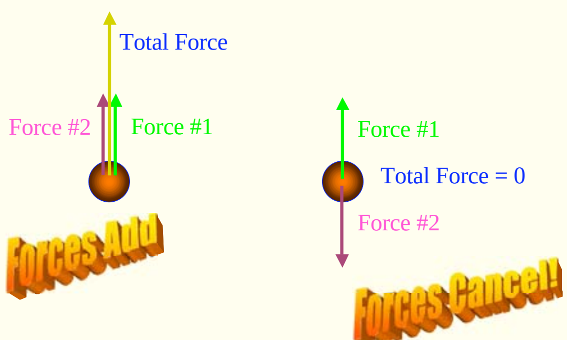
Net Forces, Friction, Air Resistance

Let's get real

Recall the Sliding Book Example

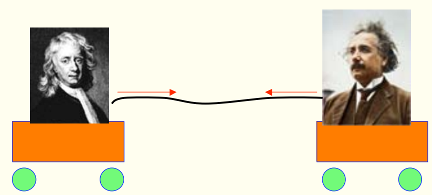
- Why do things not continue to move at constant velocity?
  - Don't things strive to be at rest (I know *I* do)?
- If the sliding book slows down, what's the force responsible?
  - How could I keep it moving at a constant velocity?
  - Do I need to apply a force to keep it moving? Why?

Forces are Vectors so Directions are Important



Newton's 3rd Law

For every action (force), there is an equal and opposite reaction (opposing force).



Force *on* Newton *by* Einstein = Force *on* Einstein *by* Newton

(But their accelerations need not be the same: Newton tries to outsmart Einstein by loading his own cart with lead bricks)

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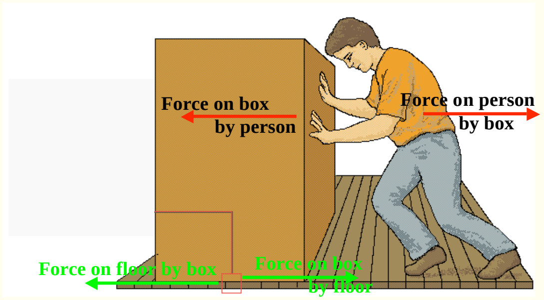
Friction is a Force



It's the sum of all the forces that determines the acceleration.
Every force has an equal & opposite partner.

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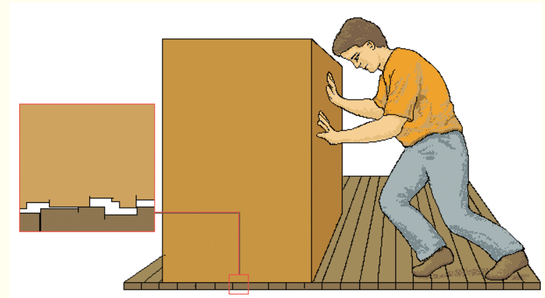
Friction Mechanism



Corrugations in the surfaces grind when things slide.
Lubricants fill in the gaps and let things slide more easily.

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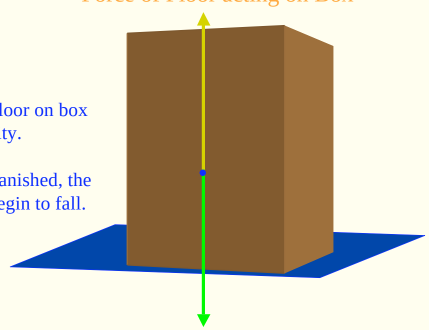
Why Doesn't Gravity Make the Box Fall?

Force of Floor acting on Box

Force from floor on box cancels gravity.

If the floor vanished, the box would begin to fall.



Force of Earth acting on Box (weight)

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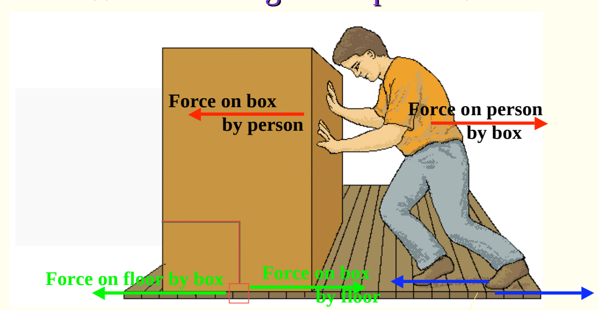
What's missing in this picture?



A pair of forces acting between person and floor.

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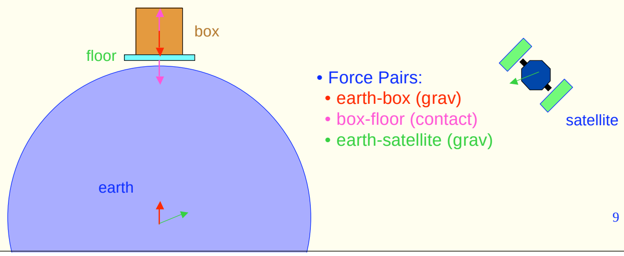
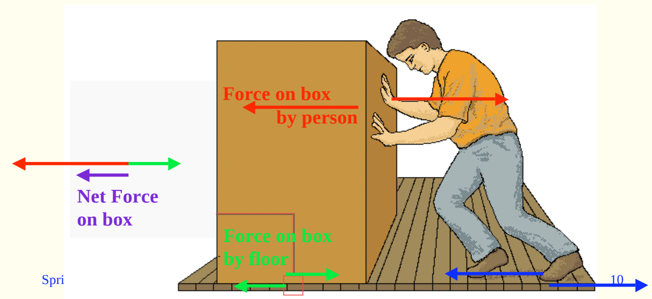
Wait: We cheated two slides back…

- When we drew the box and floor, with the "normal" force from the floor canceling the force of gravity, these weren't strictly force pairs
  - but these are the two canceling forces on the box that result in zero acceleration of the box
- The real pairs have to involve the earth:



Don't all forces then cancel?

- How does anything ever move (accelerate) if every force has an opposing pair?
- The important thing is the net force on the object of interest

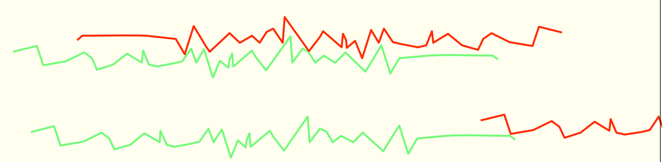


Some Questions

- Does friction always exert a force that tends to bring things to a halt?
- What does this say about the direction of the frictional force, relative to the velocity vector?
- What do you think would happen if we loaded lead bricks into the box? Would it become harder to slide?
- What are some ways to reduce frictional forces?

Static and Sliding (Dynamic) Friction

- Static frictional force: when nothing is sliding
- Sliding frictional force: when surfaces are sliding
- Static frictional forces always greater than sliding ones



- Lubrication provides microscopic rollers between surfaces

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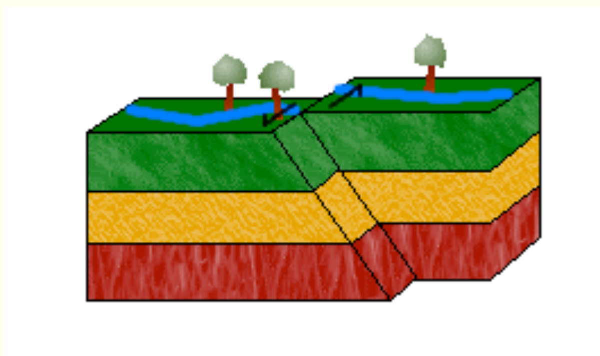
Big Consequences!



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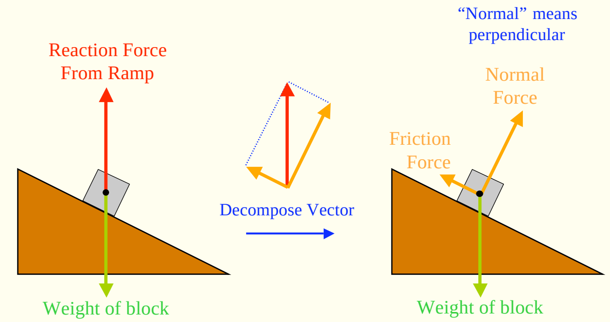
"Normal" Forces and Frictional Forces



Friction Force = Normal Force × (coefficient of friction)

$F_{friction} = \mu \cdot F_{normal}$

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Coefficient of Friction

Material on Material	μ_s = static friction	μ_k = kinetic friction
steel / steel	0.6	0.4
add grease to steel	0.1	0.05
metal / ice	0.022	0.02
brake lining / iron	0.4	0.3
tire / dry pavement	0.9	0.8
tire / wet pavement	0.8	0.7

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Stay on the road!

- What does it take to stay on the road around a curve?
  - using μ_s = 0.8 as average for tires on road, $F_{friction} = 0.8mg$
    - (Normal force is just mg on level surface)

      $F_{curve} = ma_{curve} = m \times v^2/r$
    - where r is radius of curve, say 50 m (e.g., cloverleaf exit ramp)
- Got enough friction if $F_{curve} < F_{friction}$
  - happens if $v^2 < 0.8gr$, or v < 20 m/s = 44 m.p.h.

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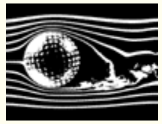
Air Resistance



- We're always "neglecting air resistance" in physics
  - Can be difficult to deal with
- Affects projectile motion
  - Friction force opposes velocity through medium
  - Imposes horizontal force, additional vertical forces
  - Terminal velocity for falling objects
- Dominant energy drain on cars, bicyclists, planes

Drag Force Quantified

- With a cross sectional area, A (in m^2), coefficient of drag of 1.0 (most objects), sea-level density of air, and velocity, v (m/s), the drag force is:

$$F_{\text{drag}} = 0.65 \cdot A \cdot v^2 \text{ Newtons}$$

- Example: Bicycling at 10 m/s (22 m.p.h.), with projected area of 0.5 m^2 exerts 32.5 Newtons
  - requires $F \cdot v$ of *power* → 325 Watts to maintain speed

"Free" Fall

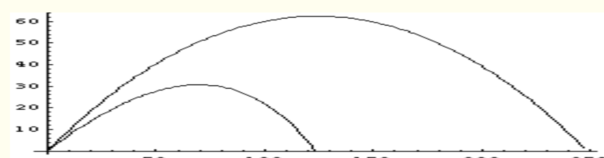
- Terminal velocity reached when $F_{\text{drag}} = F_{\text{grav}}$ (= mg)
- For 75 kg person subtending 0.5 m^2,

$$v_{\text{term}} \approx 50 \text{ m/s, or 110 m.p.h.}$$

  which is reached in about 5 seconds, over 125 m of fall
  - actually takes slightly longer, because acceleration is reduced from the nominal 9.8 m/s^2 as you begin to encounter drag
- Free fall only lasts a few seconds, even for skydivers

Trajectories with Air Resistance

- Baseball launched at 45° with v = 50 m/s:
  - Without air resistance, reaches about 63 m high, 254 m range
  - With air resistance, about 31 m high, 122 m range



Vacuum trajectory vs. air trajectory for 45° launch angle.

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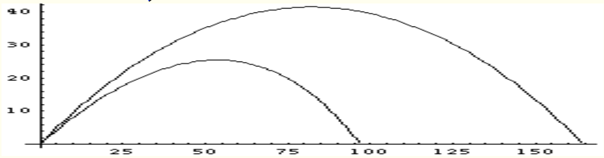
Air Trajectories, cont.

- Now v = 40 m/s, optimal angle (45° for vacuum, 40° for air):



Optimal angle for 40 m/s in air gets 97 m range vs. 164 m for vacuum trajectory.

- Golf balls actually have optimal launch of 25-30°, helped by lift forces associated with spin of the ball.

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Summary and Assignments

- Every force has an equal, opposing force
- Friction opposes motion, requiring continued application of force to maintain constant velocity
- Air resistance produces terminal velocity, alters trajectories of projectiles (for the worse).

- Assignments
  - Read Chapters 2,3,4,5 (see page selections on web)
  - Read Chapter 7
  - HW 3: due Friday (4/25):
    - Hewitt 2.E.22, 2.E.29, 2.E.33, 3.E.27, 3.P.3, 3.P.4, 3.P.10, 4.E.1, 4.E.6, 4.E.10, 4.E.30, 4.E.44, 4.P.1, 5.E.17, 5.P.2, 7.R.(4&7) (count as one), 7.R.16, 7.E.40, 7.P.2, 7.P.4

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