# Chatper 6 - Force and Motion II



"Only in the frictionless vacuum of a nonexistent abstract world can movement or change occur without that abrasive friction of conflict."

- *Saul Alinsky*

David J. Starling
Penn State Hazleton

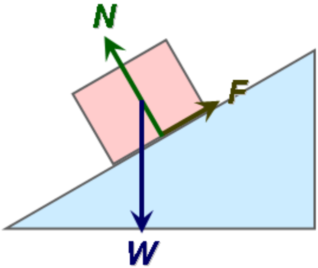
PHYS 211

# Friction





*Frictional forces affect almost every situation and tend to oppose motion.*



# Friction





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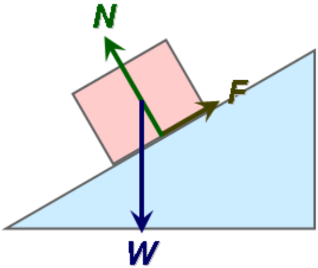
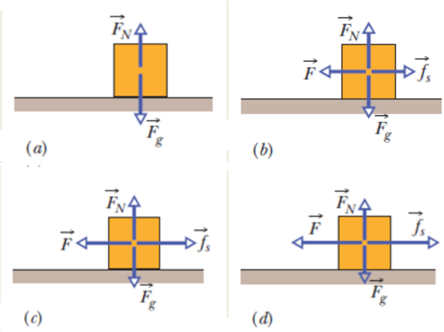



The block wants to slide down the incline so friction opposes this motion.

# Friction



**Static friction** $\vec{f}_s$ *is a force that holds an object in place (so* $\vec{v} = 0$*).*



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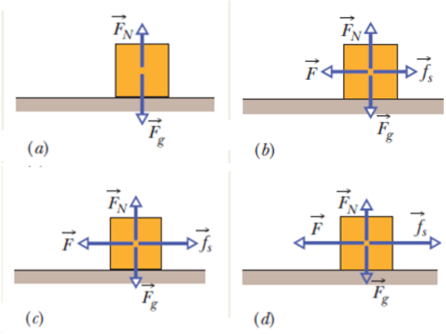


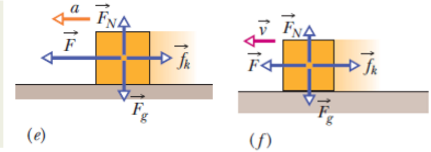

Even if the applied force $\vec{F}$ increases, the frictional force balances it.

# Friction





**Kinetic friction** $\vec{f}_k$ *is a force that opposes motion after an object begins to slide.*



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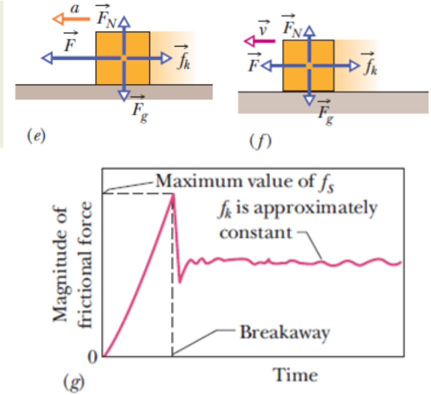
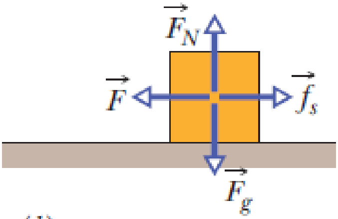



The kinetic friction force is less than the static friction force and the motion is jerky.

# Friction

**Property 1:** *For a motionless object, $\vec{f}_s$ points parallel to the contact surface and balances the sum of the other forces in the plane of that surface.*




(*b*)

# Friction



**Property 2:** *For motionless objects, the frictional force has a* **maximum value** *of*

$$f_{s,max} = \mu_s F_N,$$

*where* $\mu_s$ *is the coefficient of static friction and* $F_N$ *is the magnitude of the normal force.*

# Friction



**Property 2:** *For motionless objects, the frictional force has a* **maximum value** *of*

$$f_{s,max} = \mu_s F_N,$$

*where $\mu_s$ is the coefficient of static friction and $F_N$ is the magnitude of the normal force.*

If the other forces in that plane exceed $f_{s,max}$, then the object slides.

# Friction



**Property 3:** *For objects in motion, the frictional force is*

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# Friction



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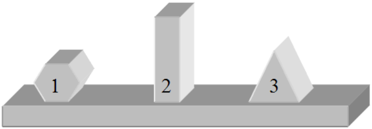
| Materials | $\mu_s$ | $\mu_k$ |
|---|---|---|
| Steel on steel | 0.74 | 0.57 |
| Aluminum on steel | 0.61 | 0.47 |
| Copper on steel | 0.53 | 0.36 |
| Rubber on concrete (dry) | 1.0 | 0.8 |
| Rubber on concrete (wet) | 0.3 | 0.25 |
| Wood on wood | 0.25-0.5 | 0.2 |
| Glass on glass | 0.94 | 0.4 |
| Teflon on Teflon | 0.04 | 0.04 |
| Teflon on steel | 0.04 | 0.04 |
| Waxed wood on wet snow | 0.14 | 0.1 |
| Waxed wood on dry snow | 0.10 | 0.04 |
| Metal on metal (lubricated) | 0.15 | 0.06 |
| Ice on ice | 0.1 | 0.03 |
| Synovial joints in humans | 0.01 | 0.003 |
| Very rough surfaces | | 1.5 |

# Friction

## Lecture Question 6.1

Three pine blocks of mass *m* are sitting on a rough surface as shown. If the same horizontal force is applied to each block, which one of the following statements is false?




**(a)** The coefficient of kinetic friction is the same for all three.

**(b)** The magnitude of the force of kinetic friction is greater for block 3.

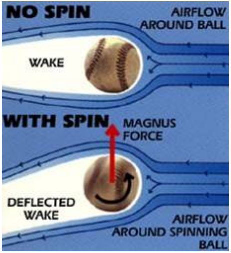
**(c)** The normal force exerted by the surface is the same for all.

**(d)** Block 3 has the greatest area in contact with the surface.

**(e)** If the force is the minimum to start block 1 moving, then that same force could be used to start any block.

# Drag

*A blunt object experiences a drag force when it moves through a fluid such as air.*




$$F_D = \frac{1}{2} C \rho A v^2$$

# Drag



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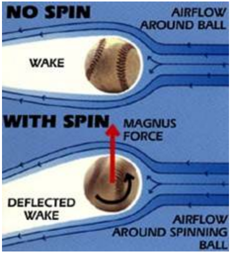



$$F_D = \frac{1}{2} C \rho A v^2$$

$C$: drag coefficient, $\rho$: density of fluid, $A$: cross-sectional area, $v$: velocity of object

# Drag



TABLE 6-1

**Some Terminal Speeds in Air**

| Object | Terminal Speed (m/s) | 95% Distance[a] (m) |
|---|---|---|
| Shot (from shot put) | 145 | 2500 |
| Sky diver (typical) | 60 | 430 |
| Baseball | 42 | 210 |
| Tennis ball | 31 | 115 |
| Basketball | 20 | 47 |
| Ping-Pong ball | 9 | 10 |
| Raindrop (radius = 1.5 mm) | 7 | 6 |
| Parachutist (typical) | 5 | 3 |

[a]This is the distance through which the body must fall from rest to reach 95% of its terminal speed.

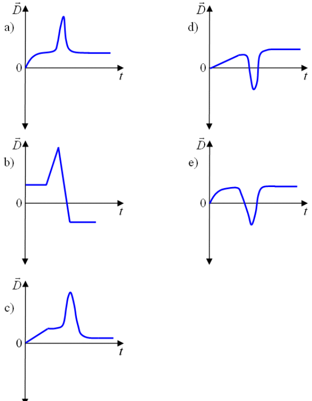
*Source:* Adapted from Peter J. Brancazio, *Sport Science,* 1984, Simon & Schuster, New York.

# Drag



**Lecture Question 6.2**

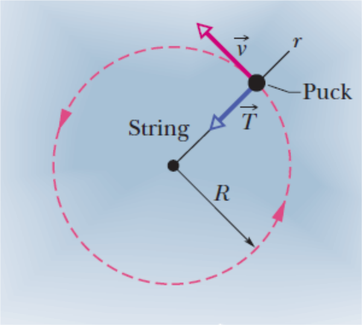
A sky diver jumps from a flying airplane and falls for several seconds before she reaches terminal velocity. She then opens her parachute, reaches a new terminal velocity, and continues her descent to the ground. Which graph of the drag force versus time best represents this situation?



# Uniform Circular Motion



*Objects moving in uniform circular motion experience an acceleration toward the center of the circle given by* $a_r = v^2/r$.



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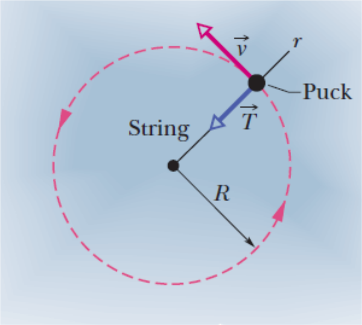


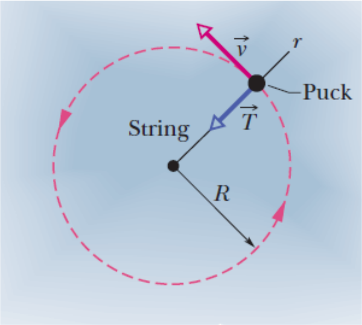

The tension $\vec{T}$ in the string is the **centripetal force**.

# Uniform Circular Motion



*The equation of motion for an object in uniform circular motion is just:*

$$F_{net} = ma \rightarrow F_{net} = m\frac{v^2}{r}$$



# Uniform Circular Motion



**Lecture Question 6.3** A ball is whirled on the end of a string in a horizontal circle of radius $R$ at constant speed $v$. By which one of the following means can the centripetal acceleration of the ball be increased by a factor of two?

- **(a)** Keep radius fixed and increase the period by a factor of 2.
- **(b)** Keep radius fixed and decrease the period by a factor of 2.
- **(c)** Keep radius fixed and increase the speed by a factor of 2.
- **(d)** Keep speed fixed and increase the radius by a factor of 2.
- **(e)** Keep speed fixed and decrease the radius by a factor of 2.