Normal Force

- A force acting “normal” (perpendicular) to a surface
  - For example
    - Upward from the floor
    - Upward from a table
    - Away from a wall
    - Down from a ceiling

The normal force is the support force exerted upon an object in contact with another stable object. For example, if a book is resting on a surface, then the surface is exerting an upward force on the book to support the weight of the book.
The normal force may be equal to, greater than, or less than the weight.

Action-Reaction Pair
The normal force (table on monitor) is the reaction of the force monitor exerts on table

Normal Force (magic?)
• How does the normal force know how big it has to be?
• Since the computer monitor is not moving it suggests that
  \[ \sum \vec{F} = 0 \]
  \[ \vec{W} + \vec{n} = 0 \]
  \[ \vec{W} = -\vec{n} \]
• How does the table dial in \( \vec{n} \) with such precision?

Normal Force (magic!)
• The surface of the table distorts like a spring when the monitor is placed on it
• The more the table distorts, the more it pushes back until it is pushing back with a force equal to that applied (\( W \))
• If you put too much onto the table .... bad things happen
Object on Inclined Surface

Normal forces are always directed perpendicular to the surface.

Object on an Inclined Surface

With x and y axes as shown:

\[
\begin{align*}
W_x &= W \sin \theta \\
N_x &= 0 \\
W_y + N_y &= 0 \\
W_y &= -W \cos \theta \\
N_y &= W \cos \theta
\end{align*}
\]

A Catalog of Forces: 3. Spring

A compressed spring exerts a pushing force on an object.

Sprung Force
A stretched or compressed spring exerts contact force.
A spring can either push (when compressed) or pull (when stretched). In either case, tail of the vector force is attached to the contact point.
No special symbol for the spring force, but we can use \( F_{spr} \).

A Catalog of Forces: 4. Tension

The rope exerts a tension force on the sled.

Tension Force
A string or rope exerts contact force on object when it pulls on it. We call this a tension force, represented by symbol \( T \). Tension is always directed along the line of the rope or string, with no component perpendicular to it.
A Catalog of Forces: 5. Friction

At the molecular level, surfaces tend to stick together, impeding motion. This produces the force we call friction. Kinetic friction, denoted by symbol $f_k$, appears when an object moves across a surface. This force opposes the motion and points in opposite direction from the velocity.

Static friction, denoted by symbol $f_s$, is force that keeps an object at rest stuck to a surface and tries to prevent motion. It points in the direction that prevents motion. Typically, it is larger than the kinetic friction that appears after the object begins to move.

A Catalog of Forces: 6. Drag

A friction-like force that opposes motion in a gas or liquid. Like kinetic friction, it appears in the direction opposite that of the motion. Example: air resistance. Air resistance is a significant force on falling leaves. It points opposite the direction of motion.

A Catalog of Forces: 7. Thrust

A contact force produced, for example, when the exhaust gases press against the inner surfaces of a jet engine.

Thrust force is exerted on a rocket by exhaust gases.
Catalog of Forces: 8-Electromagnetic

Electric and Magnetic Forces
Electricity and magnetism, like gravity, produce long range forces. You will study them in Physics 121.

Frictional Forces
Friction has its basis in surfaces that are not completely smooth:

Microscopic Friction
Surface Roughness

Magnified section of a polished steel surface showing surface irregularities about $5 \times 10^{-7}$ m (500 nm) high. This height corresponds to several thousand atomic diameters.

Adhesion

Computer graphic from a simulation showing gold atoms (below) adhering to the point of a sharp nickel probe (above) that has been in contact with the gold surface.

Friction vs. Area

Microscopic area of contact between box and floor is only a small fraction of macroscopic area of box’s bottom surface. If box turned on side, macroscopic area is increased, but microscopic area of contact remains same (because contact is more distributed). Therefore, frictional force $f$ is independent of contact area.
Kinetic Friction

*Kinetic friction:* the friction experienced by surfaces sliding against one another.

The kinetic frictional force depends on the normal force:

\[ f_k = \mu_k N \]  \hspace{1cm} (6-1)

The constant \( \mu_k \) is called the coefficient of kinetic friction.

---

Kinetic Friction and Speed

The kinetic frictional force is also independent of the relative speed of the surfaces, and of their area of contact.

---

Coefficients of Friction

<table>
<thead>
<tr>
<th>Materials</th>
<th>Kinetic, ( \mu_k )</th>
<th>Static, ( \mu_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber on concrete (dry)</td>
<td>0.80</td>
<td>1–4</td>
</tr>
<tr>
<td>Steel on steel</td>
<td>0.57</td>
<td>0.74</td>
</tr>
<tr>
<td>Glass on glass</td>
<td>0.40</td>
<td>0.94</td>
</tr>
<tr>
<td>Wood on leather</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>Copper on steel</td>
<td>0.36</td>
<td>0.53</td>
</tr>
<tr>
<td>Rubber on concrete (wet)</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>Steel on ice</td>
<td>0.06</td>
<td>0.10</td>
</tr>
<tr>
<td>Wax on glass</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Teflon on Teflon</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Synovial joints in humans</td>
<td>0.003</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Typically, \( \mu_s > \mu_k \)
Example: Shuffleboard

Cue stick pushes shuffleboard disk of mass 0.40 kg horizontally along deck. Disk leaves cue at speed of 8.5 m/s and slides distance of 8.0 m. Coefficient of kinetic friction between disk and deck?

\[ f_k = \mu_k N \]

\[ \sum F_y = ma_y = 0 \]

\[ N - mg = 0 \Rightarrow N = mg \]

\[ \sum F_x = ma_x \]

\[ -f_k = -\mu_k mg = ma_x \]

\[ a_x = -\mu_k g \]

\[ v_x^2 = v_{0x}^2 + 2a_x \Delta x \Rightarrow 0 = v_{0x}^2 - 2\mu_k g \Delta x \]

\[ \mu_k = \frac{v_{0x}^2}{2g\Delta x} = \frac{(8.5 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)(8.0 \text{ m})} = 0.46 \]

End of Lecture 10

- Before the next lecture, read Walker 6.1-2
- Homework Assignments #5b should be submitted using WebAssign by 11:00 PM on Thursday, Sept. 24.