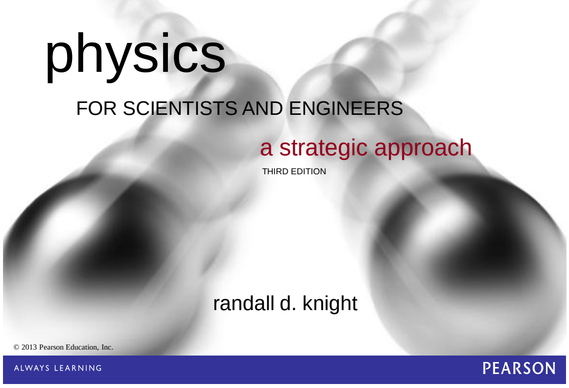
Class 11 Sections 6.4-6.6



physics

FOR SCIENTISTS AND ENGINEERS

a strategic approach

THIRD EDITION

randall d. knight

ALWAYS LEARNING PEARSON

Chapter 6 Dynamics I: Motion Along a Line

Chapter Goal: To learn how to solve linear force-and-motion problems.

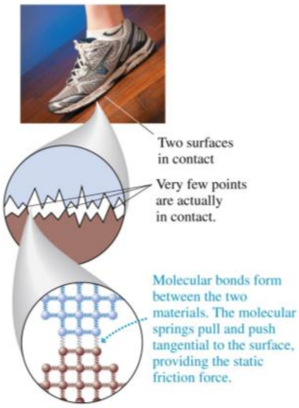
Chapter 6 Dynamics I: Motion Along a Line

Quick Note: We will not be covering the material from Knight Section 6.4 on “Rolling Friction”

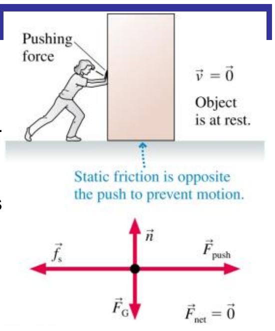
Chapter Goal: To learn how to solve linear force-and-motion problems.

Static Friction

- A shoe pushes on a wooden floor but does not slip.
- On a microscopic scale, both surfaces are “rough” and high features on the two surfaces form molecular bonds.
- These bonds can produce a force *tangent* to the surface, called the **static friction** force.



Static Friction



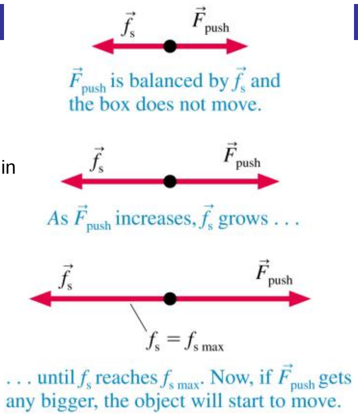
- The figure shows a person pushing on a box that, due to static friction, isn't moving.
- Looking at the free-body diagram, the *x*-component of Newton's first law requires that the static friction force must exactly balance the pushing force:

$$f_s = F_{push}$$

- $\vec{f}_s$ points in the direction *opposite* to the way the object would move if there were no static friction.

Static Friction

Static friction acts in *response* to an applied force.



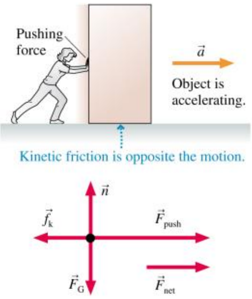
Static Friction

- Static friction force has a *maximum* possible size $f_{\mathrm{s\,max}}$.
- An object remains at rest as long as $f_\mathrm{s} < f_{\mathrm{s\,max}}$.
- The object just begins to slip when $f_\mathrm{s} = f_{\mathrm{s\,max}}$.
- A static friction force $f_\mathrm{s} > f_{\mathrm{s\,max}}$ is not physically possible.

$$f_{\mathrm{s\,max}} = \mu_\mathrm{s} n$$

where the proportionality constant μ_s is called the coefficient of static friction.

Kinetic Friction



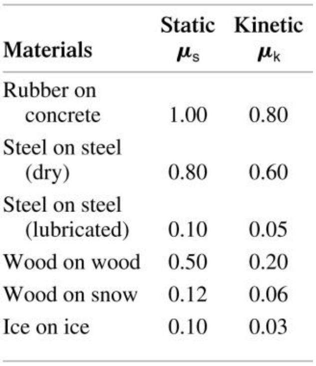
- The **kinetic friction** force is proportional to the magnitude of the normal force:

$$f_\mathrm{k} = \mu_\mathrm{k} n$$

where the proportionality constant μ_k is called the coefficient of kinetic friction.

- The kinetic friction direction is opposite to the velocity of the object relative to the surface.
- For any particular pair of surfaces, $\mu_\mathrm{k} < \mu_\mathrm{s}$.

Coefficients of Friction



Materials	Static μ_s	Kinetic μ_k
Rubber on concrete	1.00	0.80
Steel on steel (dry)	0.80	0.60
Steel on steel (lubricated)	0.10	0.05
Wood on wood	0.50	0.20
Wood on snow	0.12	0.06
Ice on ice	0.10	0.03

Rolling Motion

- If you slam on the brakes so hard that the car tires **slide** against the road surface, this is kinetic friction.
- Under normal driving conditions, the portion of the rolling wheel that contacts the surface is *stationary*, **not sliding**.
- If your car is accelerating or decelerating or turning, it is the *static friction* of the road on the wheels that provides the net force which accelerates the car.

A Model of Friction

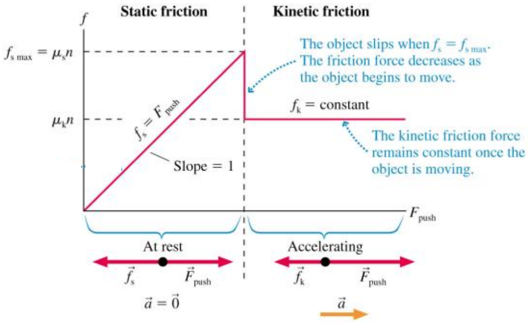
- The actual causes of friction involve microscopic surface properties and molecular bonds.
- Experiments show that reasonable predictions are produced by a model of friction — a simplification of reality:

$$\text{Static: } \vec{f}_\mathrm{s} \le (\mu_\mathrm{s} n, \text{ direction as necessary to prevent motion})$$
$$\text{Kinetic: } \vec{f}_\mathrm{k} = (\mu_\mathrm{k} n, \text{ direction opposite the motion})$$

- Here “motion” means “motion relative to the surface.”
- Force of kinetic friction is proportional to the normal force of the surface on the object.
- The *maximum* static friction force is proportional to the normal force of the surface on the object.

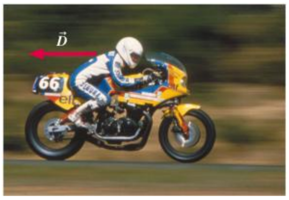
A Model of Friction

The friction force response to an increasing applied force:



Section 6.5: Drag

- The air exerts a drag force on objects as they move through the air.
- Faster objects experience a greater drag force than slower objects.
- The drag force on a high-speed motorcyclist is significant.
- The drag force direction is opposite the object's velocity.



Drag

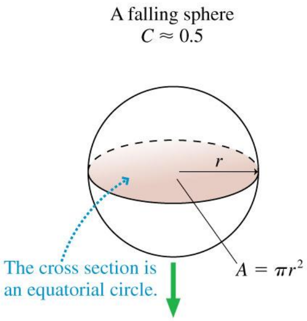
- For normal-sized objects on earth traveling at a speed v which is less than a few hundred meters per second, air resistance can be modeled as:

$$\vec{D} = \left(\tfrac{1}{2}C\rho A v^2, \text{ direction opposite the motion}\right)$$

- A is the *cross-section area* of the object.
- ρ is the density of the air, which is about 1.2 $\mathrm{kg/m^3}$.
- C is the **drag coefficient**, which is a dimensionless number that depends on the shape of the object.

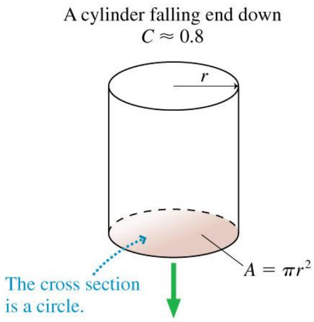
Drag

Cross-section areas for objects of different shape.



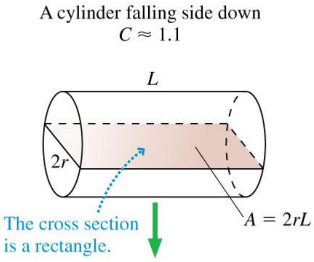
Drag

Cross-section areas for objects of different shape.

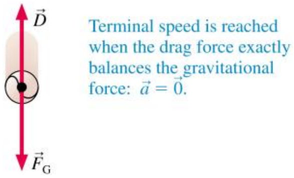


Drag

Cross-section areas for objects of different shape.



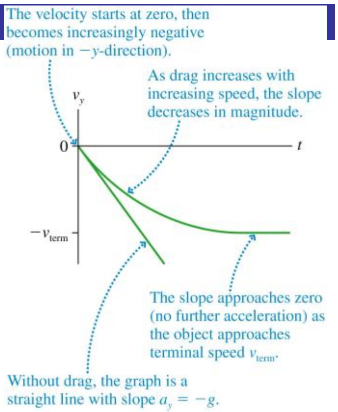
Terminal Speed



- The drag force from the air increases as an object falls and gains speed.
- If the object falls far enough, it will eventually reach a speed at which $D = F_G$.
- At this speed, the net force is zero, so the object falls at a *constant* speed, called the **terminal speed** v_{term}.

$$v_{\text{term}} = \sqrt{\frac{2mg}{C\rho A}}$$

Terminal Speed



The velocity starts at zero, then becomes increasingly negative (motion in $-y$-direction).

As drag increases with increasing speed, the slope decreases in magnitude.

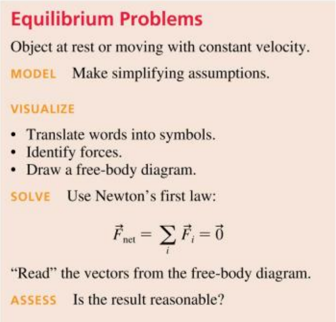
The slope approaches zero (no further acceleration) as the object approaches terminal speed v_{term}.

Without drag, the graph is a straight line with slope $a_y = -g$.

Section 6.6: More Examples of Newton's 2nd Law

Please work through the examples in Section 6.6.

General Strategy



Equilibrium Problems

Object at rest or moving with constant velocity.

MODEL Make simplifying assumptions.

VISUALIZE

- Translate words into symbols.
- Identify forces.
- Draw a free-body diagram.

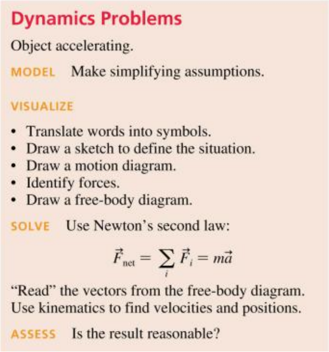
SOLVE Use Newton's first law:

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

"Read" the vectors from the free-body diagram.

ASSESS Is the result reasonable?

General Strategy



Dynamics Problems

Object accelerating.

MODEL Make simplifying assumptions.

VISUALIZE

- Translate words into symbols.
- Draw a sketch to define the situation.
- Draw a motion diagram.
- Identify forces.
- Draw a free-body diagram.

SOLVE Use Newton's second law:

$$\vec{F}_{net} = \sum_i \vec{F}_i = m\vec{a}$$

"Read" the vectors from the free-body diagram.
Use kinematics to find velocities and positions.

ASSESS Is the result reasonable?