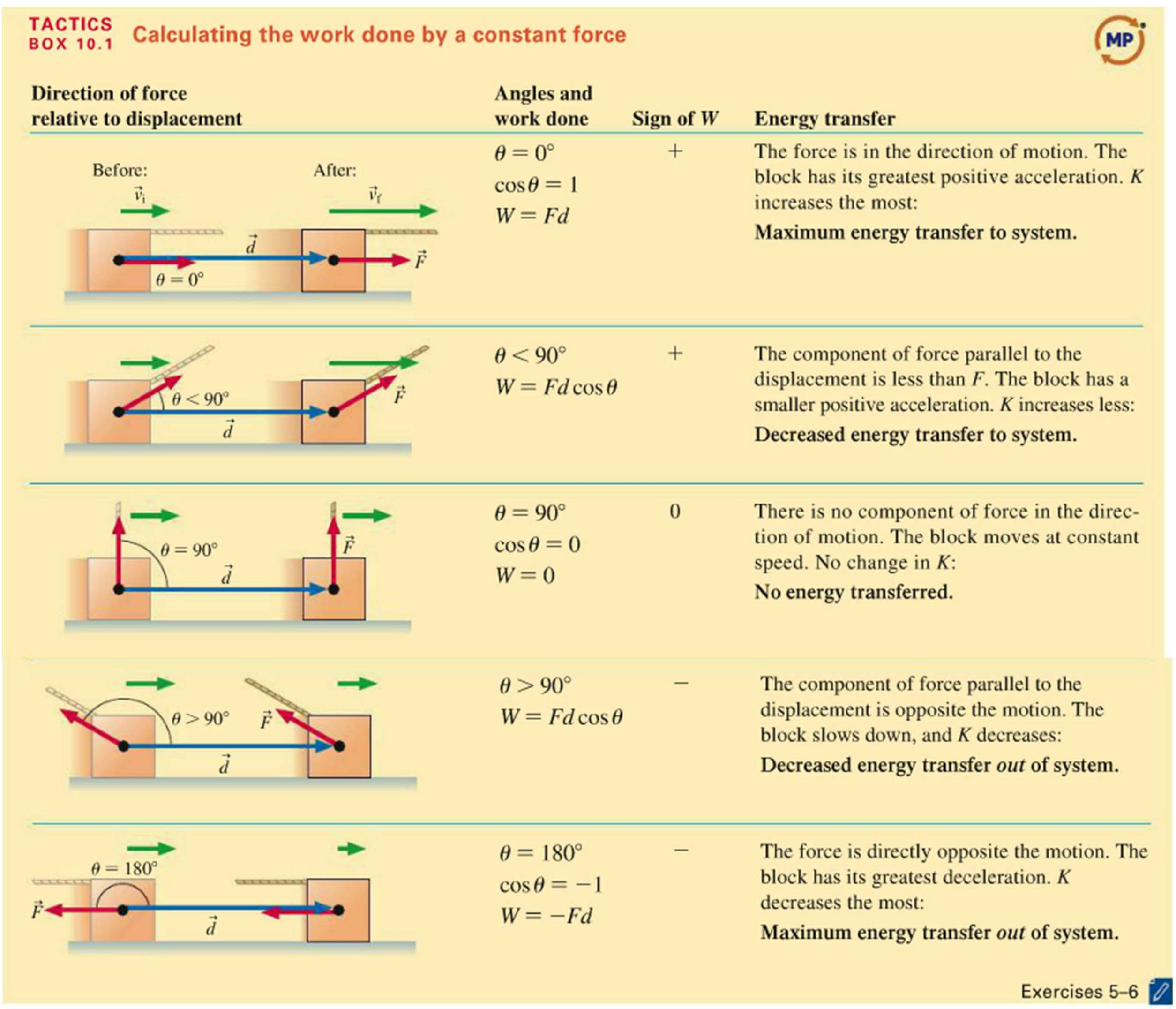
ENERGY

WORK

- **Work→** the change in energy of a system resulting from the application of a force acting over a distance.
  - ➢ Work can be done by forces outside the system (**external forces**).
  - ➢ Work can be done by forces within the system (**internal forces**).
  - ➢ The larger the displacement, the greater the work done.
  - ➢ The stronger the force, the greater the work done.
  - ➢ Unit: Joules (J)
  - ➢ 1 J = 1 N·m

$$W = Fd\cos\theta$$

- Note: Joules will be the unit for *all* forms of energy and work is energy being transferred.
- The sign of W is determined by the angle between the force and displacement vectors.



TACTICS BOX 10.1 Calculating the work done by a constant force

Direction of force relative to displacement	Angles and work done	Sign of W	Energy transfer
Before: $\vec{v}_i$ After: $\vec{v}_f$ $\vec{d}$ $\vec{F}$ $\theta = 0°$	$\theta = 0°$ $\cos\theta = 1$ $W = Fd$	+	The force is in the direction of motion. The block has its greatest positive acceleration. K increases the most: **Maximum energy transfer to system.**
$\theta < 90°$ $\vec{d}$ $\vec{F}$	$\theta < 90°$ $W = Fd\cos\theta$	+	The component of force parallel to the displacement is less than F. The block has a smaller positive acceleration. K increases less: **Decreased energy transfer to system.**
$\theta = 90°$ $\vec{d}$ $\vec{F}$	$\theta = 90°$ $\cos\theta = 0$ $W = 0$	0	There is no component of force in the direction of motion. The block moves at constant speed. No change in K: **No energy transferred.**
$\theta > 90°$ $\vec{F}$ $\vec{d}$	$\theta > 90°$ $W = Fd\cos\theta$	−	The component of force parallel to the displacement is opposite the motion. The block slows down, and K decreases: **Decreased energy transfer *out* of system.**
$\theta = 180°$ $\vec{F}$ $\vec{d}$	$\theta = 180°$ $\cos\theta = -1$ $W = -Fd$	−	The force is directly opposite the motion. The block has its greatest deceleration. K decreases the most: **Maximum energy transfer *out* of system.**

Exercises 5–6

EXAMPLE 10.2 Work done in pulling a suitcase

A strap inclined upward at a 45° angle pulls a suitcase through the airport. The tension in the strap is 20 N. How much work does the tension do if the suitcase is pulled 100 m at a constant speed?

EXAMPLE 10.1 Work done in pushing a crate

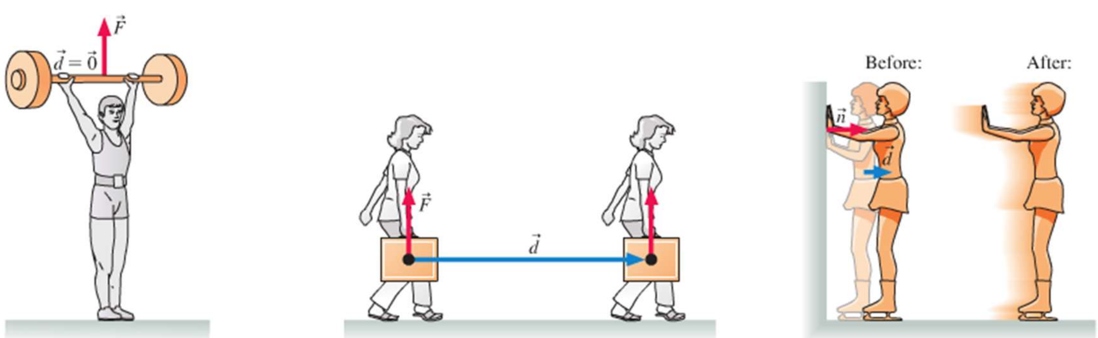
Sarah pushes a heavy crate 3.0 m along the floor at a constant speed. She pushes with a constant horizontal force of magnitude 70 N. How much work does Sarah do on the crate?

CONCEPTUAL EXAMPLE 10.3 Work done by a parachute

A drag racer is slowed by a parachute. What is the sign of the work done?

- If several forces do work on a system, the total work, or **net work**, is the sum of the work done by each force.
  - ➢ Represents the total energy to the system (if Wtotal > 0) or from the system (if Wtotal < 0).
- Forces acting perpendicular to the displacement do no work.

Forces that do no work



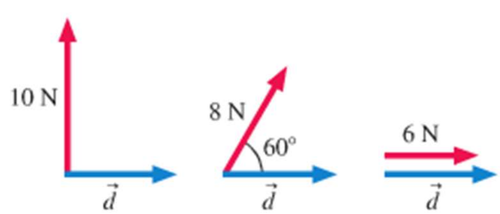
If the object undergoes no displacement while the force acts, no work is done.
This can sometimes seem counterintuitive.

A force perpendicular to the displacement does no work.
The woman exerts only a vertical force on

If the part of the object on which the force acts undergoes no displacement, no work is done.

STOP TO THINK 10.2 Which force does the most work?

A. The 10 N force
B. The 8 N force
C. The 6 N force
D. They all do the same amount of work.



POWER

- **Power→** the amount of work done over time.
    - ➢ The amount of energy transformed over time
    - ➢ Measured in Watts (W)

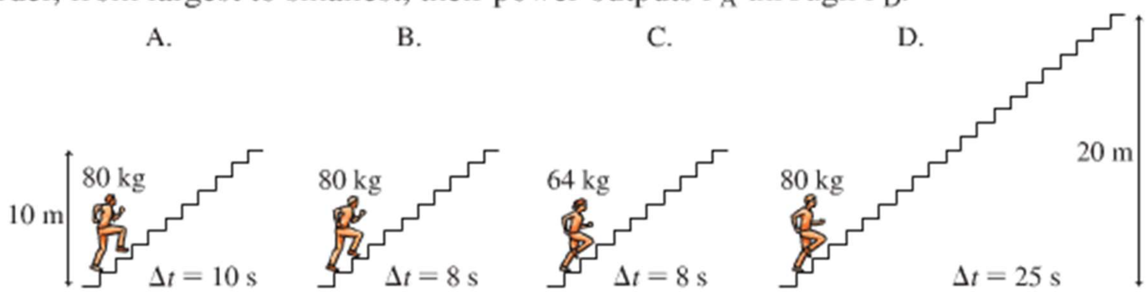
$$P = \frac{\Delta E}{\Delta t}$$

$$P = \frac{W}{\Delta t}$$

$$P = Fv$$

- The English unit of Power is horsepower (hp).
    - ➢ 1 hp = 746 W
    - ➢ Used in every car commercial ever

STOP TO THINK 10.9 Four students run up the stairs in the times shown. Rank in order, from largest to smallest, their power outputs P_A through P_D.



KINETIC ENERGY

- **Kinetic Energy** (K)→ the energy of motion.
  - The more mass an object has and the faster it moves, the more kinetic energy it has.

$$K = \frac{1}{2}mv^2$$

- Units: Joules (J)

> Example:
>
> A Boeing 747 airliner, weighing 2.2 x 10^6 N at takeoff, is cruising at a ground speed of 268 m/s (600 mi/h). Compute its kinetic energy. If 1 kg of TNT yields 4.6 x10^6 J, how much TNT is the plane's kinetic energy equivalent to?

- Kinetic energy is a *relative quantity*.
  - If you were in that jet sitting at "rest" next to your 20 kg suitcase, it would have no kinetic energy with respect to you. But to someone at "rest" on the ground watching, your bag would have an enormous amount of kinetic energy.
  - As a rule, **we are not interested in the total energy of a system, but in the energy added to or taken from it.**
- **Work-Energy Theorem**→ the net work done on an object is equal to the change in the object's kinetic energy.

$$W_{net} = \Delta K = K_f - K_i$$

> Example:
>
> According to the record books, Aleksandr Zass (known to his admirers as "Samson") would, when he wasn't bending iron bars, catch a 104-lb woman (463-N) fired from a cannon at around 45 mi/h. Assuming that Samson brought her to rest uniformly in a distance of 1.00 m, compute the average force he exerted on our heroine. As a guess, taker her "landing speed" to be 8.94 m/s (i.e., only 20 mi/h). Only a negligible amount of energy went into overcoming friction.

POTENTIAL ENERGY

- **Potential Energy** (U)→ energy stored through the interaction of two or more material objects.
  - ex: pushing a box against a spring
  - This stored energy is called potential energy since it has the *potential* to be converted into other forms of energy, such as kinetic or thermal energy.
- **Gravitational Potential Energy** (Ug)→ the potential energy of position.
  - The zero reference level for GPE is arbitrary. We get to define it.
  - Really measuring the change in GPE. Only the changes in GPE are significant.
  - The work done raising a mass equals the increase in its potential energy.

$$U_g = mgh$$

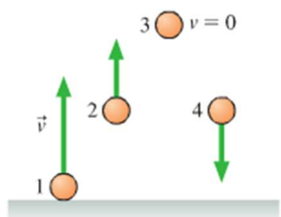
- GPE depends only on the height of an object and not on the path the object took to get there.

EXAMPLE 10.7 **Racing up a skyscraper**

In the Empire State Building Run-Up, competitors race up the 1576 steps of the Empire State Building, climbing a total vertical distance of 320 m. How much gravitational potential energy does a 70 kg racer gain during this race?

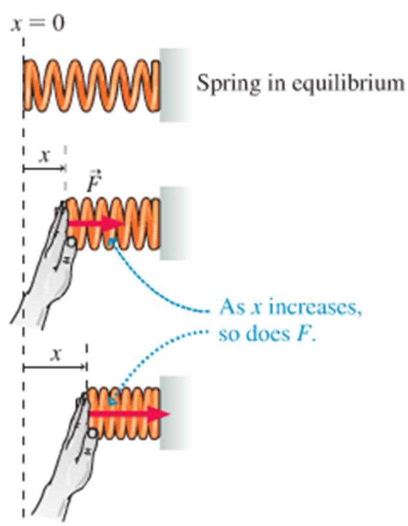
Racers head up the staircase in the Empire State Building Run-Up.

STOP TO THINK 10.4 Rank in order, from largest to smallest, the gravitational potential energies of identical balls 1 through 4.



- **Spring Potential Energy** (Us)→ potential energy stored in a spring or other elastic material.
    - ➢ The Achilles tendon stores SPE

$$U_s = \frac{1}{2}kx^2$$



EXAMPLE 10.8 **Pulling back on a bow**

An archer pulls back the string on her bow to a distance of 70 cm from its equilibrium position. To hold the string at this position takes a force of 140 N. How much elastic potential energy is stored in the bow?

STOP TO THINK 10.5 When a spring is stretched by 5 cm, its elastic potential energy is 1 J. What will its elastic potential energy be if it is *compressed* by 10 cm?

A. −4 J B. −2 J C. 2 J D. 4 J

CONSERVATION OF ENERGY

- **Conservation of Energy**→ energy can neither be created nor destroyed, only transformed.
  - ➢ total amount of energy (**total energy**) is constant when isolated from the rest of the Universe, even though energy may be transformed from one kind to another within the system.

$$K_f + U_f = K_i + U_i$$

- Usually we're only dealing with kinetic energy and gravitational potential energy (total mechanical energy).
- Energy that appears to be missing in real-world scenarios can often be traced to having been converted to thermal energy.

EXAMPLE 10.10 Hitting the bell

At the county fair, Katie tries her hand at the ring-the-bell attraction, as shown in FIGURE 10.21. She swings the mallet hard enough to give the ball an initial upward speed of 8.0 m/s. Will the ball ring the bell, 3.0 m from the bottom?

CONSERVATIVE AND NONCONSERVATIVE FORCES

- **Conservative force**→ has the property that the **total** work done by the conservative force is zero when the body moves around any closed path and returns to its initial position.
  - ➢ Ex: Someone climbing to the top of the diving board and jumping off. She does work against gravity on the way up. GPE is changed into kinetic energy as she falls, until the kinetic energy as she hits the water is the same as the amount of work it took for her to go up the ladder.
  - ➢ Potential energies are conservative.
- **Nonconservative forces**→ a force is nonconservative if the work done by the force on a body moving between two points depends on the path taken. These forces dissipate energy (don't conserve total mechanical energy).
  - ➢ Ex: friction. Frictional force takes away kinetic energy and dissipates it in the form of thermal energy (heat)
  - ➢ Ex: slamming on your brakes in your car.

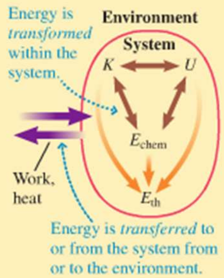
GENERAL PRINCIPLES

Basic Energy Model

Within a system, energy can be **transformed** between various forms.

Energy can be **transferred** into or out of a system in two basic ways:

- **Work:** The transfer of energy by mechanical forces
- **Heat:** The nonmechanical transfer of energy from a hotter to a colder object



Conservation of Energy

When work W is done on a system, the system's total energy changes by the amount of work done. In mathematical form, this is the **work-energy equation:**

$$\Delta E = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \cdots = W$$

A system is **isolated** when no energy is transferred into or out of the system. This means the work is zero, giving the **law of conservation of energy:**

$$\Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \cdots = 0$$

Solving Energy Transfer and Energy Conservation Problems

PREPARE Draw a before-and-after visual overview.

SOLVE

- If work is done on the system, then use the before-and-after version of the work-energy equation:

$$K_f + (U_g)_f + (U_s)_f + \Delta E_{th} = K_i + (U_g)_i + (U_s)_i + W$$

- If the system is isolated but there's friction present, then the total energy is conserved:

$$K_f + (U_g)_f + (U_s)_f + \Delta E_{th} = K_i + (U_g)_i + (U_s)_i$$

- If the system is isolated and there's no friction, then mechanical energy is conserved:

$$K_f + (U_g)_f + (U_s)_f = K_i + (U_g)_i + (U_s)_i$$

ASSESS Kinetic energy is always positive, as is the change in thermal energy.

IMPORTANT CONCEPTS

Kinetic energy is an energy of motion:

$$K = \underbrace{\tfrac{1}{2}mv^2}_{\text{Translational}} + \underbrace{\tfrac{1}{2}I\omega^2}_{\text{Rotational}}$$

Potential energy is energy stored in a system of interacting objects.

- **Gravitational potential energy:** $U_g = mgy$
- **Elastic potential energy:** $U_s = \frac{1}{2}kx^2$

Mechanical energy is the sum of a system's kinetic and potential energies:

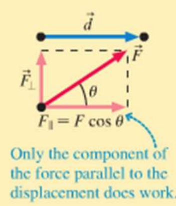
$$\text{Mechanical energy} = K + U = K + U_g + U_s$$

Thermal energy is the sum of the microscopic kinetic and potential energies of all the molecules in an object. The hotter an object, the more thermal energy it has. When kinetic (sliding) friction is present, the increase in the thermal energy is $\Delta E_{th} = f_k \Delta x$.

Work is the process by which energy is transferred to or from a system by the application of mechanical forces.

If a particle moves through a displacement $\vec{d}$ while acted upon by a constant force $\vec{F}$, the force does work

$$W = F_{\parallel}d = Fd\cos\theta$$



APPLICATIONS