Day 3: Moving Through the World / Form & Function

9:00 Feedback and Followup
9:30 Engage / Explore / Explain: Energy
• What is Energy?
• Energy & Power
• How Much Energy Does It Take?
10:45 Break
11:00 Explain
• Energy conversions and energy conservation
• Energy in the body
11:45 Extend / Evaluate
• Why do animals move as they do?
12:00 Lunch

1:00 Engage / Explore: Making Things Move, Making Things Rotate
• Torque Challenges
1:15 Explain / Extend: Force, Motion, Torque, Rotation
• Torque vs. force
• Simple machines & simple tools
1:45 Break
2:00 Extend / Evaluate: How Form Follows Function
• Muscles & Bones
• Who is a digger / who is a jumper?
• What joints in your body are most subject to problems, and why?
2:45 Closing
Energy comes in many different forms.

Mechanical energy:

- \( K \)
- \( U_g \)
- \( U_s \)

Thermal energy:

- \( E_{th} \)

Other forms include:

- \( E_{chem} \)
- \( E_{nuclear} \)
Energy transfers: work

The transfer: 

- The environment: 
  - Energy is transferred to the system.
- The system:
  - As the athlete pushes on the shot to get it moving, he is doing work on the system.
  - Energy is transferred to the environment.
- The environment:
  - When the runner slides into the base, his kinetic energy is transformed into thermal energy.

Energy transformations are changes of energy that occur between forms of energy within the system. In this chapter, we'll consider energy transfers by processes:

- Energy transfers due to work
- Energy transfers due to heat

The Basic Energy Model

The Basic Energy Model is embedded in the eText. A video to support a section's topic

Energy and Work

Work:

- Energy transfers that result from mechanical forces—pushes and pulls—applied to the system. Once the energy has been transferred to the system, it can appear in many forms. Exactly what form it takes depends on the details of the system and how the forces are applied.

Energy Transfers and Work

We've just seen that energy is transferred to or from a system by pushing or pulling on it, and this is the concept of work. In physics, "work" is the process of making a living. In physics, "work" is the process of increasing the potential or kinetic energy of a system. We use work, heat, and other forms of energy and transformations to model energy transfers in the system. But every physical system also interacts with the world around it—that is, it exchanges energy with its environment. An exchange of energy between system and environment is called an energy transfer.

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Thermal Energy is Special.

- Kinetic to thermal.
- Chemical to thermal.
- Nuclear to thermal.
A child on a swing is motionless at the highest point of her arc. As she swings back down to the lowest point, what energy transformation is taking place?

A. Potential to Kinetic
B. Kinetic to Thermal
C. Kinetic to Potential
D. Potential to Thermal
After a springbok leaves the ground, it rises to a height of over 2.0 meters.

On the way up, what energy transformation is taking place?

A. Potential to Kinetic
B. Kinetic to Thermal
C. Kinetic to Potential
D. Potential to Thermal
A baseball player slides into home, coming to rest right on the plate. What energy transformation is taking place?

A. Potential to Kinetic
B. Kinetic to Thermal
C. Kinetic to Potential
D. Potential to Thermal
A skier moves down a slope at a constant speed.

What energy transformation is taking place?

A) Potential to Kinetic

B) Kinetic to Thermal

C) Kinetic to Potential

D) Potential to Thermal
Weightlifting

Why might the weightlifter want to hold his hands so far apart on the bar?
Why does the cyclist go up the slope when moving to the back of the pack?
## Unit of Energy: Joule

<table>
<thead>
<tr>
<th>Object</th>
<th>Kinetic energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ant walking</td>
<td>$1 \times 10^{-8} \text{ J}$</td>
</tr>
<tr>
<td>Coin dropped 1 m</td>
<td>$5 \times 10^{-3} \text{ J}$</td>
</tr>
<tr>
<td>Person walking</td>
<td>70 J</td>
</tr>
<tr>
<td>Fastball, 100 mph</td>
<td>150 J</td>
</tr>
<tr>
<td>Bullet</td>
<td>5000 J</td>
</tr>
<tr>
<td>Car, 60 mph</td>
<td>$5 \times 10^5 \text{ J}$</td>
</tr>
<tr>
<td>Supertanker, 20 mph</td>
<td>$2 \times 10^{10} \text{ J}$</td>
</tr>
</tbody>
</table>
Unit of Power: Watt

1 Watt = 1 Joule per second

The English unit of power is the *horsepower*. The conversion factor to watts is

\[ 1 \text{ horsepower} = 1 \text{ hp} = 746 \text{ W} \]

Many common appliances, such as motors, are rated in hp.
Power $\times$ Time = Energy

(Kilowatts) $\times$ (Hours) = Kilowatt-hours

**Hairdryer**

$(1.5\text{ kW}) \times (0.10\text{ h}) = 0.15\text{ kWh}$

*At 12¢ per kWh, this is about 2¢*
What appliance in your home uses the most energy over the course of a day?
Power × Time = Energy

(Kilowatts) × (Hours) = Kilowatt-hours

Energy stored in battery: 66 kWh
Power $\times$ Time = Energy

(Kilowatts) $\times$ (Hours) = Kilowatt-hours

Enough to run my house for 3 days!
A 100 W incandescent bulb emits approximately 4 W of visible light.

What is the efficiency?

\[ e = \frac{\text{what you get}}{\text{what you had to pay}} \]
4 W of visible light for 25 W electricity input

\[ e = \frac{\text{what you get}}{\text{what you had to pay}} \]
Energy use in the body
Efficiency for the Body

We’ll assume that the body has 25% efficiency.

\[(\text{Energy used by the body}) = 4 \times (\text{Energy needed to complete a task})\]
Power:
590 W

Specific Power
7.7 W/kg
Energy Inputs

1.0 Calorie = 1000 calorie = 4200 J = 4.2 kJ

1.0 kJ = 1000 J = 240 calorie = 0.24 Calorie
Using Energy

When you walk up a flight of stairs at a constant speed, what energy transformation is taking place?

A  Chemical to Kinetic

B  Chemical to Potential

C  Chemical to Kinetic and Thermal

D  Chemical to Potential and Thermal
Using Energy

When you walk at a constant speed on level ground, what energy transformation is taking place?

A. Chemical to Kinetic
B. Chemical to Potential
C. Chemical to Thermal
D. Potential to Thermal
CHAPTER 11

Using Energy

The metabolic energy used in an activity depends on an individual's size, level of fitness, and other variables. But we can make reasonable estimates for the power used in various activities for a typical individual. Some values are given in Table 11.4.

**Efficiency of the Human Body**

Suppose you climb a set of stairs at a constant speed, as in FIGURE 11.6. What is your body's efficiency for this process? To find out, let's apply the work-energy equation. We note first that no work is done on you: There is no external input of energy, as there would be if you took the elevator. Furthermore, if you climb at a constant speed, there's no change in your kinetic energy. However, your gravitational potential energy clearly increases as you climb, as does the overall thermal energy of you and perhaps the surrounding air. This latter fact is something you know well: If you climb several sets of stairs, you certainly warm up in the process! And, finally, your body must use chemical energy to power your muscles for the climb.

For this case of climbing stairs, then, the work-energy equation reduces to

$$E_{chem} + E_{th} + U_g = 0$$

(11.4)

Thermal energy and gravitational potential energy are increasing, so $E_{th}$ and $U_g$ are positive; chemical energy is being used, so $E_{chem}$ is a negative number. We can get a better feeling about what is happening by rewriting Equation 11.4 as

$$E_{chem} = U_g + E_{th}$$

The magnitude of the change in the chemical energy is equal to the sum of the changes in the gravitational potential and thermal energies. Chemical energy from your body is converted into potential energy and thermal energy; in the final position, you are at a greater height and your body is slightly warmer.

Earlier in the chapter, we noted that the efficiency for stair climbing is about 25%. Let's see where that number comes from.

1. **What you get.** What you get is the change in potential energy: You have raised your body to the top of the stairs. If you climb a flight of stairs of vertical height $y$, the increase in potential energy is $U_g = mg \times y$. Assuming a mass of 68 kg and a change in height of 2.7 m (about 9 ft, a reasonable value for a flight of stairs), we compute

$$U_g = (68 \text{ kg})(9.8 \text{ m/s}^2)(2.7 \text{ m}) = 1800 \text{ J}$$

2. **What you had to pay.** The cost is the metabolic energy your body used in completing the task. As we've seen, physiologists can measure directly how much energy your body uses to perform a task. A typical value for climbing a flight of stairs is

$$E_{chem} = 7200 \text{ J}$$

Given the definition of efficiency in Equation 11.2, we can compute an efficiency for climbing the stairs:

$$e = \frac{U_g}{E_{chem}} = \frac{1800 \text{ J}}{7200 \text{ J}} = 0.25 = 25\%$$

For the types of activities we will consider in this chapter, such as running, walking, and cycling, the body's efficiency is typically in the range of 20–30%. We will generally use a value of 25% for the body's efficiency for our calculations.

Efficiency varies from individual to individual and from activity to activity, but this rough approximation will be sufficient for our purposes in this chapter.

**Table 11.4 Metabolic power use during activities of 68 kg individual**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Metabolic power (W)</th>
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<tr>
<td>Typing</td>
<td>125</td>
</tr>
<tr>
<td>Ballroom dancing</td>
<td>250</td>
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<tr>
<td>Walking at 5 km/h</td>
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<tr>
<td>Running at 15 km/h</td>
<td>1150</td>
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</tbody>
</table>
Cost of Locomotion

Human, running

Red kangaroo, hopping
Power independent of speed.

Power proportional to speed.
Runner A and Walker B (who have the same mass) complete a 5.0 km course. Who uses more energy?

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Looking at the world through the lens of physics.

It was much easier to take a walk with Pumba than it is with Milo.

Why?
Two legs, two gaits.
Model

Power

Speed
Transition
Four legs, three gaits.

- Walk
- Trot
- Gallop / Canter
Pumbalation

Brian walking, Pumba trotting.
Milocomotion

Mismatch #1

Mismatch #2

Run for it!
Force Makes Things Move.

Torque Makes Things Rotate.

Where You Push Matters.
Units of Force

1 pound $\approx 5$ Newtons

Milo’s weight is about 60 pounds. He pushes on the ground with force of about 300 N.
Torque

Forces make things move.

Torques make things rotate.

\[ \tau = rF_\perp \]

Torque due to a force with perpendicular component \( F_\perp \) acting at a distance \( r \) from the pivot.
Balancing torques.

Who needs to sit closer to the pivot, the person with the larger mass or the person with the smaller mass?
Balancing torques.

\[ F_1 \times r_1 = F_2 \times r_2 \]
A person is lifting a 100 N weight. (Ignore the weight of the arm.)
• What is the force provided by the muscle?
A person is lifting a 100 N weight. (Ignore the weight of the arm.)

- What is the force provided by the muscle?
A man (weight 700 N) stands on the toes of one foot. What is the force provided by the Achilles tendon?
What is the force in the joint?

700 N

12 cm 6 cm

1400 N
Range & Speed vs. Strength
Throwing sports
Jumping
Digging

Armadillo Skeleton
Euphractus sp.
Class: Mammalia
Order: Edentata
DINUC 1902
Bite force

Forces and Torques in the Body

This force acts 35 cm from the pivot. The force in the joint acts at the pivot, so it does not contribute a torque.

SOLVE

The tension in the tendon tries to rotate the arm counter-clockwise, so it produces a positive torque. The torque due to the barbell, which tries to rotate the arm in a clockwise direction, is negative. For static equilibrium, the magnitudes of the two torques must be equal. Given the forces and distances we identified, we can write

\[ T \times 4.0 \text{ cm} = F \times 35 \text{ cm} \]

We can solve this equation for the tension in the tendon. The distances appear in a ratio, so the units cancel; there is no need for unit conversion:

\[ T = \frac{F \times 4.0 \text{ cm}}{35 \text{ cm}} \]

The tendon tension comes from the muscles, which must provide a force nearly 9 times the weight lifted! For this lift, the biceps in the arms are pulling with a combined force of about 1 ton, which makes this impressive lift seem even more amazing.

The tendon sustains a very large tension force. The maximum possible tendon tension is fixed by the cross-section area of the tendon and the tensile strength given in Table 8.4:

\[ T = \frac{F \times 4.0 \text{ cm}}{35 \text{ cm}} \]

The required tension for the lift is 36% of the maximum possible tension.

ASSESS

The large value for the tendon tension makes sense, given the problem statement, as does the fact that the tension is a significant fraction of what the tendon can support. The lift is possible, but it's nearing the limit of what the tissues of the body can do.

Lifting muscle (biceps) - Tendon - Elbow joint

FIGURE 8.29 The arm lifting a barbell.

These forces cause torques about the elbow.

FIGURE 8.30 A simplified model of the arm and weight.

Let's look at one more example, the motion of the jaw. A typical person can generate a bite force of 1200 N at the second molars, a force that is probably greater than the person's weight. The masseter muscle that provides most of the force to close your jaw isn't a particularly large muscle, but its attachment is quite favorable for providing large forces, as FIGURE 8.31a shows. The force vector shows the approximate line of force of the masseter muscle. The line of the force is about 5 cm from the pivot, compared to about 7 cm from the molars. This means that the force at the molars is nearly equal to the full force of the muscle. This is a dramatic difference from the previous examples. There's a trade-off, though—you may be capable of great bite strength, but your jaw has a very limited range of motion and you have limited bite speed.

FIGURE 8.31b shows a dog jaw along with the pivot and the approximate line of force of the masseter. The prominent canine teeth at the front of the jaw are much farther from the pivot than the muscle, so the canine teeth are well adapted for rapid, slashing bites. Cats have much shorter jaws than dogs. What does this imply about their bite speed and force?

Making light work of moving

The tendon force is so large in Example 8.12 because the weight is supported much farther from the elbow than the point where the tendon attaches. If the weight is supported closer to the elbow, the downward torque of the weight is much less, reducing the necessary tendon and muscle force. In the picture, two people are using lifting straps to carry a heavy appliance. The straps hang very close to the elbow, so the required muscle force to support the weight is much less than it would otherwise be.
Why do dogs have long snouts while cats do not?
Thanks!