



The Big Idea

Energy is a measure of the amount of, or potential for, dynamical activity in something. The total amount of energy in the universe is always the same. This symmetry is called a conservation law. Physicists have identified five conservation laws that govern our universe.

A group of things (we'll use the word *system*) has a certain amount of energy. Energy can be added to a system; for instance, when chemical bonds in a burning log break, they release heat. Energy can be lost from a system; for instance, when a spacecraft "burns up" its energy of motion during re-entry, it loses energy and the surrounding atmosphere gains the lost energy. A *closed* system is one for which the energy is constant, or *conserved*. In this chapter, we will often consider closed systems, for which the total amount of energy stays the same, but transforms from one kind to another. We will consider transfers of energy between systems – known as *work* – in more detail in Chapter 8.

Key Definitions

- m = mass (in kilograms, kg)
- h = height above the ground (in meters, m)
- v = speed (in meters per second, m/s)
- g = acceleration due to gravity (9.8 m/s^2)
- E = energy (in Joules; $1 \text{ J} = 1 \text{ kg}\cdot\text{m}^2/\text{s}^2$)

Key Equations

- $K = \frac{1}{2} mv^2$ Kinetic energy
- $U_g = mgh$ Gravitational potential energy

Key Concepts

- The energy of motion is kinetic energy, K . Whenever an object is in motion it has kinetic energy. The faster it is going, the more energy it has.
- The energy due to gravity is called gravitational potential energy, U_g , which gets higher the farther off the ground you are.
- Molecules have chemical potential energy due to the bonds between the electrons; when these bonds are broken, energy is released which can be transferred into kinetic and/or potential energy. 1 food Calorie is equal to 4180 Joules of stored chemical potential energy.
- Energy can be transformed from one kind into the other; if the total energy at the end of the process appears to be less than at the beginning, the "lost" energy has been transferred to another system, often by heat or sound waves.

Key Applications

- In “roller coaster” problems, the gravitational potential energy at the top of one hill turns into kinetic energy at the next valley. It turns back into potential energy as you round the next hill, and so on. However, some of the energy is lost to the tracks and air as heat, which is why the second rise is often not as big as the first.
- In “pole-vaulter” problems, the athlete’s body breaks down the food molecules to change some of the bonding energy into energy that is used to power the body. This energy goes on to turn into kinetic energy as the athlete gains speed. The kinetic energy can be changed into potential energy as the athlete gains height.
- In “pendulum” problems, the potential energy at the highest point in a pendulum’s swing changes to kinetic energy when it reaches the bottom and then back into potential energy when it reaches the top again. At any in-between point there is a combination of kinetic energy and potential energy, but the total energy remains the same.

Energy Conservation Problem Set

1. A stationary bomb explodes into hundreds of pieces. Which of the following statements best describes the situation?
 - a. The kinetic energy of the bomb was converted into heat.
 - b. The chemical potential energy stored in the bomb was converted into heat and gravitational potential energy.
 - c. The chemical potential energy stored in the bomb was converted into heat and kinetic energy.
 - d. The chemical potential energy stored in the bomb was converted into heat, sound, kinetic energy, and gravitational potential energy.
 - e. The kinetic and chemical potential energy stored in the bomb was converted into heat, sound, kinetic energy, and gravitational potential energy.
2. You hike up to the top of Granite Peak in the Trinity Alps to think about physics.
 - a. Do you have more potential or kinetic energy at the top of the mountain than you did at the bottom? Explain.
 - b. Do you have more, less, or the same amount of energy at the top of the mountain than when you started? (Let’s assume you did not eat anything on the way up.) Explain.
 - c. How has the total energy of the Solar System changed due to your hike up the mountain? Explain.
 - d. If you push a rock off the top, will it end up with more, less, or the same amount of energy at the bottom? Explain.
 - e. For each of the following types of energy, describe whether you *gained* it, you *lost* it, or it stayed the same during your hike:
 - i. Gravitational potential energy
 - ii. Energy stored in the atomic nuclei in your body
 - iii. Heat energy
 - iv. Chemical potential energy stored in the fat cells in your body
 - v. Sound energy from your footsteps
 - vi. Energy given to you by a wind blowing at your back

3. Just before your mountain bike ride, you eat a 240 Calorie exercise bar. (You can find the conversion between food Calories and Joules in the chapter.) The carbon bonds in the food are broken down in your stomach, releasing energy. About half of this energy is lost due to inefficiencies in your digestive system.

a. Given the losses in your digestive system how much of the energy, in Joules, can you use from the exercise bar?

After eating, you climb a 500 m hill on your bike. The combined mass of you and your bike is 75 kg.

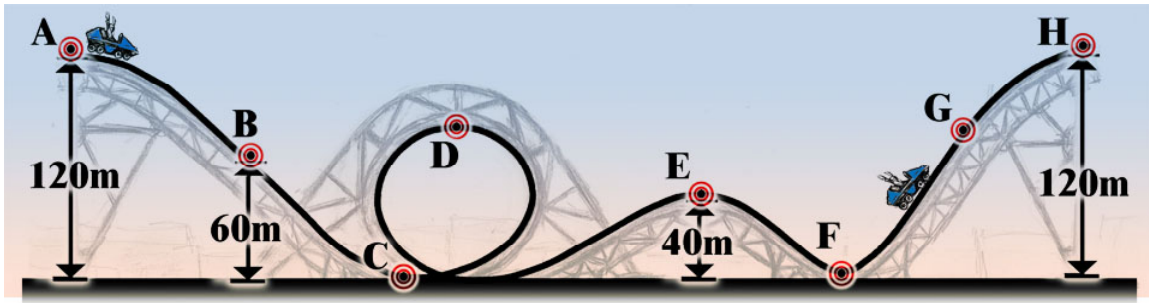
- b. How much gravitational potential energy has been gained by you and your bike?
c. Where did this energy come from?
d. If you ride quickly down the mountain without braking but losing half the energy to air resistance, how fast are you going when you get to the bottom?

4. You find yourself on your bike at the top of Twin Peaks in San Francisco. You are facing a 600 m descent. The combined mass of you and your bicycle is 85 kg.

- a. How much gravitational potential energy do you have before your descent?
b. You descend. If all that potential energy is converted to kinetic energy, what will your speed be at the bottom?
c. Name two other places to which your potential energy of gravity was transferred besides kinetic energy. How will this manifest itself in your speed at the bottom of the hill? (No numerical answer is needed here.)



5. Before a run, you eat an apple with 1,000,000 Joules of binding energy.
- a. 550,000 Joules of binding energy are wasted during digestion. How much remains?
b. Some 95% of the remaining energy is used for the basic processes in your body (which is why you can warm a bed at night!). How much is available for running?
c. Let's say that, when you run, you lose 25% of your energy overcoming friction and air resistance. How much is available for conversion to kinetic energy?
d. Let's say your mass is 75 kg. What could be your top speed under these idealized circumstances?
e. But only 10% of the available energy goes to KE, another 50% goes into heat exhaust from your body. Now you come upon a hill if the remaining energy is converted to gravitational potential energy. How high do you climb before running out of energy completely?
6. A car goes from rest to a speed of v in a time t . Sketch a schematic graph of kinetic energy vs. time. You do not need to label the axes with numbers.
7. A 1200 kg car traveling with a speed of 29 m/s drives horizontally off of a 90 m cliff.
- a. Sketch the situation.
b. Calculate the potential energy, the kinetic energy, and the total energy of the car as it leaves the cliff.
c. Make a graph displaying the kinetic, gravitational potential, and total energy of the car at each 10 m increment of height as it drops

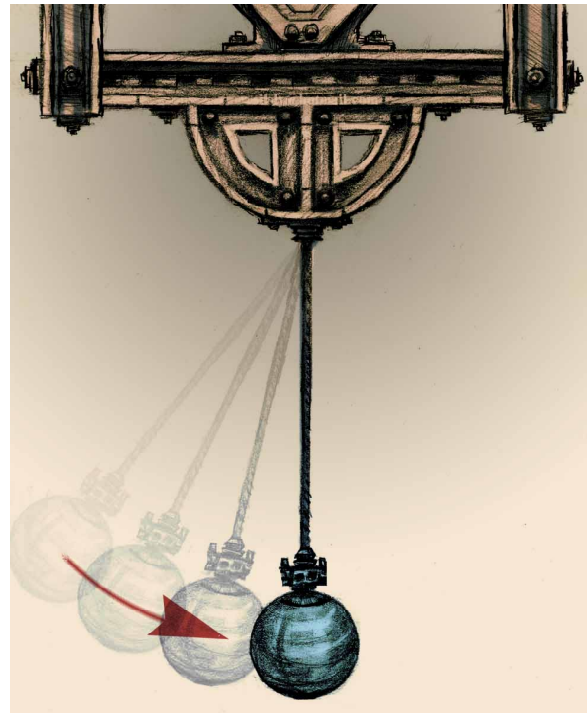


8. A roller coaster begins at rest 120 m above the ground at point A, as shown above. Assume no energy is lost from the coaster to frictional heating, air resistance, sound, or any other process. The radius of the loop is 40 m.

- Find the speed of the roller coaster at points B, C, D, E, F, and H.
- At point G the speed of the roller coaster is 22 m/s. How high off the ground is point G?

9. A pendulum has a string with length 1.2 m. You hold it at an angle of 22 degrees to the vertical and release it. The pendulum bob has a mass of 2.0 kg.

- What is the potential energy of the bob before it is released? (*Hint: use geometry to determine the height when released.*)
- What is its speed when it passes through the midpoint of its swing?
- Now the pendulum is transported to Mars, where the acceleration of gravity g is 2.3 m/s^2 . Answer parts (a) and (b) again, but this time using the acceleration on Mars.



10. On an unknown airless planet an astronaut drops a 4.0 kg ball from a 60 m ledge. The mass hits the bottom with a speed of 12 m/s.

- What is the acceleration of gravity g on this planet?
- The planet has a twin moon with exactly the same acceleration of gravity. The difference is that this moon has an atmosphere. In this case, when dropped from a ledge with the same height, the 4.0 kg ball hits bottom at the speed of 9 m/s. How much energy is lost to air resistance during the fall?

11. A 1500 kg car starts at rest and speeds up to 3.0 m/s.

- a. What is the gain in kinetic energy?
- b. We define efficiency as the ratio of output energy (in this case kinetic energy) to input energy. If this car's efficiency is 0.30, how much input energy was provided by the gasoline?
- c. If 0.15 gallons were used up in the process, what is the energy content of the gasoline in Joules per gallon?

12. A pile driver's motor expends 310,000 Joules of energy to lift a 5400 kg mass. The motor is rated at an efficiency of 0.13 (see 11b). How high is the mass lifted?

