


UCSD Physics 10



Net Forces, Friction, Air Resistance

Let's get real

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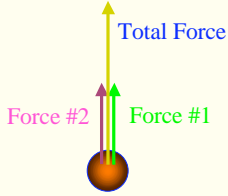
Recall the Sliding Book Example

- **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?

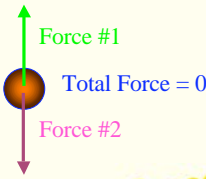
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Forces are Vectors so Directions are Important



Forces Add



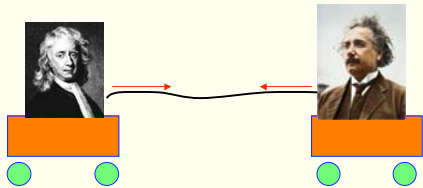
Forces Cancel!

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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

The diagram shows a person in an orange shirt pushing a large brown box on a wooden floor. Four force vectors are shown: a red arrow pointing left from the person to the box labeled 'Force on box by person', a red arrow pointing right from the box to the person labeled 'Force on person by box', a green arrow pointing left from the box to the floor labeled 'Force on floor by box', and a green arrow pointing right from the floor to the box labeled 'Force on box by floor'.

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

The diagram shows a person pushing a box. A callout box on the left shows a microscopic view of the surfaces, revealing corrugations (bumps) that grind against each other. A red line connects this callout to the contact surface between the box and the floor in the main diagram.

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?

The diagram shows a brown box on a blue floor. A yellow arrow points upwards from the top of the box, labeled 'Force of Floor acting on Box'. A green arrow points downwards from the center of the box, labeled 'Force of Earth acting on Box (weight)'.

Force from floor on box
cancels gravity.
If the floor vanished, the
box would begin to fall.

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What's missing in this picture?

The diagram shows a person pushing a box with force vectors. A blue arrow points to the right from the person's feet, labeled 'A pair of forces acting between person and floor.' This arrow is missing from the previous diagram.

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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:

- Force Pairs:
 - earth-box (grav)
 - box-floor (contact)
 - earth-satellite (grav)

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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

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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?

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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

“Normal” means perpendicular

Friction Force = Normal Force × (coefficient of friction)
 $F_{\text{friction}} = \mu \cdot F_{\text{normal}}$

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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!

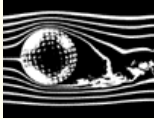



- **What does it take to stay on the road around a curve?**
 - using $\mu_s = 0.8$ as average for tires on road, $F_{\text{friction}} = 0.8mg$
 - (Normal force is just mg on level surface)
 - $F_{\text{curve}} = ma_{\text{curve}} = m \times v^2 / r$
 - where r is radius of curve, say 50 m (e.g., cloverleaf exit ramp)
- **Got enough friction if $F_{\text{curve}} < F_{\text{friction}}$**
 - happens if $v^2 < 0.8gr$, or $v < 20 \text{ m/s} = 44 \text{ m.p.h.}$

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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

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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 \rightarrow 325 Watts to maintain speed


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"Free" Fall

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

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

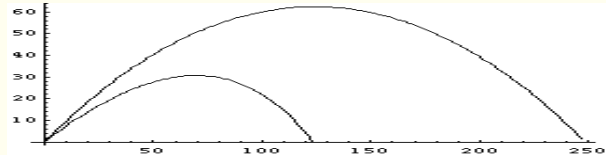


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Trajectories with Air Resistance

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

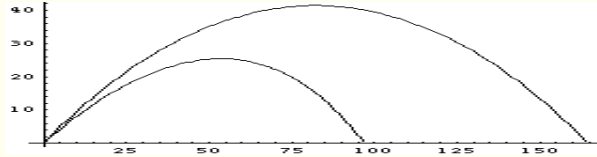


Vacuum trajectory vs. air trajectory for 45° launch angle.

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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.

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