PHYC10003 Physics 1

Lecture 7: Force

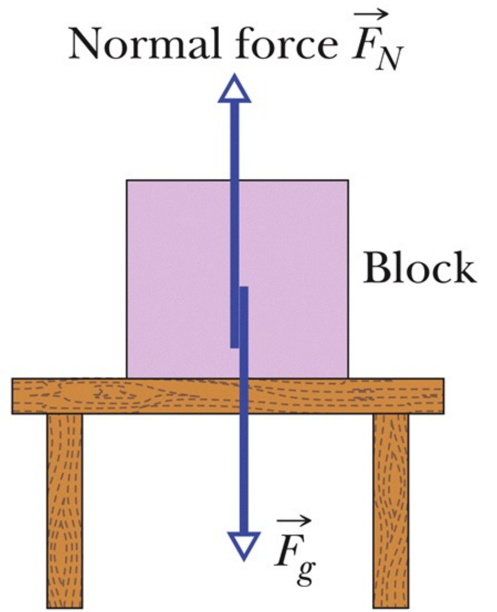
Examples of forces and superposition

Last lecture

- Newton's Third Law of Motion
- Action and reaction
- Resolution of Forces
- Motion: Graphical approach
- Kinematics: algebraic approach

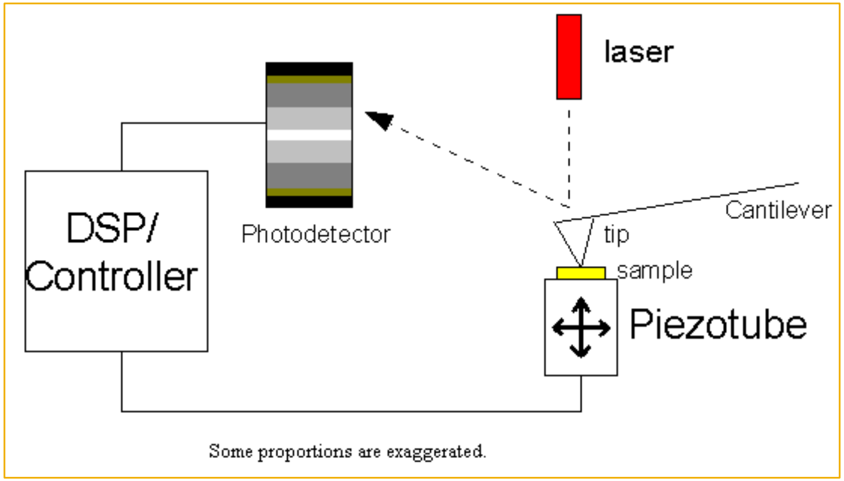
Forces – examples already discussed

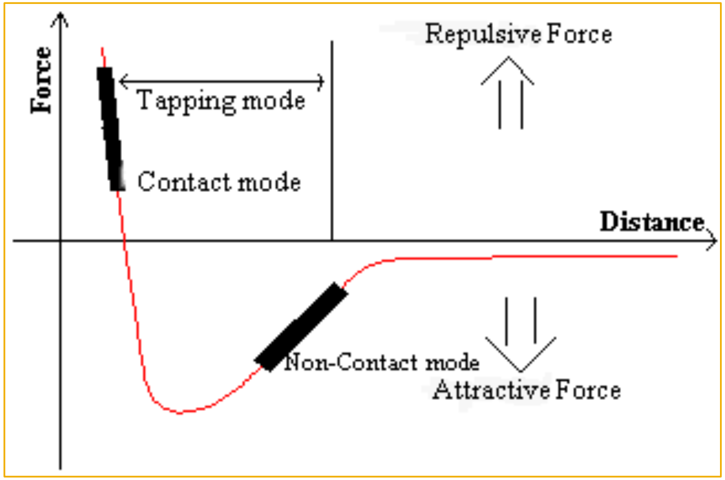
- Gravitational force
- Tension in a string
- Normal force



Normal reaction force

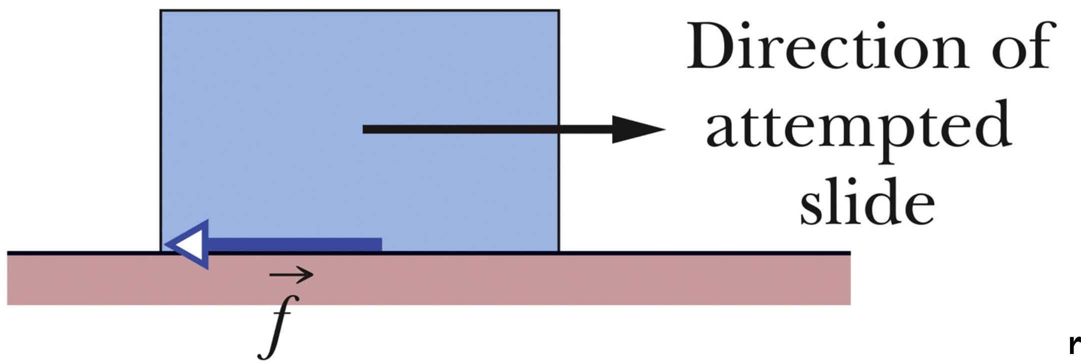
- The origin of the Normal force is intermolecular repulsion
- Force can be measured directly using an Atomic Force microscope: by the deflection of the tip and in turn, by the amount of displacement of the reflected laser beam.





6-1 Frictional force

- **Frictional force** or **friction**:
  - Occurs when one object slides or attempts to slide over another
  - Directed along the surface, opposite to the direction of intended motion



re 5-8

6-1 Friction

- Friction forces are essential:
  - Picking things up
  - Walking, biking, driving anywhere
  - Writing with a pencil
  - Building with nails, weaving cloth
- But overcoming friction forces is also important:
  - Efficiency in engines
  - (20% of the petrol used in an automobile goes to counteract friction in the drive train)
  - Roller skates, fans, bicycles
  - Anything that we want to remain in motion

6-1 Friction: three examples

- Three experiments:
  - Slide a book across a counter. The book slows and stops, so there must be an acceleration parallel to the surface and opposite the direction of motion.
  - Push a book at a constant speed across the counter. There must be an equal and opposite force opposing you, otherwise the book would accelerate. Again the force is parallel to the surface and opposite the direction of motion.
  - Push a crate or other heavy object that does not move. To keep the crate stationary, an equal and opposite force must oppose you. If you push harder, the opposing force must also increase to keep the crate stationary. Keep pushing harder. Eventually the opposing force will reach a maximum, and the crate will slide.

6-1 Friction: two distinct types

- Two types of friction
- The **static frictional force**:
  - The opposing force that prevents an object from moving
  - Can have any magnitude from 0 N up to a maximum
  - Once the maximum is reached, forces are no longer in equilibrium and the object slides
- The **kinetic frictional force**:
  - The opposing force that acts on an object in motion
  - Has only one value
  - Generally smaller than the maximum static frictional force

6-1 Friction

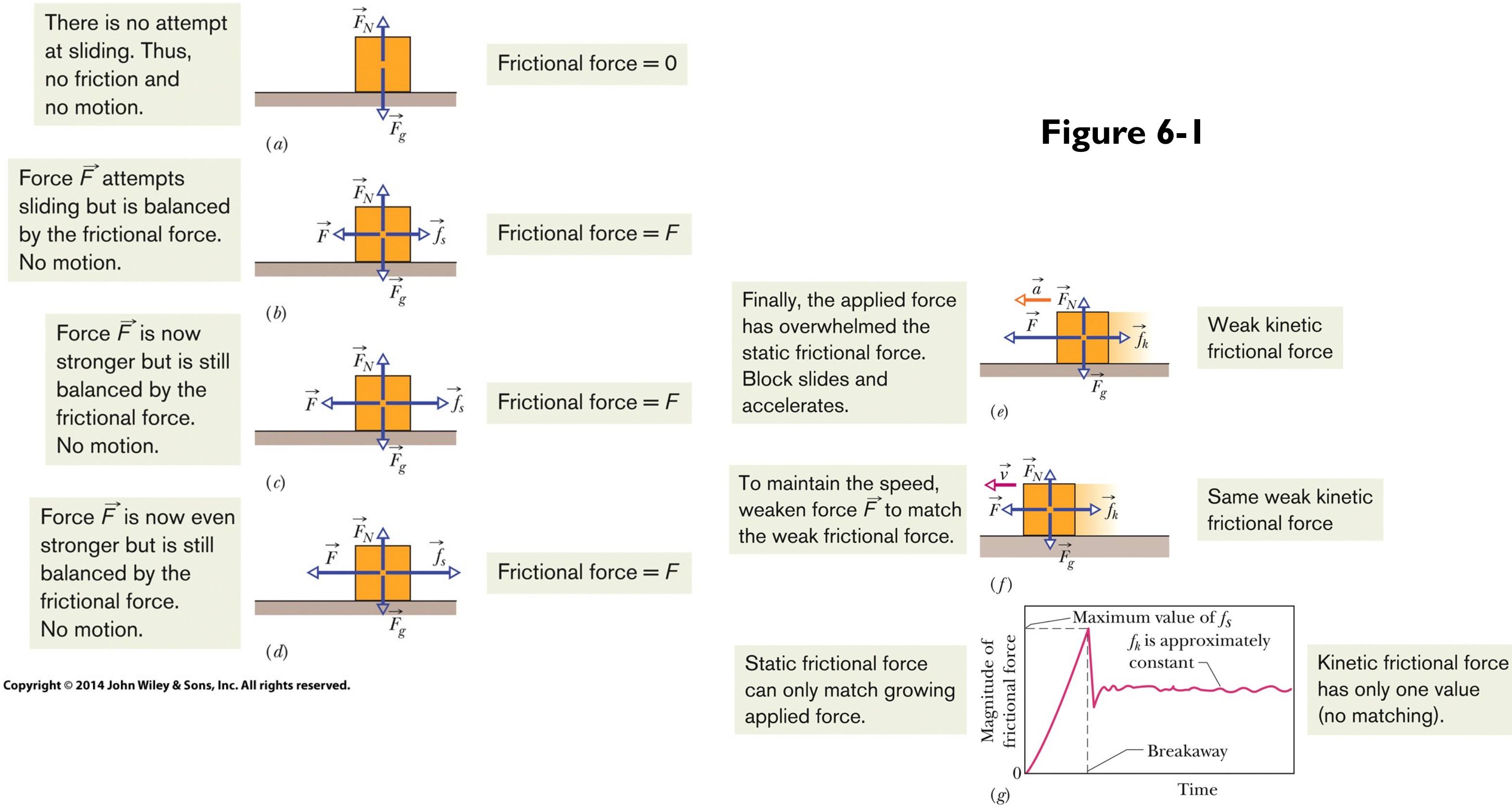


Figure 6-1

6-1 Friction: microscopic view

- Microscopic picture: surfaces are bumpy
- Friction occurs as contact points slide over each other
- The contact points act like 'welds'. The 'welds' are stronger if the pressure is greater.

- Greater force normal to the contact plane increases the friction because the surfaces are pressed together and make more contact
- Sliding that is jerky, due to the ridges on the surface, produces squeaking/squealing/sound

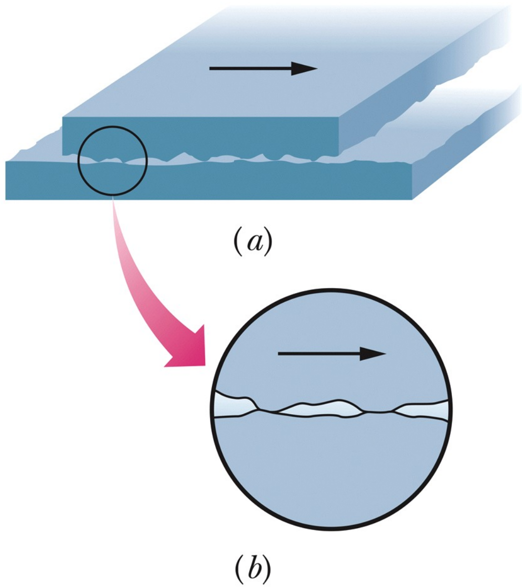


Figure 6-2

6-1 Friction: general properties

- The properties of friction
  1. If the body does not move, then the applied force and frictional force balance along the direction parallel to the surface: equal in magnitude, opposite in direction
  2. The magnitude of f_s has a maximum $f_{s,max}$ given by:

$$f_{s,\max} = \mu_s F_N, \qquad \textbf{Eq. (6-1)}$$

where μ_s is the **coefficient of static friction**. If the applied force increases past $f_{s,max}$, sliding begins

6-1 Coefficient of friction

3. Once sliding begins, the frictional force decreases to f_k given by:

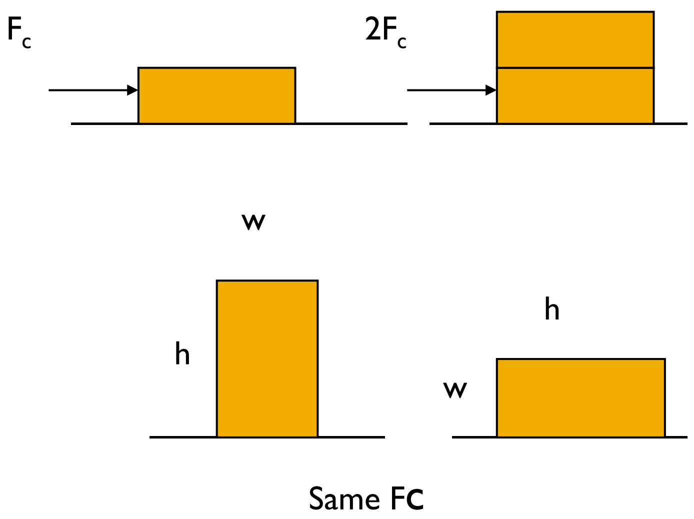
$$f_k = \mu_k F_N, \qquad \text{Eq. (6-2)}$$

where μ_k is the **coefficient of kinetic friction**.

- Magnitude F_N of the normal force measures how strongly the surfaces are pushed together
- The values of the friction coefficients are unitless and must be determined experimentally
- $\mu_s > \mu_k$ so kinetic friction is always less than static.

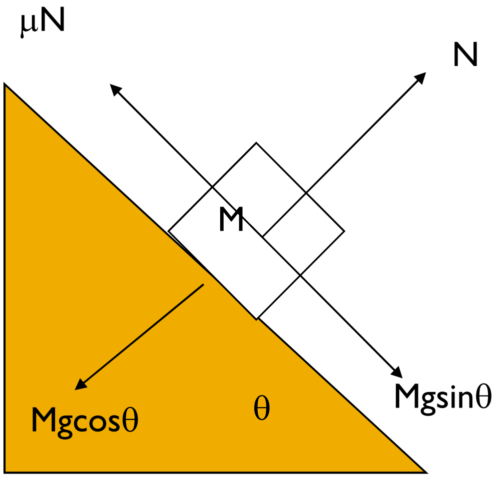
6-1 Friction – weight and contact area

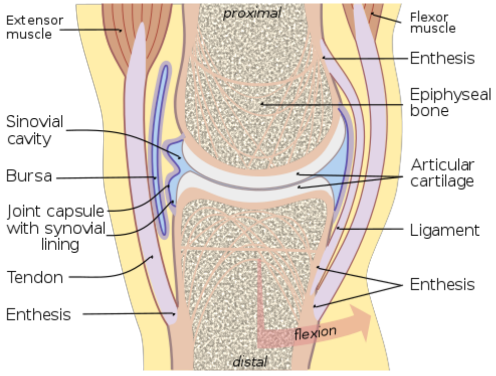
- More observations
  - Critical force, F_C, to overcome friction depends linearly on the weight of the object
- F_C does not depend on the contact area, for most materials (rubber is an exception)



Measuring μ_K and μ_s

- Gradually increase θ
- When the block just begins to move …
  - $Mg \sin\theta = \mu_s N$
  - $Mg \cos\theta = N$
- Hence $\tan\theta = \mu_s$
- Further increases in θ will result in the block accelerating down the plane with an acceleration $a = (g \sin\theta - \mu_K g \cos\theta)$





μ_s = 0.5 for wood, 0.04 for teflon and 0.003 for sinovial fluid

6-1 Friction: example

- Assume that μ_k does not depend on velocity
- Note that these equations are not vector equations

Checkpoint 1

A block lies on a floor. (a) What is the magnitude of the frictional force on it from the floor? (b) If a horizontal force of 5 N is now applied to the block, but the block does not move, what is the magnitude of the frictional force on it? (c) If the maximum value $f_{s,\max}$ of the static frictional force on the block is 10 N, will the block move if the magnitude of the horizontally applied force is 8 N? (d) If it is 12 N? (e) What is the magnitude of the frictional force in part (c)?

Answer: (a) 0 (b) 5 N (c) no (d) yes (e) 8 N

6-1 Friction: components

Example For a force applied at an angle:

- Decompose the force into *x* and *y* components
- Balance the vertical components (F_N, F_g, F_y)
- Balance the horizontal components (f, F_x)
- Solve for your unknown,
  noting that F_N and f are related

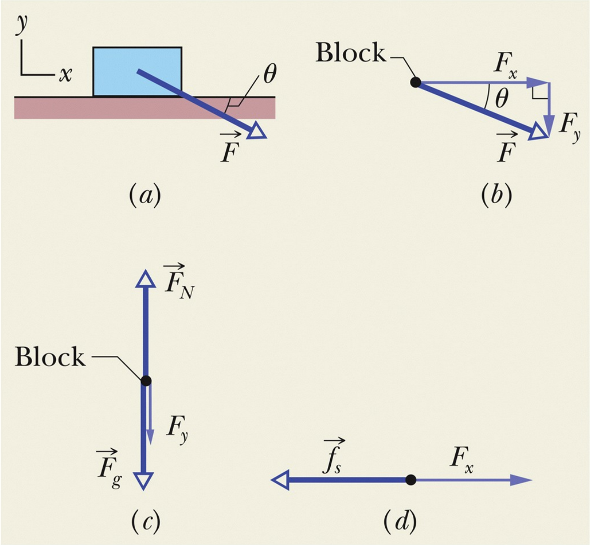
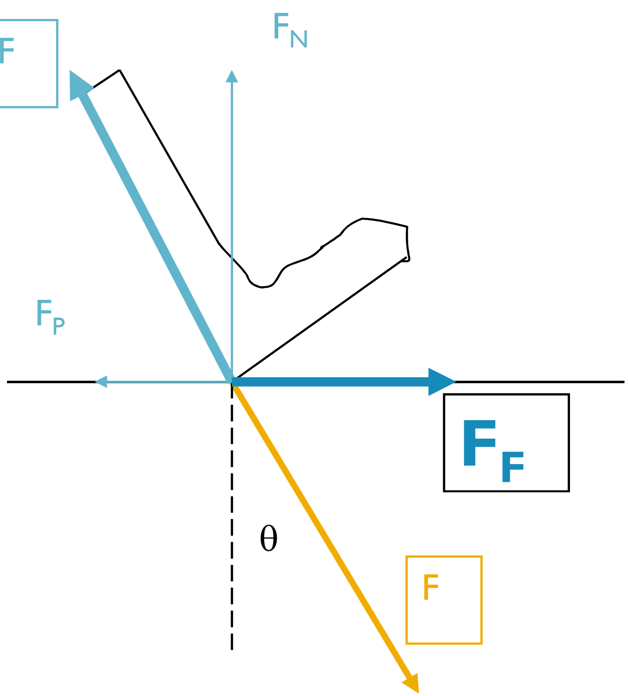


Figure 6-3

Example: Person walking on ice

What is the condition to avoid slipping?



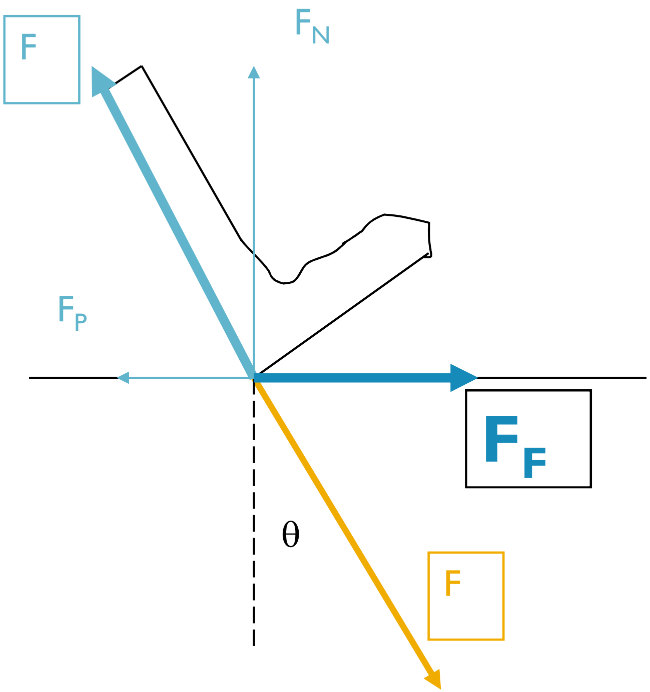
F_{FG} = force of foot on ground.

F_{GF} = force on ground on foot which is decomposed into F_N and F_P.

The friction force F_F is shown

Now $F_P = F_N \tan\theta$

Example: Person walking on ice cont…



Now $F_P = F_N \tan\theta$

For no slip we require

$F_F > F_P$

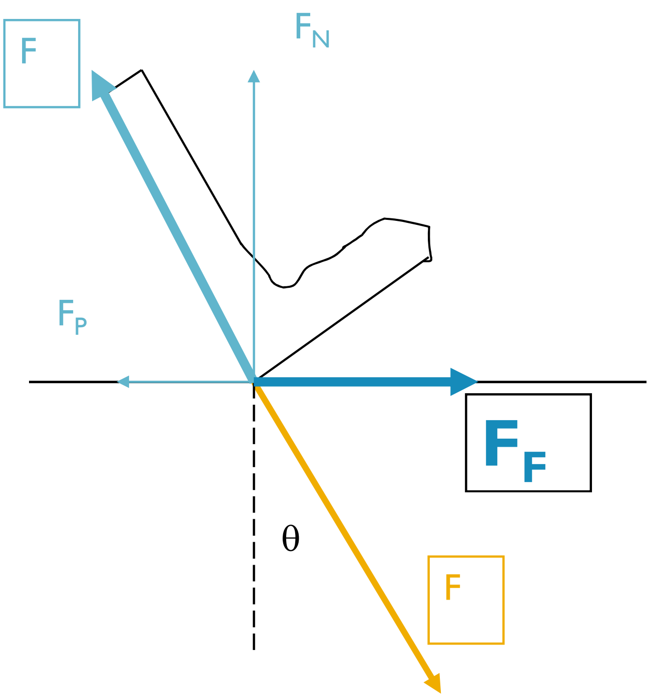
$\mu_s F_N > F_P = F_N \tan\theta$

So the slip condition is

$\mu_s > \tan\theta$

which does not depend on the force, i.e. not dependent on the weight of the person

Example: Person walking on ice cont…



Wearing leather shoes, and walking on a wooden floor, $\mu_S = 0.54$, and since $\mu_S > \tan\theta$, $\theta < 28°$.

BUT on ice, $\mu_S \ll 0.54$, so we must make θ small to avoiding sliding.

This is accomplished by taking smaller steps!

6-2 Friction: drag force

- A **fluid** is anything that can flow (gas or liquid)
- When there is relative velocity between fluid and an object there is a **drag force**:
  - That opposes the relative motion
  - And points along the direction of the flow, relative to the body
- Here we examine the drag force for
  - Air
  - With a body that is not streamlined
  - For motion fast enough that the air becomes turbulent (breaks into swirls)

6-2 Friction: drag force

- For this case, the drag force is:

$$D = \frac{1}{2}C\rho A v^2, \qquad \textbf{Eq. (6-14)}$$

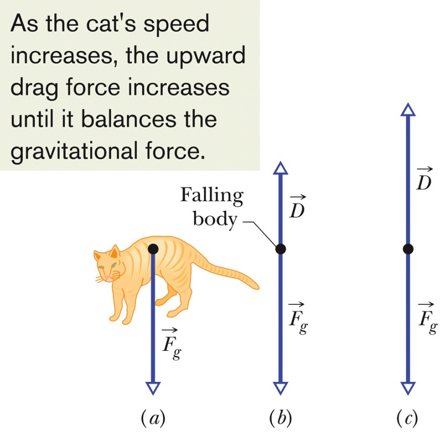


Figure 6-6

- Where:
  - v is the relative velocity
  - ρ is the air density (mass/volume)
  - C is the experimentally determined drag coefficient
  - A is the effective cross-sectional area of the body (the area taken perpendicular to the relative velocity)
- In reality, C is not constant for all values of v

6-2 Friction: drag force

- The drag force from the air opposes a falling object

$$D - F_g = ma,$$ **Eq. (6-15)**

- Once the drag force equals the gravitational force, the object falls at a constant **terminal speed**:

$$v_t = \sqrt{\frac{2F_g}{C\rho A}}.$$ **Eq. (6-16)**

- Terminal speed can be increased by reducing A
- Terminal speed can be decreased by increasing A
- Skydivers use this to control descent

6-2 Friction: terminal velocity

Example Speed of a rain drop:

- Spherical drop feels gravitational force $F = mg$:
  - Express in terms of density of water

$$F_g = V\rho_w g = \tfrac{4}{3}\pi R^3 \rho_w g.$$

- So plug in to the terminal velocity equation using the values provided in the text:
  - Use $A = \pi R^2$ for the cross-sectional area

$$v_t = \sqrt{\frac{2F_g}{C\rho_a A}} = \sqrt{\frac{8\pi R^3 \rho_w g}{3C\rho_a \pi R^2}} = \sqrt{\frac{8R\rho_w g}{3C\rho_a}}$$

$$= \sqrt{\frac{(8)(1.5\times 10^{-3}\ \mathrm{m})(1000\ \mathrm{kg/m^3})(9.8\ \mathrm{m/s^2})}{(3)(0.60)(1.2\ \mathrm{kg/m^3})}}$$

$$= 7.4\ \mathrm{m/s} \approx 27\ \mathrm{km/h}. \qquad \text{(Answer)}$$

Simulating terminal velocity

- A hailstone of mass 4.8×10^{-4} kg falls through the air and experiences a net drag force of
  - $F = Dv^2$ where $D = 2.50 \times 10^{-5}$ kg/m.

Q: What is the terminal velocity?

A: When $F = 0$, $mg - Dv^2 = 0$ and $v = -13.7$ m/s

Q: How long does it take to reach terminal velocity.

A: Use Euler's method for iteratively solving the dynamics problem.

The falling hailstone

t(s)	x(m)	v(m/s)	F(mN)	a(m/s^2)
0	0	0	– 4.704	–9.8
0.2	0	–1.96	– 4.608	–9.5999
0.4	–0.392	–3.88	– 4.3276	–9.0159
0.6	–1.168	–5.6832	–3.8965	–8.1178
0.8	–2.30	–7.3068	–3.3693	–7.0193
1.0	–3.77	–8.7107	–2.8071	–5.8481
1.2	–5.51	–9.8803	–2.2635	–4.7156
1.4	–7.48	–10.823	–1.7753	–3.6986
1.6	–9.65	–11.563	–1.3616	–2.8366
1.8	–11.96	–12.13	–1.03	–2.14
2	–14.4	–12.56	–0.762	–1.59
... listing results after each fifth step				
3	–27.4	–13.49	–0.154	–0.321
4	–41.0	–13.67	–0.0291	–0.0606
5	–54.7	–13.71	–0.00542	–0.0113

- At each step
- $x_{i+1} = x_i + v_i \Delta t$
- $v_{i+1} = v_i + (F_i/m)\Delta t$
- $F_i = mg - Dv^2$

The hailstone reaches 99.95% of v_T after 5.0 s, 99.99% of v_T after 6.0 s, 99.999% of v_T after 7.4 s.

Summary

- Friction
- Microscopic view of friction
- Drag
- Terminal velocity
- Dynamics simulation