Lecture

• Review: Newton’s Laws of Motion
• Friction force vs. applied force.
• Static and kinetic friction.
• Drag, terminal speed.
Review: Newton’s Laws

• A force is a push or pull.

Newton’s first law (often called the law of inertia).

Every object continues in its state of rest or of uniform velocity, as long as no net force acts on it.

• An inertial reference frame is one in which Newton’s first law is valid.

Newton’s Second Law is the relation between acceleration and net force \( \Sigma \vec{F} = m \vec{a} \)

Newton’s third law: Whenever one object exerts a force on a second object, the second exerts an equal force in the opposite direction on the first \( \vec{F}_{12} = -\vec{F}_{21} \).
Example

A traffic light weighing 122 N hangs from a cable tied to two other cables fastened to a support, as shown. The upper cables make angles of 37.0° and 53.0° with the horizontal. These upper cables are not as strong as the vertical cable, and will break if the tension in them exceeds 100 N. Will the traffic light remain hanging in this situation, or will one of the cables break?

*Note that $a_x = a_y = 0$ (i.e. the light is not accelerating)*

FBD (knot)

\[
\sum F_x = T_2 \cos 53^\circ - T_1 \cos 37^\circ = 0
\]

\[
\sum F_y = T_1 \sin 37^\circ + T_2 \sin 53^\circ - T_3 = 0
\]

FBD (light)

\[
\sum F_y = T_3 - mg = 0
\]

\[mg = 122N\]
Example

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Note that \( a_x = a_y = 0 \) (i.e. the light is not accelerating)

\[
\begin{align*}
\Sigma F_x &= T_2 \cos 53^\circ - T_1 \cos 37^\circ = 0 \\
\Sigma F_y &= T_1 \sin 37^\circ + T_2 \sin 53^\circ - 122N = 0
\end{align*}
\]

\[
\begin{align*}
T_2 &= T_1 \frac{\cos 37^\circ}{\sin 53^\circ} = 1.33 T_1 \\
T_1 \sin 37^\circ + 1.33 T_1 \sin 53^\circ - 122N &= 0
\end{align*}
\]

\[
T_1 = 73.4 N \\ T_2 = 97.4 N
\]

\( T_1 \) & \( T_2 \) < 100 N, the cable does not break!
If you push with force $F$ on either the heavy box ($m_1$) or the light box ($m_2$), in which of the two cases below is the contact force between the two boxes larger?

a) case A

b) case B

c) same in both cases
Two blocks of masses 2m and m are in contact on a horizontal frictionless surface. If a force F is applied to mass 2m, what is the force on mass m?

a) 2 F  
b) F  
c) 1/2 F  
d) 1/3 F  
e) 1/4 F
A block of mass m rests on the floor of an elevator that is moving upward at constant speed. What is the relationship between the force due to gravity and the normal force on the block?

a) $F_N > mg$

b) $F_N = mg$

c) $F_N < mg$ (but not zero)

d) $F_N = 0$

e) It depends on the size and weight of the elevator
A block of mass \( m \) rests on the floor of an elevator that is accelerating upward. What is the relationship between the force due to gravity and the normal force on the block?

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c) \( F_N < mg \) (but not zero)

d) \( F_N = 0 \)

e) It depends on the size and weight of the elevator
Consider two identical blocks, one resting on a flat surface, and the other resting on an incline. For which case is the magnitude of the normal force greater?

- a) case A
- b) case B
- c) both the same \((N = mg)\)
- d) both the same \((0 < N < mg)\)
- e) both the same \((N = 0)\)
Example

Two boxes are on top of a frictionless table while being pulled by a force of magnitude 40.0 N.

A) What are the accelerations of box A and box B.

B) What is the tension of the rope connecting box A and box B?
Example

Two boxes are on top of a frictionless table while being pulled by a force of magnitude 40.0 N.

A) What are the accelerations of box A and box B.
B) What is the tension of the rope connecting box A and box B?

\[ \Sigma F_x = F_p = (m_A + m_B)a_x \]

\[ (22.0 \text{ kg})a_x = 40.0 \text{ N} \]

\[ a_x = 1.82 \text{ m/s}^2 \]
Example

Two boxes are on top of a frictionless table while being pulled by a force of magnitude 40.0 N.

A) What are the accelerations of box A and box B.

B) What is the tension of the rope connecting box A and box B?

\[ \Sigma F_x = T = m_B a_x \]

\[ T = 12.0 \text{ kg} \times (1.82 \text{ m/s}^2) = 21.8 \text{ N} \]
In which case does block m experience a larger acceleration? In (1) there is a 10 kg mass hanging from a rope and falling. In (2) a hand is providing a constant downward force of 98 N. Assume massless ropes and $|\vec{g}| = 9.8 \text{ m/s}^2$.

a) case 1  
b) acceleration is zero  
c) both cases are the same  
d) depends on value of m  
e) case 2
Example: Frictionless Table

a) Find the accelerations of $m_1$ and $m_2$

b) Find the tension on the rope.

How does $T_1$ compare to $T_2$?

$T_1 = T_2$ (Ideal Pulley)

How does $a_1$ compare to $a_2$?

$a_1 = a_2$

Σ$F_x = T = m_1a$

Σ$F_y = F_N - m_1g = 0$

Σ$F_x = m_2g - T = m_2a$

Σ$F_y = 0$
Friction
Friction Force vs Applied Force

• Observation 1: The static frictional force increases as the applied force increases, until it reaches its maximum.

• Observation 2: Then the object starts to move, and the (nearly constant) kinetic frictional force takes over.

• Observation 3: The kinetic frictional force is less than the maximum static frictional force.
What Causes Friction

On a microscopic scale, most surfaces are rough. The exact details are not yet known, but the force can be modeled in a very simple way.
Friction On Different Surfaces

Table

Mirror

Rubber
Friction Dependence on Mass
Friction Dependence on Surface Area
On a microscopic scale, most surfaces are rough. The exact details are not yet known, but the force can be modeled in a very simple way.

For kinetic ("sliding") friction: \[ f_k = \mu_k F_N \]

\( \mu_k \) is the coefficient of kinetic friction and is different for every pair of surfaces.
Static Friction

Static friction is the frictional force between two surfaces that are not moving along each other.

Static friction keeps objects on inclines from sliding and keeps objects from moving when a force is first applied.

\[ f_s \leq \mu_s F_N \]

\( \mu_s \) is the coefficient of static friction.

At the moment when the static friction force is at a maximum \( (f_{s_{\text{max}}}) \) we have:

\[ f_{s_{\text{max}}} = \mu_s F_N \]
Your little sister wants you to give her a ride on her sled. On level ground, what is the easiest way to accomplish this?

a) pushing her from behind

b) pulling her from the front

c) both are equivalent

d) it is impossible to move the sled

e) tell her to get out and walk