Chapter 5

The Laws of Motion

Applications of Newton’s Law

- Assumptions
  - Objects can be modeled as particles
  - Masses of strings or ropes are negligible
    - When a rope attached to an object is pulling it, the magnitude of that force, **T**, is the **tension** in the rope
  - Interested only in the external forces acting on the object
    - can neglect reaction forces
  - Initially dealing with frictionless surfaces

Objects in Equilibrium

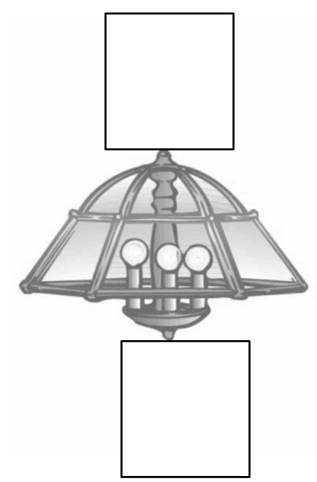
- If the acceleration of an object that can be modeled as a particle is zero, the object is said to be in **equilibrium**
- Mathematically, the net force acting on the object is zero

$$\sum F = 0$$
$$\sum F_x = 0 \text{ and } \sum F_y = 0$$

Equilibrium, Example 1

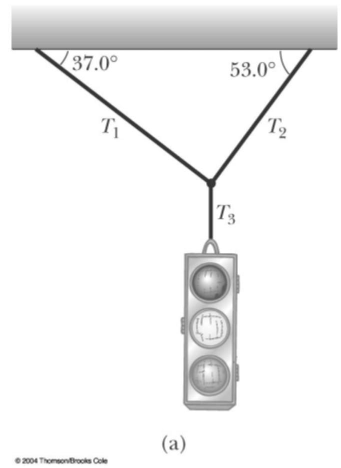
- A lamp is suspended from a chain of negligible mass
- The forces acting on the lamp are
  - the force of gravity (**F**$_g$)
  - the tension in the chain (**T**)
- Equilibrium gives

$$\sum F_y = 0 \rightarrow T - F_g = 0 \qquad T = F_g$$



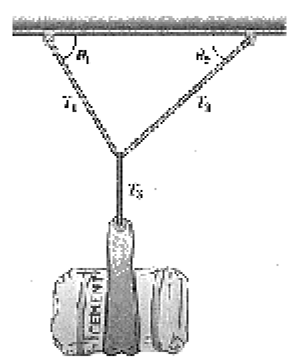
Equilibrium, Example 2

- Conceptualize the traffic light
- Categorize as an equilibrium problem
  - No movement, so acceleration is zero
- Analyze



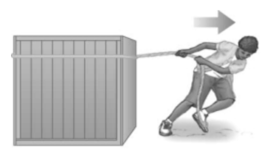
Webassign Problem

- A bag of cement of weight 425 N hangs from three wires as suggested in the figure below. Two of the wires make angles ?1 = 55.0° and ?2 = 26.0° with the horizontal. Assuming the system is in equilibrium, find the tensions in the wires.



Newton's Second Law, Example 1a

- Forces acting on the crate:
  - A tension, the magnitude of force **T**
  - The gravitational force, $\mathbf{F}_g$
  - The normal force, **n**, exerted by the floor

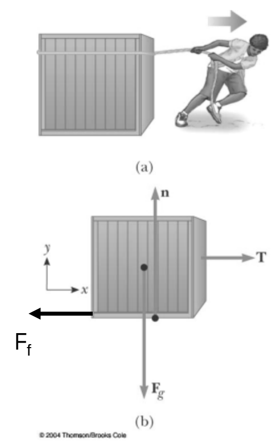


Newton's Second Law Example 1b

- Apply Newton's Second Law in component form:

Newton's Second Law, Example

- Suppose the person pulls with a force that is equal to 100 N and the friction force between the crate and the floor is 20 N, solve for the acceleration if the mass of the crate is 10 kg.

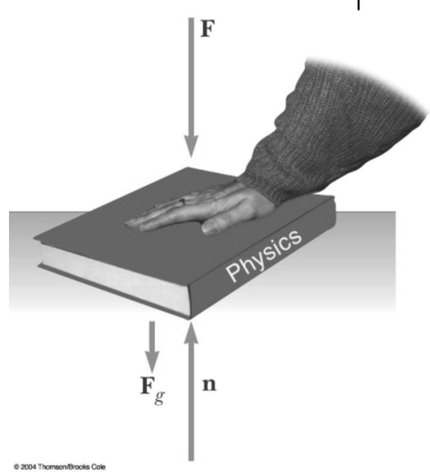


Note About the Normal Force

- The normal force is **not** always equal to the gravitational force of the object
- For example, in this case

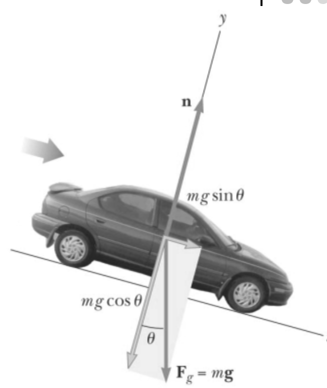
$$\sum F_y = n - F_g - F = 0$$
$$\text{and } n = F_g + F$$

- **n** may also be less than $\mathbf{F}_g$



Inclined Planes

- Forces acting on the object:
  - The normal force, **n**, acts perpendicular to the plane
  - The gravitational force, $\mathbf{F}_g$, acts straight down
- Choose the coordinate system with *x* along the incline and *y* perpendicular to the incline
- Replace the force of gravity with its components
- **What is the acceleration if the car is sliding along the icy incline? Take the incline angle to be 10º.**



Multiple Objects

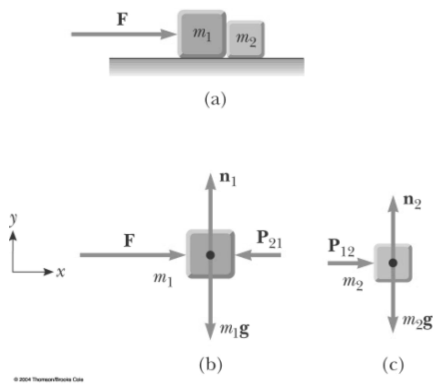
- When two or more objects are connected or in contact, Newton's laws may be applied to the system as a whole and/or to each individual object
- Whichever you use to solve the problem, the other approach can be used as a check

Multiple Objects, Example 1

- First treat the system as a whole:

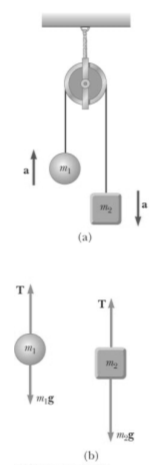
$$\sum F_x = m_{\text{system}} a_x$$

- Apply Newton's Laws to the individual blocks
- Solve for unknown(s)
- Check: $|\mathbf{P}_{21}| = |\mathbf{P}_{12}|$

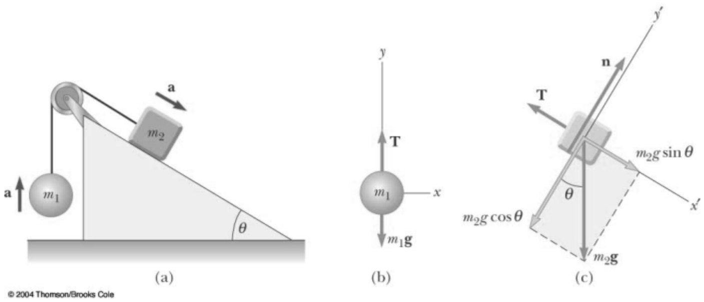


Multiple Objects, Example 2

- Forces acting on the objects:
  - Tension (same for both objects, one string)
  - Gravitational force
- Each object has the same acceleration since they are connected
- Draw the free-body diagrams
- Apply Newton's Laws
- Solve for the unknown(s)



Multiple Objects, Example 3



- Draw the free-body diagram for each object
  - One cord, so tension is the same for both objects
  - Connected, so acceleration is the same for both objects
- Apply Newton's Laws
- Solve for the unknown(s)

Problem-Solving Hints Newton's Laws

- Conceptualize the problem – draw a diagram
- Categorize the problem
  - Equilibrium ($\Sigma \mathbf{F} = 0$) or Newton's Second Law ($\Sigma \mathbf{F} = m\,\mathbf{a}$)
- Analyze
  - Draw free-body diagrams for each object
  - Include only forces acting on the object

Problem-Solving Hints Newton's Laws, cont

- Analyze, cont.
  - Establish coordinate system
  - Be sure units are consistent
  - Apply the appropriate equation(s) in component form
  - Solve for the unknown(s)
- Finalize
  - Check your results for consistency with your free- body diagram
  - Check extreme values

Forces of Friction

- When an object is in motion on a surface or through a viscous medium, there will be a resistance to the motion
  - This is due to the interactions between the object and its environment
- This resistance is called the *force of friction*

Forces of Friction, cont.

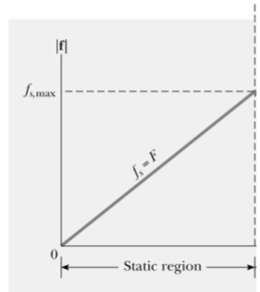
- Friction is proportional to the normal force
  - $f_s \le \mu_s n$ and $f_k = \mu_k n$
  - These equations relate the magnitudes of the forces, they are not vector equations
- The force of static friction is generally greater than the force of kinetic friction
- The coefficient of friction (μ) depends on the surfaces in contact

Forces of Friction, final

- The direction of the frictional force is opposite the direction of motion and parallel to the surfaces in contact
- The coefficients of friction are nearly independent of the area of contact

Static Friction

- Static friction acts to keep the object from moving
- If **F** increases, so does $\boldsymbol{f}_s$
- If **F** decreases, so does $\boldsymbol{f}_s$



Kinetic Friction

- The force of kinetic friction acts when the object is in motion
- Although μ_k can vary with speed, we shall neglect any such variations
- $f_k = \mu_k n$

Some Coefficients of Friction

Table 5.2

Coefficients of Friction[a]

	μ_s	μ_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	1.0	0.8
Wood on wood	0.25–0.5	0.2
Glass on glass	0.94	0.4
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

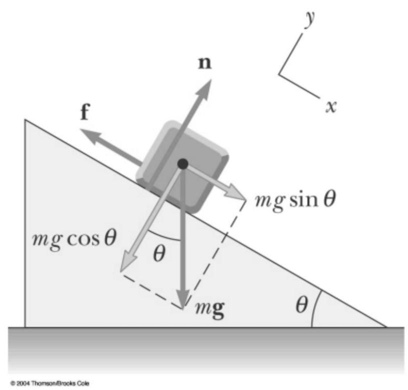
[a] All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

Friction in Newton's Laws Problems

- Friction is a force, so it simply is included in the Σ**F** in Newton's Laws
- The rules of friction allow you to determine the direction and magnitude of the force of friction

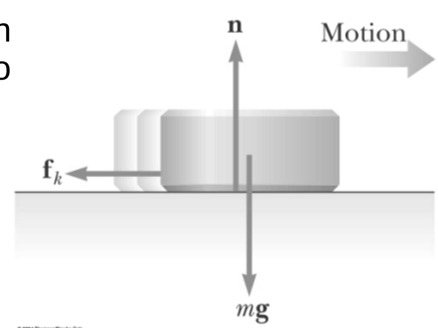
Friction Example, 1

- The block is sliding down the plane, so friction acts up the plane
- This setup can be used to experimentally determine the coefficient of friction

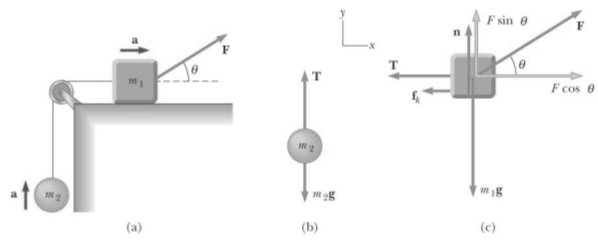


Friction, Example 2

- Draw the free-body diagram, including th force of kinetic frictio
  - Opposes the motion
  - Is parallel to the surfaces in contact
- Continue with the solution as with any Newton's Law problem



Friction, Example 3



- Friction acts only on the object in contact with another surface
- Draw the free-body diagrams
- Apply Newton's Laws as in any other multiple object system problem