How much surface area is interacting
d) A & C
e) A, B & C

Microscopic details of static and sliding friction

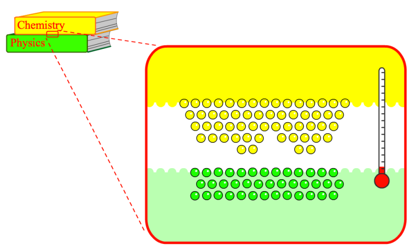
- Atoms of same material (color) all hooked together by forces like tiny springs
- Viewed at atomic level surfaces are never perfectly smooth
- The atoms from the two surfaces catch and drag against each other producing a force that opposes motion called friction



Friction and heat

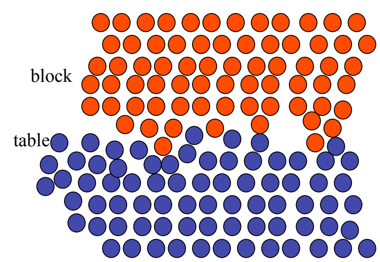
Dragging surfaces across each other causes atoms to start vibrating= heat!
Heat energy produced = work done = $F_{friction}$ x distance moved.
Examples:

-Rubbing hands together to keep warm
- Rubbing 2 sticks to start a fire
- Spinning tires on car



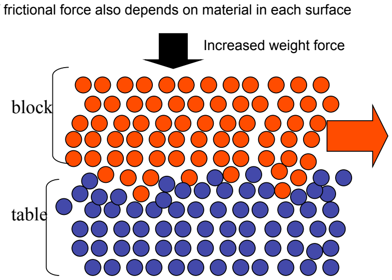
Why is maximum static friction force greater than sliding friction force?

- When stationary, atoms at surfaces can get embedded and stuck more than when sliding.
  ⇒ So maximum *static* friction force bigger than *sliding* friction force.



What if you increase the weight of an object?

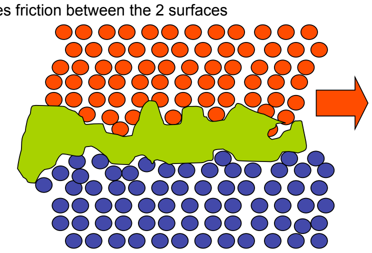
- Frictional force increases proportional to weight
- More force pushing surfaces together
  ⇒ atoms at surface mesh together more
  ⇒ more friction
- Size of frictional force also depends on material in each surface



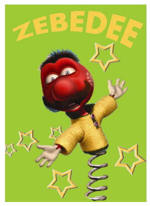
How does a lubricant affect friction?

A lubricant is:

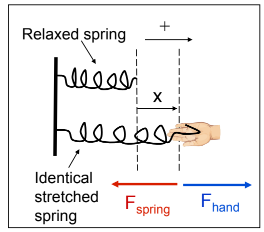
- A layer of slimy stuff between surfaces
- Doesn't stick to either surface, flows out of way of surface atoms
- Keeps surfaces apart
- e.g. oil, snow, water
- Reduces friction between the 2 surfaces



Springs – another kind of force



Everything you need to know about springs



- Hand holding spring at distance x
- Hand pulling to right
- Spring pulling to left
- In equilibrium: $F_{hand} = F_{spring}$

From experiment we know:
$F_{spring} \propto x$ (force proportional to dist)

Extension (m)

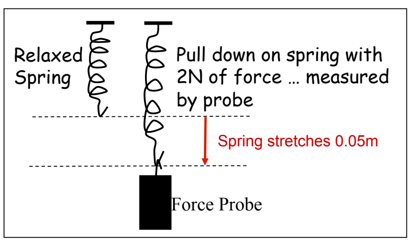
$F_{spring} = - kx$

Force of spring (N)

Minus sign:
Spring force opposes extension
Vectors in opposite directions

Spring constant
Positive number
Units: N/m
Property of spring

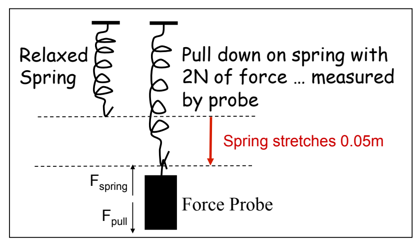
Investigating springs



How much would it stretch if pull down on spring with force of 4 N?

a. 0.02m
b. 0.05m
c. 0.10m
d. 0.15m
e. 0.20m

Investigating springs

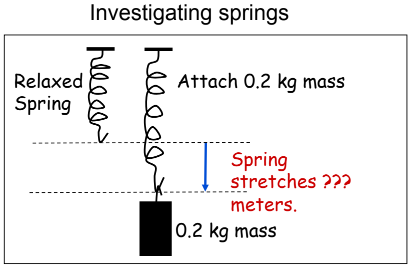


How much would it stretch if pull down on spring with force of 4 N?

a. 0.02m
b. 0.05m
c. 0.1m
d. 0.15m
e. 0.2m

$F_{spring} = -k\, x$
In equilibrium $\Rightarrow F_{pull} = F_{spring} = kx$
Double the force $\Rightarrow$ Double the extension

Investigating springs

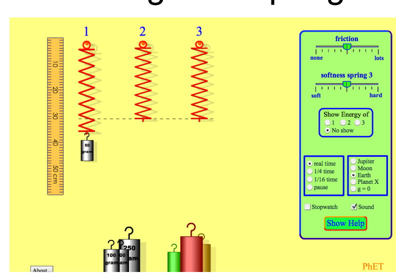


How much would it stretch if we hang a 0.2 kg mass on the spring (compared to the initial 2N force case)?

a. same distance as for 2 N force
b. ½ as far
c. 2 times as far
d. more than 2 times as far
e. Less than ½ as far

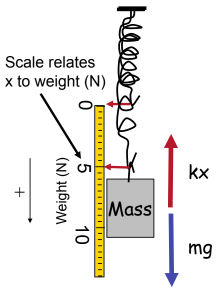
Answer is a. Same distance because spring experiences same force
$F_{gravity} = 0.2\ kg \times 9.8\ m/s^2 = 2\ N$

Practicing with Springs…



http://phet.colorado.edu/sims/mass-spring-lab/mass-spring-lab_en.html

Scales



- Scales (eg bathroom scales) are just calibrated springs.
- On scales, mass is stationary and in eqm.
  - ⇒ Net force = 0
  - ⇒ Spring force balances weight force

In equilibrium:
⇒ $F_{net} = 0$
⇒ $F_{net} = mg - kx = 0$
⇒ $mg = kx$

x directly related to weight force, mg.

So if you have a spring and measure the value of k (calibrate it), then you can hang any weight on it, and from x can calculate the weight (mg) and (if on earth) the mass (m)

Example

I hang a 2 kg mass from a spring and it stretches 2cm.
What is the spring constant (k) of the spring? (assume g = 10m/s^2)

a) 10 N/m
b) 100 N/m
c) 1000N/m
d) 10000 N/m
e) None of these.

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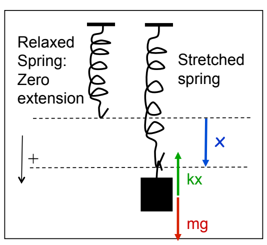

- $\underline{F}_{spring} = -k\underline{x}$
- In equilibrium.
- Net force = mg – kx = 0

- mg = kx
- k = mg/x

$$= \frac{2\text{kg}\times 10\text{m/s}^2}{0.02\text{m}}$$

= 1000N/m (remember 1N = 1kg m/ s^2)

Example

I hang a 2 kg mass from a spring and it stretches 2cm. This implies that k = 1000N/m.
I remove the first mass and hang a different, unknown mass off the same spring. It stretches 8cm from its natural length.
What is the second mass in kg?

a) 2 kg
b) 2/3 kg
c) 4kg
d) 8kg
e) Not enough information given

Example

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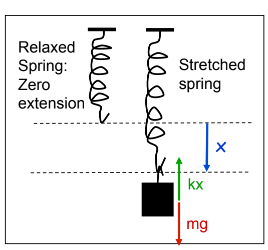


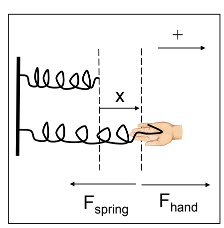
mg = kx
m = kx/g

$$= \frac{(1000\text{N/m})(0.08\text{m})}{10\text{N/kg}}$$

= 8kg

(remember 1N = 1kg m/ s^2)

Important note about vectors in diagrams and equations



In diagrams:

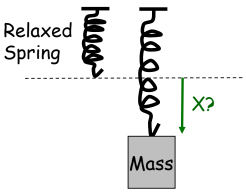
- Always define the + (positive) direction
- Arrow represents direction (sign of vector)
- Letter is the MAGNITUDE so always represents a POSITIVE number

In equations:

- Arrow in diagram relates to sign in front of letter in equation (±)
- Letter represents a positive number

In equilibrium:
Net force = $F_{hand} - F_{spring} = 0$
$F_{hand} = F_{spring}$

More spring questions



Now hang 0.05 kg mass (0.5N of force) off 2 different springs. They are both initially the same length but one is made of thick stiff wire and the other is made of thin bendy wire.

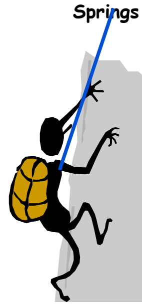
Which spring will stretch more?

a. They will stretch the same distance
b. Thick wire spring stretches less
c. Thick wire spring stretches more

Answer is b. Thick wire spring stretches less

F_{spring} must still balance same weight, mg.
$mg = kx$
$x = mg/k$
But, k is larger for fatter, stiffer springs
⇒ less extension for the same force

Springs in ropes … what's good choice of rope



For climbing, best to use …

a. rope with soft spring (lots of stretch)
b. rope with stiff spring (not much stretch)
c. doesn't matter… any spring is good.

a. Soft spring.
• Takes longer time to stretch out.
• Smaller peak deceleration if stopping fall
• Smaller force.
• Just like driving car into foam rather than wal