Chapter 7

Work and Energy

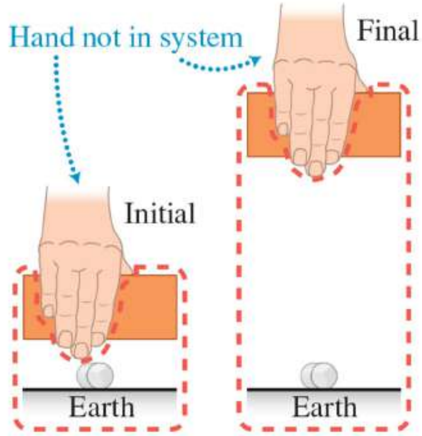
7.1 Work and energy

OALG 7.1.1 Observe and find a pattern

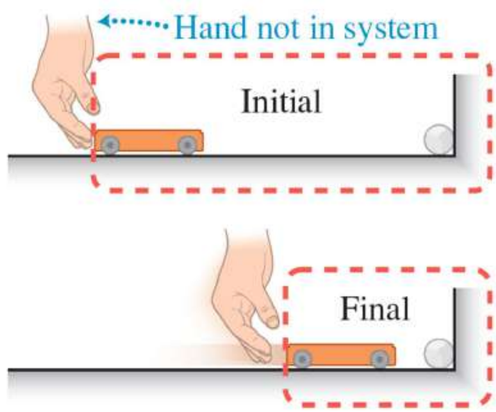
Below you see the description of several experiments. You can either repeat the experiments yourself if you have a brick and chalk at home, watch the videos at https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-experiment-video-13 or read their descriptions here.

All three experiments involve a well-defined system and a process in which the system changes from an initial state to a final state. At the end of this process, we find that the system has the potential to do something it couldn't do before—to crush a piece of chalk into many pieces. In each chase, the chalk-crushing ability (CCA) increases due to the intervention of an external agent (you). For each situation, draw arrows indicating the direction of the external force that you (outside the system) exert on a system object and the displacement of the object while you exert the force in order to increase the CCA of the system. Fill in the table that follows to help you complete this activity.

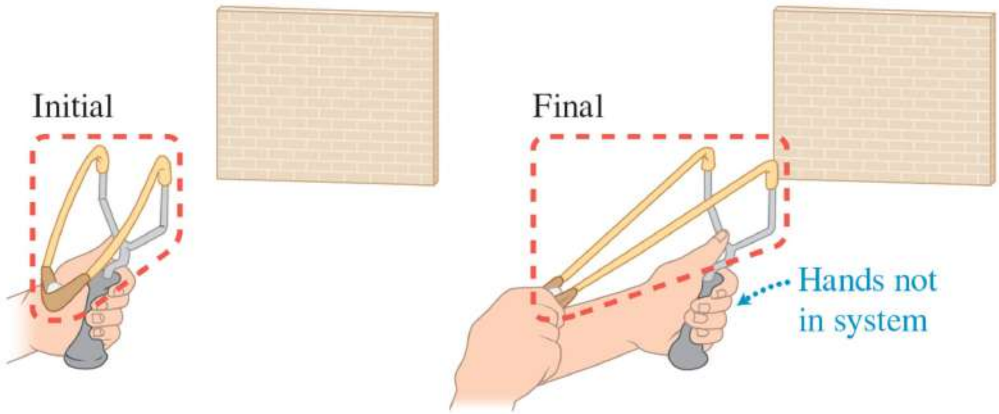
a. The system includes a brick with a flat bottom, Earth, and a piece of chalk. You (outside the system) pull up on brick so that slowly rises 0.5 m above the piece of chalk. After this lifting process, you release the brick. It falls and breaks the chalk.



b. The system includes a low friction cart that can roll on a floor and a piece of chalk that is placed by the vertical wall. You (outside the system) continuously push the cart over a set distance so that it rolls faster and faster toward the chalk on the wall and breaks the chalk when it hits it.



c. The system includes a slingshot that holds a piece of chalk. Your instructor (outside the system) slowly pulls back on the sling. When she/he releases the sling, the chalk shoots out at high speed and hits the wall, causing the chalk to break.


Initial
Final
Hands not
in system

Experiment	**a.**	**b.**	**c.**
Draw arrows indicating the direction of the force you exerted on the system $\vec{F}_{\text{Y on S}}$ and the displacement $\vec{d}$ of the object in the system while you were exerting the force.			

d. Look for a pattern in what was done to the system to increase its chalk-crushing ability (CCA). Then, devise a new physical quantity to describe this pattern. Be explicit.

OALG 7.1.2 Observe and find a pattern

In Activity 7.1.1, you found that the external force you exerted on an object in a system *increased* the ability of the system to smash a piece of chalk. The force you exerted on the object in the system was always in the direction of the displacement of that object. Suppose that a friend outside the system decides to save the chalk in the first two experiments by exerting with her hand an opposing force on the brick or on the cart after they are released. In each case your friend pushes on the moving object opposite to the direction of its velocity. Describe for parts **a.** and **b.** of Activity 7.1.1 the direction of the force your friend exerts on the moving object relative to the displacement of the object as she stops it—in other words, what does she do to *reduce* the chalk-crushing ability of the system? Watch 2 first experiments in the video in Observational Experiment Table 7.2 on page 179 in the textbook.

a. The system includes a 1-kg brick with a flat bottom and a string attached to the top, Earth, and a piece of chalk. You (outside the system) pull up on the string so that the 1-kg brick slowly rises 0.5 m above the piece of chalk. After this lifting process, you release the block, and it starts falling. Your friend then starts pushing upward on the falling brick, slows it down, and the brick does not break the chalk.

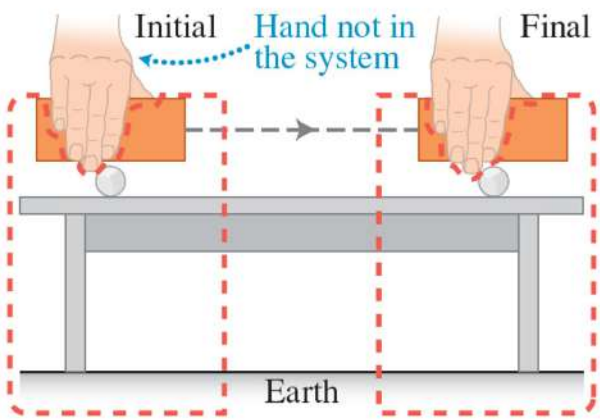
b. The system includes a 1-kg dynamics cart that can roll on a low-friction horizontal dynamics track and a piece of chalk that is taped to the fixed vertical end of the track. You (outside the system) push the cart so that it rolls faster and faster. Before the cart reaches the chalk, your friend pushes on it opposite its displacement. This causes the cart to slow down and stop so that it does not break the chalk.

c. How could you modify the definition of the quantity you devised in Activity 7.1.1 to account for the system's loss of chalk-crushing ability thanks to your friend's intervention?

OALG 7.1.3 Observe and find a pattern

Consider a system that includes Earth and a 1-kg brick. This is Experiment 3 in the Observational Experiment table 7.2 video in the textbook.

a. You (outside the system) hold the brick so that it stays about 2 cm above a table. A piece of chalk is placed on the table under the brick. If you release the brick and it falls on the chalk, the chalk does not break (it's too close to the chalk).



b. Next you slowly walk about 1 m beside the table, continually keeping the brick 2 cm above the surface. After you have walked the 1 m, the brick hangs over a second identical piece of chalk. Draw the force exerted by you on the brick and the displacement of the brick as you walked the 1 m.

c. Did the *vertical* force that you exerted on the brick while moving it *horizontally* above the tabletop cause the system to have a better chance of crushing the second piece of chalk than the first piece? Revise the quantity you devised in the last two activities to account for this result. Your revision will involve the angle between the external force exerted on the object in the system and the object's displacement. We call this physical quantity *work* and denote it with a symbol *W*.

d. Compare your definition of work to the equation 7.1 on page 180 in the textbook. Read and interrogate subsection Section 7.1 in the textbook to see the big picture related to the physical quantity of work.

OALG 7.1.4 Construct a mathematical model

a. Construct a mathematical equation that relates changes in chalk-crushing ability, ΔCCA, to the new physical quantity you devised in Activities 7.1.1–7.1.3.

b. A group of students in your class came up with the following equation: $W = \Delta CCA$. Does it seem reasonable? Explain.

OALG 7.1.5 Observe and explain

Watch a video of a person pulling a 5-kg bob across a wooden surface slowly, at constant speed https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-7-1-5 across about a 2-m distance. The video was taken with a thermal camera. The bob has sandpaper glued to its bottom to increase friction. The experiment was recorded with a regular camera (the first part of the video) and with a thermal camera (the second part of the video). The thermal images show the surface temperature of the objects. Temperatures on thermal images in the video are represented with colors in the interval from 27.9 °C (dark blue) to 30°C (white).

a. Watch the video and describe how the surfaces of the board and the bob changes as the result.
b. Analyze the process using the system bob-board. The person pulling is outside the system.

c. Describe how the system (bob and board) is different after the person did the work than before the bob started moving. Notice that the chalk-crushing ability of the bob did not change ($\Delta CCA = 0$), and yet the person did work on it. Does this fit with the equation you just invented in Activity 7.1.4? How you could modify the equation you came up with in Activity 7.1.4 to account for this anomalous result? Check your answer with the explanation on page 178 in the textbook (Experiment 4).

OALG 7.1.6 Describe

You do work on a system to change its ability to do something—for example, to crush chalk or to make the touching surfaces of objects in a system warm. In Activities 7.1.1 through 7.1.5, the work done on the system by the external force caused different types of changes in the system. Think of how you can describe each type of change in the system as a result of the work done on it, and come up with a name for it.

a. The external force caused the block to move higher above Earth's surface.

b. The external force caused the cart to move faster and faster.

c. The external force caused the slingshot to stretch.

d. The external force caused the surfaces of the touching objects to warm.

e. Read and interrogate text on page 178 in the textbook that provides official names for these types of changes. Note that a single object does not have gravitational potential energy, only the system of object-Earth does.

OALG 7.1.7 Apply

Describe a real-life situation in which an external force does the following:

a. positive work on a system;

b. positive work on a system, but with a value that is less than in part a.;

c. negative work on a system;

d. zero work even though an object in the system moves.

Note that your situations should be different from the scenarios we've already encountered in Activities 7.1.1–7.1.5.

OALG 7.1.8 Apply

Watch the videos and describe work- energy process that occurs when we play with each toy https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-7-1-8. Specify the system and initial and final states.

OALG 7.1.9 Read and interrogate

Read and interrogate Section 7.1 in the textbook and answer Review Question 7.1.

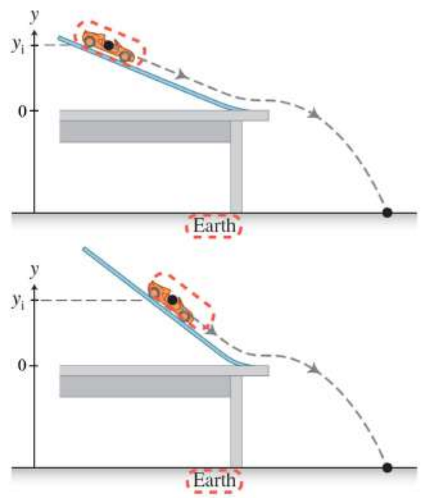
OALG 7.1.10 Practice

Answer Questions 1-3 and 5-7 on page 209 and solve Problems 1, 2, 7 and 9 on pages 210-211 in the textbook.

7.2 Energy is a conserved quantity

OALG 7.2.1 Observe and explain

Watch the video of the cart going down the ramp and landing in a can https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-7-2-1.
a. Describe what happens in the video when the steepness of the track is changed. What physical quantities do not change? How can you explain the results of the experiment?



b. Choose the cart, the track and Earth as a system. The initial state is when the cart is just released and the final state is when it is leaving the track (right before it flies off). What can you say about the total energy in the initial and final state in different experiments? Is it the same or different? How do you know? Use the information from the video to back up your assessment of energies.

c. What can you say about the dependence of gravitational potential energy on the length of the track that the cart travels? On the height from which it was released? Back up your answer with the evidence from the video.

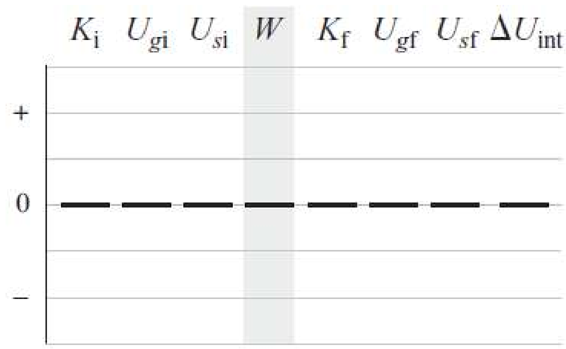
d. Read and interrogate subsection "Work-energy bar charts" on pages 182-184 in the textbook. How can you represent the processes in the experiments in the video using work-energy bar charts? How will your analysis change if Earth is not a part of the system?

OALG 7.2.2 Represent and reason

Analyze the following experiment: A rope pulls a skier, initially at rest, up a hill. *Initial state:* A skier is at rest at the bottom of the hill. *Final state:* The skier is moving at moderate speed at the top of the hill. *System:* Includes the skier, rope, and Earth but excludes the motor that pulls the rope up the hill. Ignore friction.

a. Draw a sketch showing initial and final states.

b. Construct a qualitative work–energy bar chart using the grid below, or on your whiteboard.



OALG 7.2.3 Represent and reason

Experiment 1: A ball, initially at rest, is dropped from a certain height above the ground.

Initial state: Ball at rest *y* meters above the ground.

Final state: Ball is moving at speed *v,* just before it hits the ground.

System: Just the ball (Earth does work on the ball here).

Experiment 2: A ball, initially at rest, is dropped from a certain height above the ground.

Initial state: Ball at rest *y* meters above the ground.

Final state: Ball is moving at speed *v,* just before it hits the ground.

System: The ball *and* the Earth are the system.

For each experiment to:

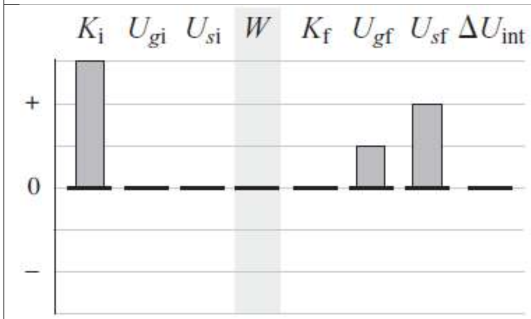
a. Draw a sketch showing initial and final states.

b. Construct a qualitative work-energy bar chart.

OALG 7.2.4 Bar-chart Jeopardy

a. Describe in words, and then

b. sketch a process (the system, its initial and final states, and any work done on the system) that is consistent with the qualitative work–energy bar chart shown below. There are many possible choices.

Bar chart for a process	**Describe in words one possible consistent process.**	**Sketch the process just described.**
		

OALG 7.2.5 Represent and reason

Devise a graphical method to determine the work done by an external force on a system object. *Note:* P = person and O = object. For each of the processes described below.

a. Sketch the process.

b. Draw $F_{\text{P on O}\,y}$ versus y (for vertical motion) or $F_{\text{P on O}\,x}$ versus x (for horizontal motion).

c. Describe how to use the graph to find the work done by the specified force.

Processes:

1. Shumaila lifts a backpack from the floor to the desk, exerting a constant upward force. The backpack and Earth (not Shumaila) are the system.

2. Kruti catches a medicine ball in the gym. The ball and Earth are the system but not Kruti. Her hands move back toward her body while stopping the ball. Assume that she exerts a constant force on the ball.

3. Ben stretches a horizontal rubber cord by 6.0 cm. To stretch the cord by 1.0 cm Ben exerts a 10.0-N force, and then to stretch the cord by 2.0 cm he exerts a 20.0-N force, to stretch the cord by 3.0 cm he exerts a 30.0 N force and so forth. The spring and Earth (not Ben) are the system.

OALG 7.2.6 Read and interrogate

Read and interrogate sub-section "The generalized work-energy principle" in Section 7.2 in the textbook and answer Review Question 7.2.

OALG 7.2.7 Practice

Answer Questions 3,4, and 11 on page 209 and solve problems 39, 40 and 45 on page 212 in the textbook.

7.3 Quantifying gravitational potential and kinetic energies

OALG 7.3.1 Find the relationships

To develop mathematical expressions for gravitational potential energy and kinetic energy, we analyze the following situation: a cable lifts a block from vertical position y_i to vertical position y_f. When at position y_i, the block is moving up at speed v_{yi}, and when at position y_f it is moving up at greater speed v_{yf}.

a. Sketch the situation. Include a labeled vertical axis.

b. Write an expression for the work the cable does on the block during its displacement $y_f - y_i$.

c. Draw a force diagram for the block. Use it to find an expression for the force that the cable exerts on the block in terms of its mass *m*, acceleration *a*, and the gravitational constant *g*. Substitute this expression into the expression in part **b.**

d. Use a kinematics equation to convert the acceleration *a* in the equation from part **b.** into an expression involving the block's speeds v_i and v_f and its displacement $y_f - y_i$.

e. Substitute the expression from part **d.** into the expression for the force that the cable exerts on the block found in part **c**.

f. Substitute the new expression in part **e.** for the force that the cable exerts on the block into the expression for work in part **b**.

g. Examine the expressions that you derived in parts **e.** and **f**. Do you see that the work that the cable did on the block equals the sum of the changes of two quantities: $mgy_f - mgy_i$ and $\frac{1}{2}mv_{yf}^2 - \frac{1}{2}mv_{yi}^2$? Discuss how these expressions can be used to write an expression for the gravitational potential energy of the block–Earth system and an expression for the kinetic energy of the block.

h. Read and interrogate Section 7.3 in the textbook, especially paying attention to Table 7.5 on page 188. Explain where the values of the quantities in every cell of the table came from. How is it possible that the heavier cart changes momentum more than the lighter cart while the changes in their kinetic energies are the same?

OALG 7.3.2 Test your ideas

In the previous activity you learned mathematical models for the gravitational potential energy and kinetic energy. Imagine the following experiment. You have two spherical objects – a marble (mass 8 g) and a steel bearing (mass 24 g). The have the same diameter – 18 mm. You also have a florist foam block made of material that deforms easily and keeps the shape after being deformed.

a. Use these models to predict from which height you need to drop the steel ball so that it makes the same indentation in the florist foam as the marble that was dropped from the height of 150 cm. Assume that the size of indentation relates to the conversion of kinetic energy into internal. Indicate any assumptions that you made.

b. Watch the video of the experiment https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-7-3-2 and compare your prediction to the outcome. Discuss the reasons for the mismatch if it occurred.

OALG 7.3.3 Practice

Solve Problems11-14, 18 and 21 on page 211 in the textbook.

7.4 Quantifying elastic potential energy

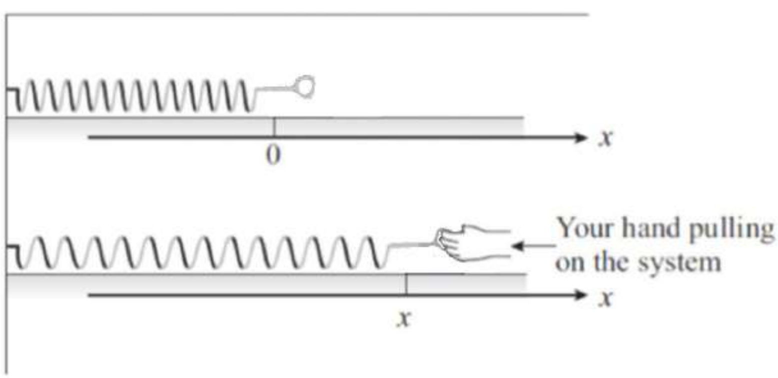
OALG 7.4.1 Read and interrogate

Read and interrogate sub-section Hooke's law in Section 7.4 "Quantifying elastic potential energy". What does the minus sign in the equation mean?

OALG 7.4.2 Find the relationship

Determine an expression for the elastic potential energy of a stretched spring. The spring is the system, and you stretch it from its equilibrium position ($x = 0$) to some final position x. You are outside the system. The spring is very easy to stretch at first but gets more and more difficult as you stretch it farther. (Remember that $F_{\text{Y on S}\,x} = kx$ i.e., the force that "you" exert on the "spring.")

a. Examine the sketch of the situation below, showing the system and the external object exerting a force on it. Note the origin of the *x*-axis at the end of the unstretched spring that you start pulling.



b. Draw a graph ($F_{\text{Y on S}\,x}$ versus x) and find the work that you did while stretching the spring from 0 to x as the area under the curve.

c. Examine the expression for work that you derived in part **b.** Do you see that the work that you did on the spring equals $\frac{1}{2}kx^2$? How does this expression relate to the elastic potential energy of the spring that you have stretched?

OALG 7.4.3 Read and interrogate

Read and interrogate subsection Elastic potential energy in Section 7.4 in the textbook and answer Review Question 7.4.

OALG 7.4.4 Practice

Answer Questions 10 and 13 on pages 209- 210 and solve Problem 24 on page 211.

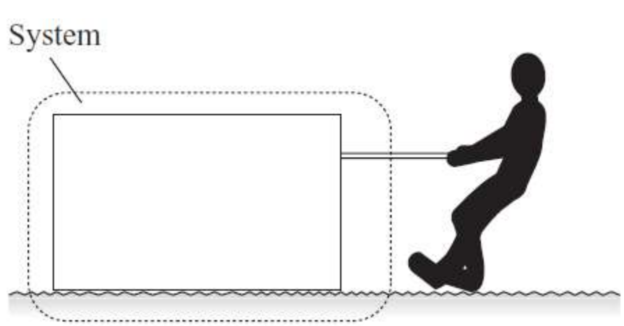
7.5 Friction and energy conversion

OALG 7.5.1 Read and interrogate

Read and interrogate Section 7.5 in the textbook and answer Review Question 7.5.

OALG 7.5.2 Represent and reason

Determine an expression for the change in internal energy due to friction in a system that consists of a crate and a rough horizontal surface on which it slides. You, outside the system, pull on a rope attached to the crate so that it moves slowly at constant velocity (see figure below). At the end of the process, the bottom of the crate and the surface on which it was moving have become warmer.

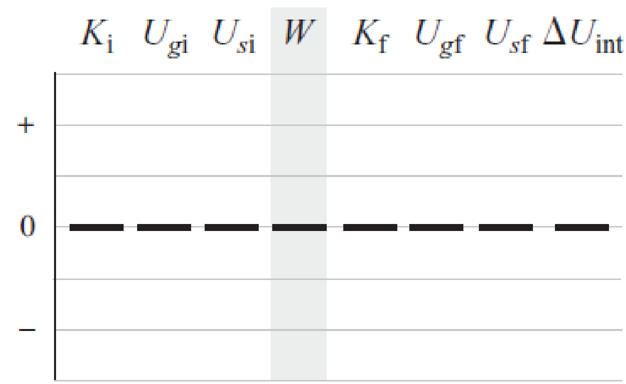


a. Write an expression for the work done on the system by the external force of the rope on the crate as the rope pulls the crate a distance *s* across the surface exerting a force $\vec{F}_{\text{R on C}}$.

b. Choose the crate alone as an object of interest and draw a force diagram for the crate. Apply Newton's second law for the horizontal *x*-axis. How are $\vec{F}_{\text{R on C}}$ (the force the rope exerts on the crate) and $\vec{f}_{\text{k S on C}}$ (the kinetic friction force that the surface exerts on the crate) related?

c. Now, combine parts **a.** and **b.** to write an expression for the work done by the force $\vec{F}_{\text{R on C}}$ on the system that consists of a crate and a rough horizontal surface on which it slides. Is it positive or negative?

d. Represent the process that you analyzed in part **c.** with a bar chart.



e. Examine the bar chart. Write an expression for the change in internal energy of the system and decide whether it increases or decreases.

OALG 7.5.3 Apply

Watch the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-7-5-3 and use it to answer questions. The coins in the experiment are equal.

a. Describe your observations.

b. Explain what you observed in words and with the bar charts. Choose the system to be a coin and the table on which it slides. The initial state is when the coin leaves the ruler and the final state is when it stops. The bar charts for the two objects (coins) should represent the difference in their motion.

OALG 7.5.4 Observe and explain

Watch the video taken with the thermal camera
https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-7-5-4.
a. Describe your observations.
b. Explain what you observed in words and with the bar charts. Choose the system to be the ball and the floor. The initial state is when the ball is moving fast just before it hits the floor and the final state is when it stops.

OALG 7.5.5 Practice

Solve problems 25, 28 and 29 on page 211 in the textbook.

7.6 Skills for analyzing processes using the work-energy principle

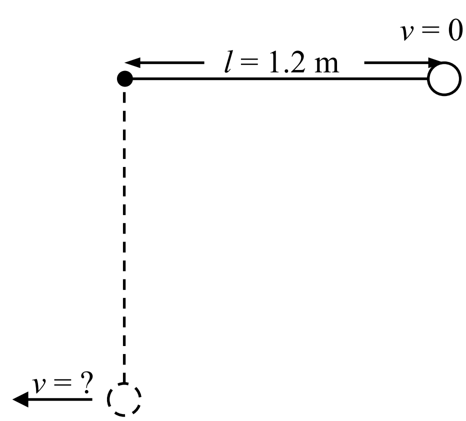
OALG 7.6.1 Reason

a. Summarize the results of the activities in Sections 7.3-7.5 to construct a generalized work–energy relationship—a relationship between the initial energy of a system, the external work done on the system, and the final energy of the system.

b. After you wrote the relationship, read and interrogate the subsection "The generalized work-energy principle" on page 184 in the textbook.

OALG 7.6.2 Reason

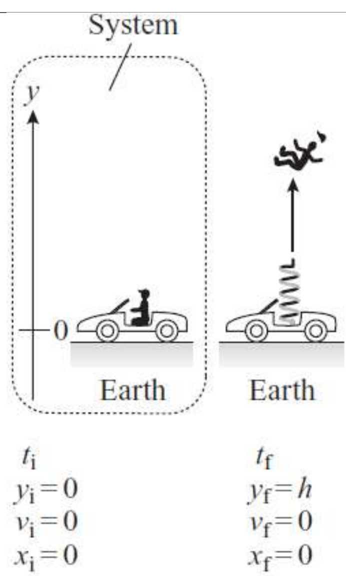
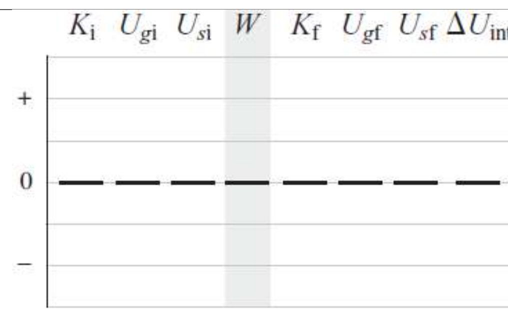
A pendulum consisting of a light string and an object (mass 2 kg) is released from a horizontal position and swings down (see the figure at right). Find the speed of the object when the pendulum reaches the bottom of its swing (as shown by the dashed lines in the figure) using your knowledge of energy.

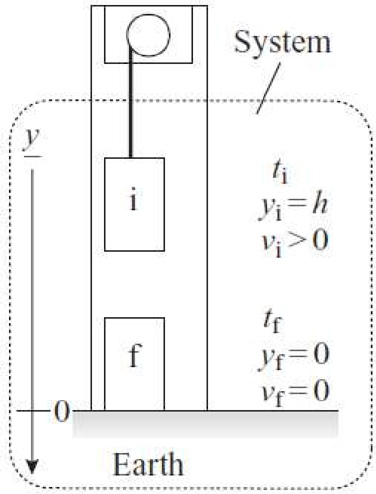
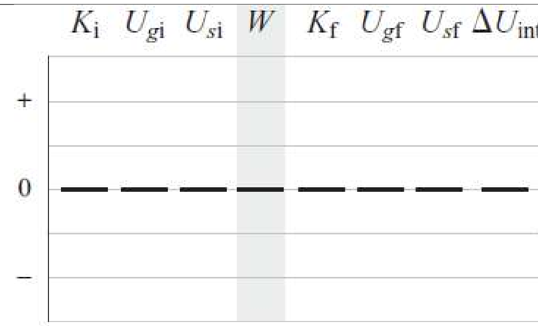


Could you figure this out using kinematics? Why, or why not?

OALG 7.6.3 Represent and reason

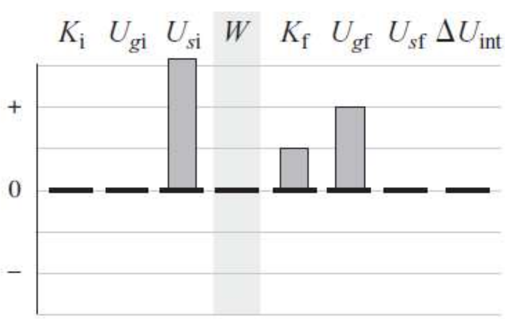
Word descriptions and pictorial representations of two work–energy processes are provided in the table that follows. Complete the last column of the table. Do not solve for anything.

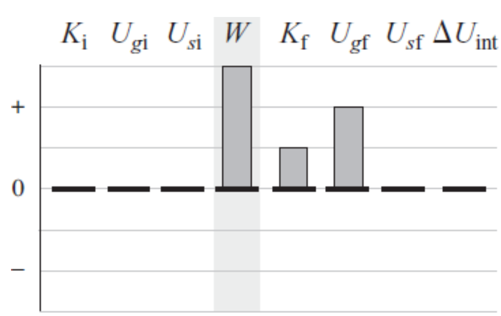
Word description	**Picture description**	**(i) Construct a bar chart for the process and apply in symbols the generalized work–energy principle.**
A stunt car has an ejector seat that rests on a vertical spring compressed a distance x_i .When the spring is released, the seat with its passenger is launched out of the car and reaches a maximum height h_f above its starting position.		
Word description	**Picture description**	**Construct a bar chart for the process and apply in symbols the generalized work–energy principle.**

An elevator, while moving down at speed v_i, approaches the ground floor and slows to a stop in a distance h.		

OALG 7.6.4 Bar-chart Jeopardy

Each of the two bar charts below describes a real process. Answer the following questions to describe the possible processes. Do not solve for anything.





a. Draw an initial–final sketch of a process that might be described by the bar chart. Identify the system.

b. Describe the process in words.

c. Use the bar chart to apply in symbols the generalized work–energy equation to the process.

OALG 7.6.5 Regular problem

a. A 1000-kg elevator is moving downward. While moving down at 4.0 m/s, its speed decreases steadily until it stops in 6.0 m. Determine the magnitude of the tension force that the cable exerts on the elevator while it is stopping. Solve the problem, following the problem-solving strategy.

Sketch and translate • Sketch the initial and final states of the process, labeling known and unknown information. • Include the object of reference and the coordinate system. • Choose the system of interest. Sometimes you might need to go back and redefine your system after you draw a bar chart if you find that the chosen system is not convenient.	
Simplify and diagram • What simplifications can you make to the objects, interactions, and processes? • Decide which energy types are changing. • Are external objects doing work? • Use the initial-final sketch to help draw a work-energy bar chart. Include work bars (if needed) and initial and final energy bars for the types of energy that are changing. Specify the zero level of gravitational potential energy.	
Represent mathematically • Convert the bar chart into a mathematical description of the process. Each bar in the chart will appear as a single term in the equation.	

Solve and evaluate • Solve for the unknown and evaluate the result. • Does it have the correct units? Is its magnitude reasonable? Do the limiting cases make sense?	

b. After you finish your solution, compare your work to the work in Example 7.6 on page 195 in the textbook. After that practice applying problem solving strategy in Conceptual Exercise 7.2 on page 185 and Example 7.8 on page 197.

OLG 7.6.6 Equation Jeopardy

Below you see the application of the generalized work–energy equation to two different processes (in fact, there are many possible processes described by each equation). For each mathematical description

a. Construct a sketch,

b. Identify the system,

c. Write a word description, and

d. Draw a bar chart that is consistent with the equation.

Process 1:

$$\tfrac{1}{2}kx_i^2 = \tfrac{1}{2}mv^2 + mgy$$

Process 2:

$$mgd\sin 20^\circ = \tfrac{1}{2}kx^2$$

OALG 7.6.7 Evaluate the solution

The problem: A 40,000-N/m spring cart launcher, initially compressed 0.50 m, is released and launches you and your cart (with total mass 100 kg) up a 30° incline. What distance along the incline do you travel before stopping?

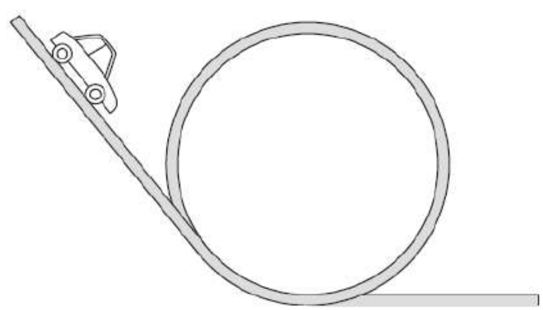
Proposed solution: $\frac{1}{2}(40{,}000\text{ N/m})(0.50\text{ m}) = (100\text{ kg})(9.8\text{ N/kg})y \quad \Rightarrow \quad y = 10.2\text{ m}$

a. Identify any missing elements or errors in the solution.

b. Provide a corrected solution if you find any missing elements or errors.

OALG 7.6.8 Pose a problem

Pose a problem that can be solved with the generalized work–energy principle using the situation depicted in the illustration below. Make a list of necessary givens and assumptions to solve the problem. After you devise your problem, solve Problem 75 on page 215 in the textbook.



OALG 7.6.9 Real-world application: Velcro ball

Watch the video of a Velcro ball thrown upward and being stuck to the ceiling covered with Velcro [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-7-6-9]. Represent the process for the initial state when the ball just left the hand of the experimenter and the final when the ball is stuck to the ceiling using the following systems:

a. The ball and the ceiling;

b. The ball, Earth, and the ceiling.

OALG 7.6.10 Practice

Answer Question 22 on Page 210 and solve Problems 36, 41-43, 46, 63, 72, 74, 76, and 77 on pages 212-215 in the textbook.

7.7 Collisions

OALG 7.7.1 Observe and find a pattern

Study the slow-motion videos of several collisions of two carts [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-7-7-1]. The collisions where both the kinetic energy and the momentum are constant are called *elastic*; the collisions in which only momentum is constant are called *inelastic*. Classify all the videoed collisions into those two categories. The masses of the carts are given in the video.

Experiment	**Analysis**	**Decision (is the collision elastic or inelastic?)**

OALG 7.7.2 Read and interrogate

Read and interrogate Section 7.7 in the textbook and answer Review Question 7.7.

OALG 7.7.3 Application experiment: Measuring the coefficient of kinetic friction

The goal is to use your knowledge of energy and momentum to determine the coefficient of kinetic friction between a tissue box and the table in the following video. [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-7-7-3].

The flour-filled balloon has a mass of 54.7g, the tissue-box has a mass of 161.1g.

Observing the experiments
Observe two experiments that can be used to determine the coefficient of kinetic friction. For each experiment:

Constructing the mathematical model

Start with the experiment with the flower balloon hitting the box and the box sliding to a stop. Think of how you can analyze the process conceptually (using energy and momentum bar charts) to find the coefficients of kinetic friction and then how you can convert these bar charts into mathematical representations. The following steps might help you:

a. Divide the process into three smaller processes that each involves one central physics idea. Represent each smaller process with a relevant bar chart (think of whether energy bar chart of momentum bar chart will be easier to analyze mathematically). Carefully choose your system for every sub-process.

b. Once you have the bar charts, convert them into mathematical representations (models). Check if what you wrote will help you determine the coefficient of kinetic friction.

c. Identify the physical quantities you will need to measure in order to determine the coefficient of kinetic friction.

d. Repeat the process for the second experiment (pulling the box with the scale). Here you might want to use the force diagram to construct the mathematical model.

e. What assumptions did you make in your mathematical models? Specifically, what is the effect making each of them will have on the result produced by your mathematical model (will it make the calculated value smaller, larger, or randomly different than the real-world value)? Explain your reasoning.

Collecting data

a. Measure the physical quantities you identified in parts **c** and **d** in the previous step.

c. Record the data. What is the uncertainty in each measurement?

d. Use the mathematical procedure you devised to determine the coefficient of kinetic friction in both experiments. Estimate the uncertainty in your results.

e. Decide if the results of the two experiments are consistent or not. What is your judgment about the model you used to represent the situation shown in the video?

If you need to improve the mathematical model

a. Think about assumptions you made in your mathematical models. Which of your assumptions is least likely to be valid? Describe how you will revise part of your mathematical procedure to deal with this. What additional measurements will you need to make?

b. Construct force diagrams, and energy and/or momentum bar charts for your revised mathematical method.

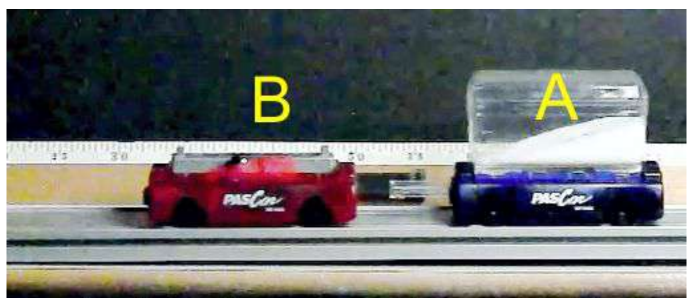
c. Come up with a new equation for the coefficient of kinetic friction that incorporates your revisions. Again, do not plug in numbers.

d. Make any additional measurements you need, and then use your new equation to determine a revised value of the coefficient of kinetic friction.

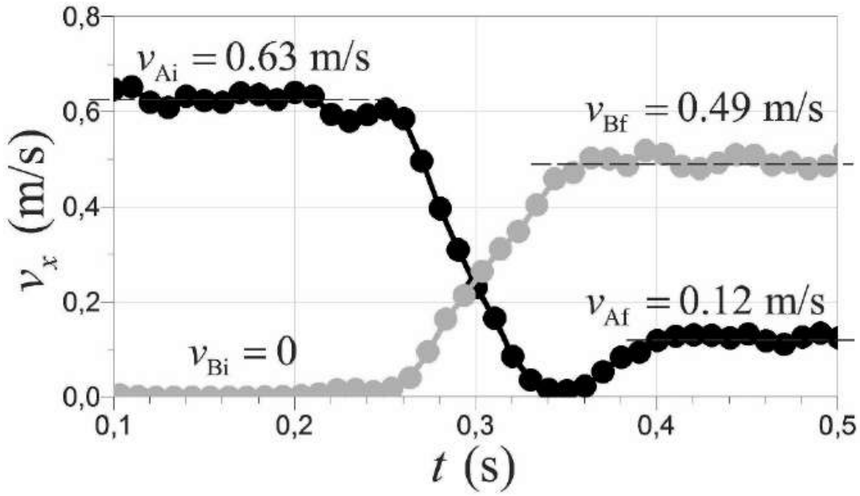
e. Now are the results of the two independent methods consistent? Now what is your judgment about the mathematical model?

f. Are any of the other assumptions in your revised mathematical model questionable? How could you revise your mathematical procedure further to deal with these?

OALG 7.7.4 Analyze



You have two low-friction carts on a track. You fix a metal rod on cart B and a plastic box on cart A. Cart A has a spring bumper that compresses and expands elastically. You put some sugar mixed with a few steel ball bearings in the box on cart A (see figure on the right). Using modeling clay, you adjust the total mases of the carts so they are both equal to 565 g. You push cart A so that it starts moving towards cart B (which is initially at rest). The carts collide. You take a video of the experiment and analyze it (watch the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-7-7-5]). The figure below shows the velocity-versus-time graph for both carts during the collision. Average velocities of the carts before and after the collision are also shown on the graph.



In the following activities take both carts as the system.

a. Take the situation at $t = 0.20$ s as the initial state, and the situation at $t = 0.45$ as the final state. Can you say that the total momentum of the system is constant in this process? If not, explain what might have caused the total momentum change. Can you say that the total mechanical energy of the system is constant in this process? If not, estimate the change of the total mechanical energy and explain into what other forms of energy it was converted.

b. At $t = 0.35$ s, cart A almost stopped moving but after that time it sped up and continued moving with constant speed. Explain the mechanism that made the cart speed up. (*Hint*: watch the video again and carefully observe what is going on during the collision.)

c. Represent the processes in the experiment using impulse-momentum and work-energy bar charts. Take both carts as the system. Draw bar charts with three states. Take the situation at time $t = 0.2$ s as the initial state, the situation at time $t = 0.35$ s as the intermediate state, and the situation at time $t = 0.45$ s as the final state. If several parts of the system are moving, use additional bar charts to account separately for each part.

d. Your friend notices that the magnitudes of the slopes of the velocity-versus-time curves for the carts during the collision are different. He argues: "Different slopes mean different accelerations during the collision. Because the masses of the carts are equal, this means that the magnitudes of the forces exerted by one cart on another are not equal during the collision. I think that, based on this experiment, we can reject Newton's third law." Do you agree or disagree with your friend? If you disagree, find the mistakes in your friend's reasoning and show that the outcome and the data obtained in this experiment are consistent with Newton's laws.

e. Make a list of the physical quantities that you can determine based on the graph and data given above, and determine their values.

OALG 7.7.5 Practice

Answer Question 14 on page 210 and solve Problems 48, 50, 52 and 53 on Page 213.

7.8 Power

OALG 7.8.1 Reason

Matt, a weightlifter, can bench press 100 kg (220 lbs). He can lift the 100 kg from a height of 0.8 m above the ground to a height of 1.3 m in 0.2 seconds. Matt wants to determine the rate at which work is done on the barbell and weights. What should he do to determine the rate at which he does work on the barbell and weights?

7.8.2 Develop a relation

Your friend Jade brings in two motors to class. She wants to install one of them in her lawnmower but wants to make sure that she picks the best motor. Your job is to determine a rating system for the motors to determine which one will cut her grass most efficiently.

You set the motors on top of a table and attach a string and 10.0 kg bob to each of them. You see that Motor 1 pulls the bob from the floor to the top of the table in 0.032 seconds. You see that Motor 2 pulls the bob from 5 cm above the floor to the top of the table in 0.020 seconds.

a. Estimate the height of the table. Devise a physical quantity that can describe the motor's ability to pull the bob up. What is its value for the first motor? The second motor? Are the numbers reasonable? How do you know?

b. Read and interrogate the definition of power in Section 7.8 in the textbook. How did your definition compare?

7.9 Improving our model of gravitational potential energy

7.9.1 Reason

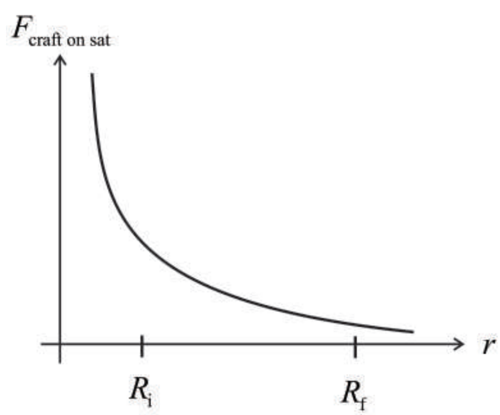
Imagine that a 'space elevator' has been built to transport supplies from the surface of Earth to a spaceship that is located infinitely far away from Earth (so far that the gravitational interaction of the ship and Earth can be neglected). The elevator moves at constant velocity, except for the very brief acceleration and deceleration at the beginning and end of the trip.

a. How much work must be done to transport the supplies from Earth's surface to the ship? To answer this question draw an $F_{\text{Elevator on Supplies}}(r)$ graph.

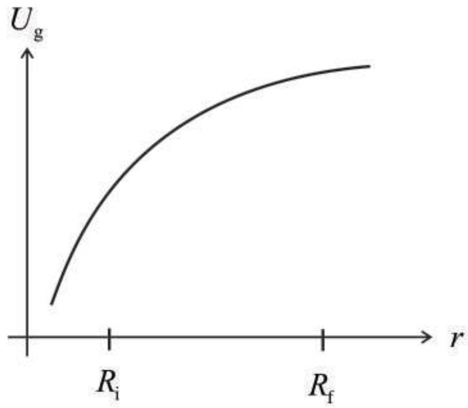
b. Draw a bar chart representing the process. What is the gravitational potential energy of the supplies-Earth system at the infinite distance from Earth? What sign should the gravitational potential energy of interaction have when the supplies are on Earth?

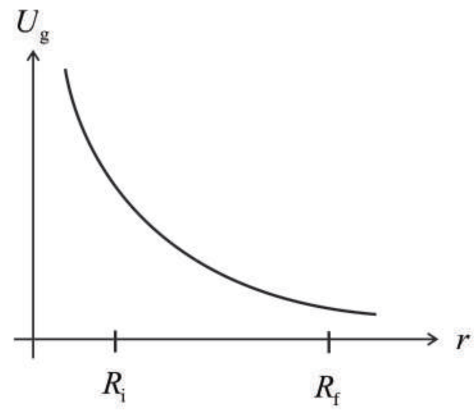
7.9.2 Represent and reason

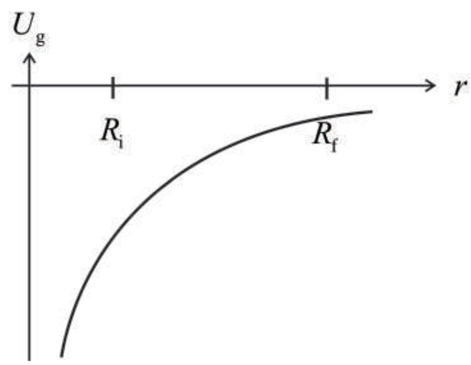
Imagine that you are trying to move a satellite very far away from Earth by using another spacecraft. The graph on the right shows how the force exerted by the spacecraft on the satellite depends on the separation between Earth and the satellite, as the satellite is pulled very slowly into space.



a. Which of the graphs below could represent the gravitational potential energy of the Earth-satellite system as a function of the separation between the two? If none of the graphs can represent U_g, explain why not.







b. Consider the interaction between the satellite and Earth. At what separation should the gravitational potential energy of the Earth-satellite system be equal to zero?

c. Which of these mathematical expressions could represent the gravitational potential energy of the Earth-satellite system? If none of them can, explain why not.

$$U_g = -\frac{GM_E m_s}{r} \qquad U_g = -\frac{Gm_s}{r} \qquad U_g = GM_E m_s r$$

7.9.3 Reason

The two expressions for gravitational potential energy look very different. The first one ($U_g = mgy$) was developed for processes with elevation changes on or near Earth's surface. Does the new expression $U_g = -\frac{GM_E m_S}{r}$ produce a similar result for such a change? Explain. Do not forget that $g = G\frac{M_E}{r^2}$.

7.9.4 Read an interrogate

Read and interrogate Section 7.9 in the textbook and answer Review Question 7.9.

OALG 7.9.5 Practice

Answer Questions 18-21 on page 210 and solve Problem 65 on page 214 in the textbook.