PHYSICS

Principles and Problems

Chapter 10: Work, Energy, and Machines

McGraw Hill Education

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BIG IDEA

Doing work on a system changes the system's energy.

Table Of Contents

Energy and Work

MAIN IDEA

Work is the transfer of energy that occurs when a force is applied through a displacement.

Essential Questions

- What is work?
- What is energy?
- How are work and energy related?
- What is power, and how is it related to work and energy?

Energy and Work

Review Vocabulary

- Law of conservation of momentum **states that the momentum of any closed, isolated system does not change**

New Vocabulary

- Work – **the transfer of energy that occurs when a force is applied through a displacement.**
- Joule – **the SI unit of work and energy**
- Energy – **the ability of a system to produce change in itself or the world around it**

Energy and Work

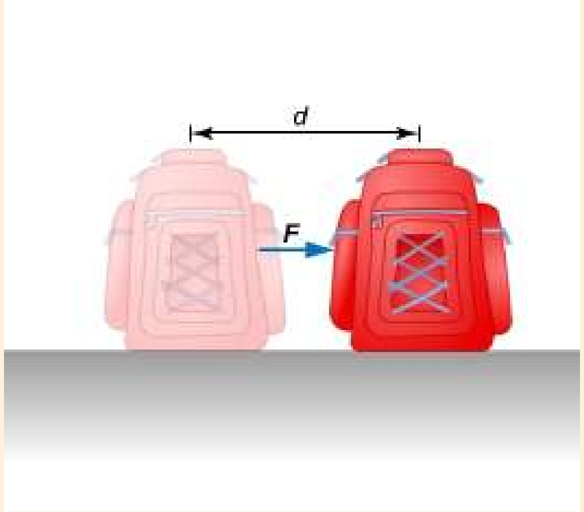
New Vocabulary

- Work-energy theorem – states that when work is done on a system, the result is a change in the system's energy
- **Kinetic energy – the energy associated with motion**
- **Translational kinetic energy – energy due to the motion of a system's center of mass**
- **Power – the rate at which energy is transformed**
- **Watt – 1 J of energy transferred or transformed in 1 s; the unit of power**

Work (cont.)

- A force, *F*, was exerted on an object while the object moved a distance, *d*, as shown in the figure.

- **If *F* is a constant force, exerted in the direction in which the object is moving, then work, *W*, is the product of the force and the object's displacement.**



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Work (cont.)

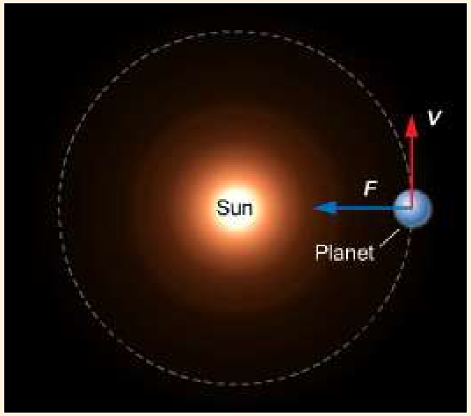
- Work is equal to a constant force exerted on an object in the direction of motion, multiplied by the object's displacement.

$$W = Fd$$

- **The SI unit of work is called a joule. One joule is equal to 1N•m.**

Work (cont.)

- The equation $W = Fd$ holds true only for constant forces exerted in the direction of motion.
- **An everyday example of a force exerted perpendicular to the direction of motion is the motion of a planet around the Sun, as shown in the fi**



- **If the orbit is circular, then the force is always perpendicular to the direction of motion.**

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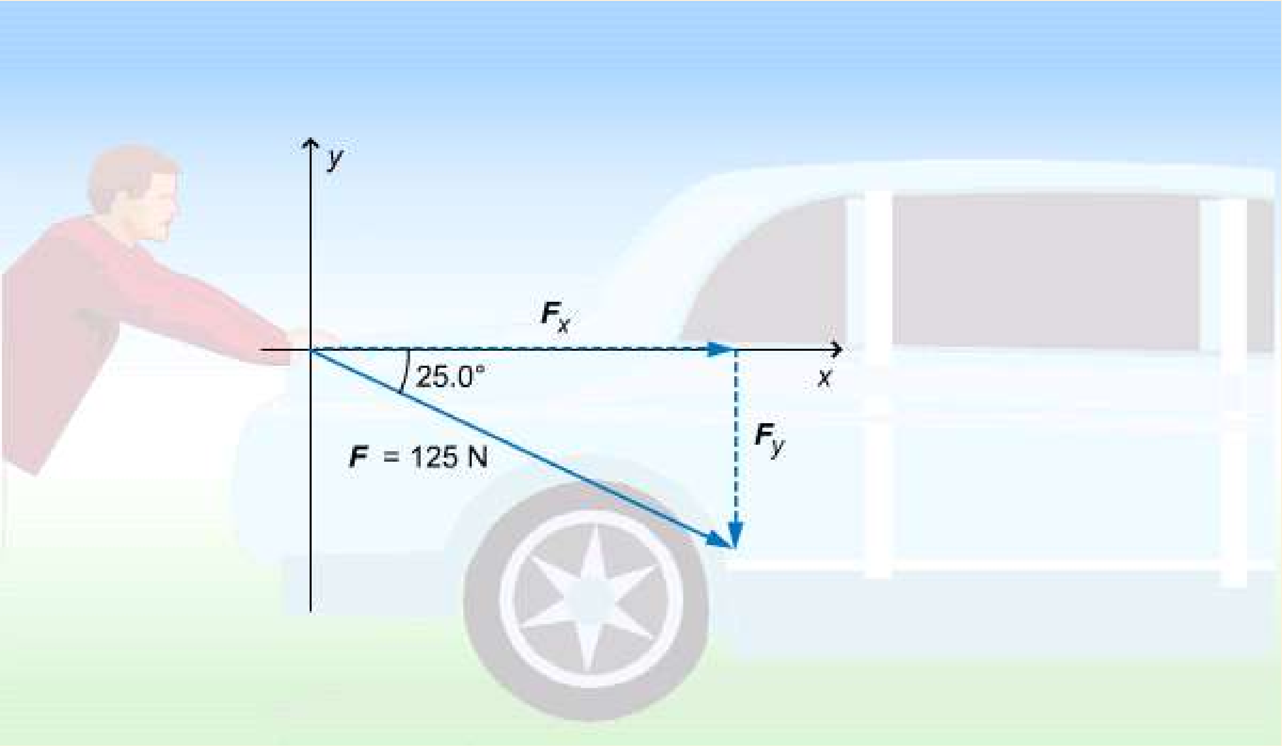
Work (cont.)



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Work (cont.)

- When a force is applied angle causes an object to move horizontally, only the horizontal component of the force does work.

The equation for work when force is applied at an angle:

$W = Fd\cos\theta$

Work (cont.)

Get it? Determine the work you do when you exert a force of 3N at an angle of 45° from the direction of motion for 1 m.

- $W = Fd\cos\theta = (3)(1)\cos(45)$

Work (cont.)

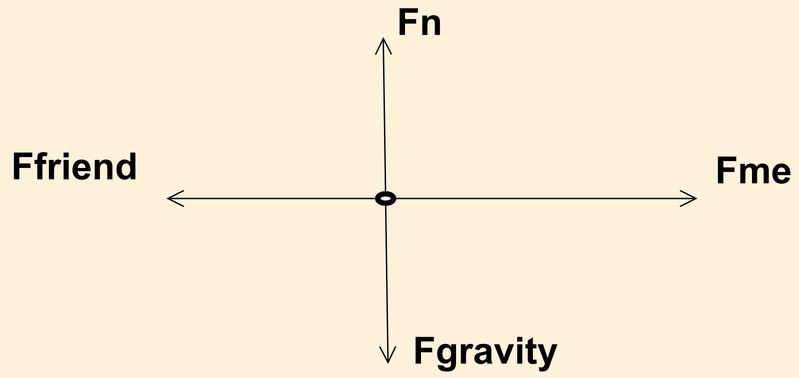
- Other agents exert forces on the pushed car as well.
- **Earth's gravity acts downward, the ground exerts a normal force upward, and friction exerts a horizontal force opposite the direction of motion.**

Work (cont.)

- The upward and downward forces are perpendicular to the direction of motion and do no work. For these forces, θ = 90°, which makes cos θ = 0, and thus, W = 0.

Work (cont.)

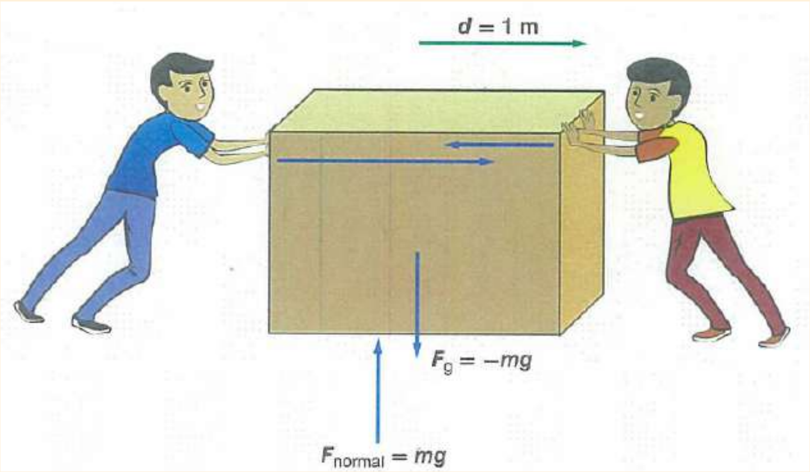
- Draw a force diagram showing the force you exert (Fme) to the right on a box and the force your friend exerts (Ffriend) to the left on the box. As a result of these two forces, the box moves to the right. Also show the gravitational force and the normal force. Explain why some forces do not work on the box.



•The normal force and gravity do no work on the box because they are not along the direction of the box's motion.

Work (cont.)

- It is important to consider all the forces acting on an object separately. Consider you are pushing a box on a frictionless surface while your friend is trying to prevent you from moving it.
- **What forces are acting on the box and how much work is being done?**



Work (cont.)

- The force you exert ($F_{\text{on box by you}}$) is the direction of the displacement, so the work you do is:

$$W = F_{\text{on box by you}}d$$

- Your friend exerts a force ($F_{\text{on box by friend}}$) in the direction opposite the displacement ($\theta = 180°$). Because cos 180° = -1, your friend does negative work:

$$W = -F_{\text{on box by friend}}d$$

Work (cont.)

- *Get it? Explain why you do positive work on the box and your friend does negative work on the box.*
  - ***You do positive work because your force is exerted in the direction of displacement***
  - ***Your friend does negative work because the force applied is in the direction opposite of displacement.***

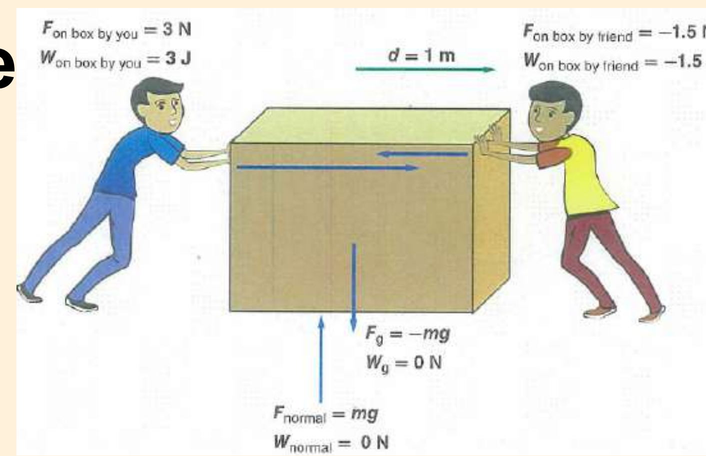
Work (cont.)

- The total work done on a system is the sum of the work done by each agent that exerts a force on the system.

- **The total work done on the box would be:**

$$W = F_{\text{on box by you}}d - F_{\text{on box by friend}}d$$

$$W = 3 - 1.5 = 1.5J$$



Work (cont.)

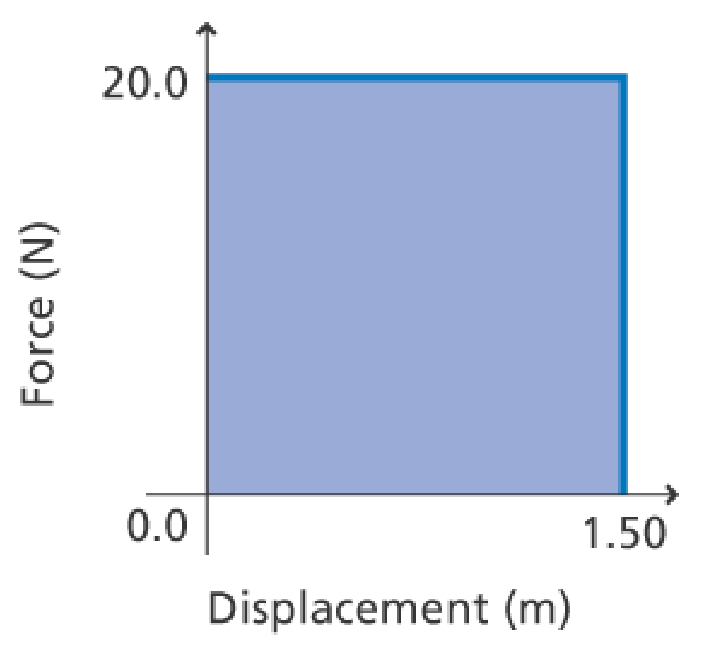
- Get it? Describe another scenario in which you do work on a system, and explain how much work is done on the system.

•Suppose you pull straight up on a fishing line that has bait and a sinker attached. If the bait, fishing line, and sinker have a mass of 0.15 N and you pull it straight up 8.0m, you do 1.2 J of work.

•$W = Fd\cos\theta = (.15)(8)\cos(90) = 1.2$ J

Work (cont.)

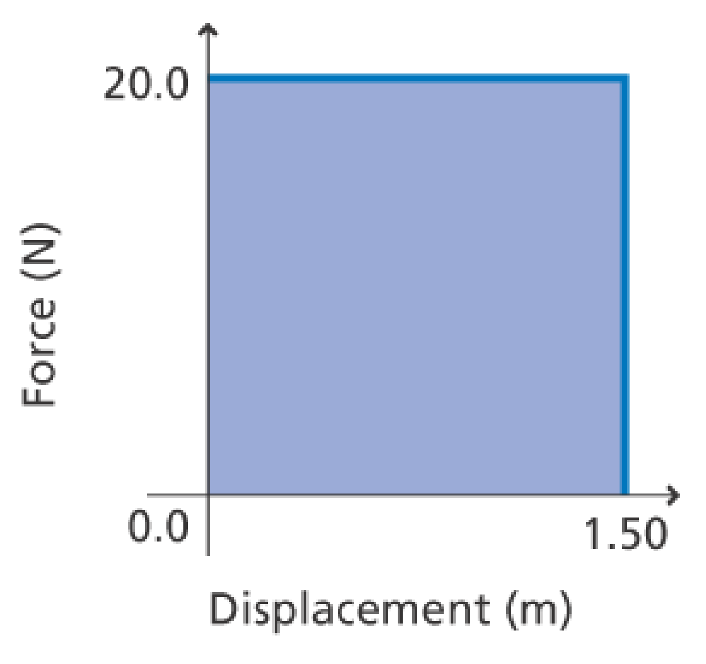
- A graph of force versus displacement lets you determine the work done by a force. This graphical method can be used to solve problems in which the force is changing.



•The work can be found by finding the area of the graph.

Work (cont.)

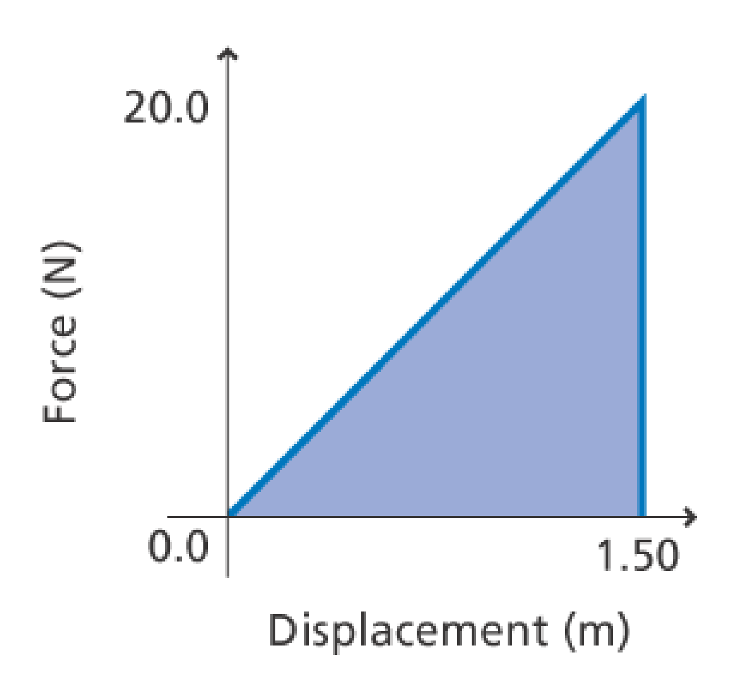
- The adjoining figure shows the work done by a constant force of 20.0 N that is exerted to lift an object a distance of 1.50 m.



- **The work done by this constant force is represented by $W = Fd$ = (20.0 N)(1.50 m) = 30.0 J.**

Work (cont.)

- This figure shows the force exerted by a spring, which varies linearly from 0.0 N to 20.0 N as it is compressed 1.50 m.



- **The work done by the force that increases linearly (compressed the spring) is the area under the graph, which is the area of a triangle, ½ (base) (altitude), or W = ½ (20.0 N)(1.50 m) = 15.0 J.**

Work (example.)

- An ice skater slides toward a sled sitting on the ice and hits against it. The skater exerts a 12.6 N force on the sled at an angle of 15.3° below the horizontal. The sled them moves 15.4 m forward. How much work did the skater do on the sled? Assume friction is negligible.

1. Analyze and sketch the problem:

Known: F = **12.6 N**d = **15.4 m**θ = **15.3°**

Unknowns: **W** = ?

Work (example.)

- What is the system? **The sled**
- What is the force that is doing work on the system? **The skater's push**

2. Solve for the unknown

$W = Fd\cos\theta = (12.6)(15.4)\cos(15.3) = 187$ J

Work (example.)

3. Evaluate the answer

Explain why your units for work are correct: **The unit for work is joules, and a newton-meter is equal to a joule.**

Explain why the sign of the answer is correct: **The skater does work on the sled, and the work should be the same direction as the force.**

Energy (cont.)

- The **work-energy theorem** states that when work is done on a system, the result is a change in the system's energy.
- This theorem can be represented by the following equation:

$$W = \Delta E$$

Energy (cont.)

Give an example of a force that does work on a system. Then use the work-energy theorem to your example.

- Ex: If a soccer player kicks a ball, the player’s foot does work on the ball. According to the work-energy theorem, work done on a system is equal to the change in the system’s energy. Therefore, the change in the ball’s energy is equal to the amount of work that the player’s foot does on the ball.

Energy (cont.)

- The ability of an object to produce a change in itself or the world around it is called **energy** and is represented by the symbol E.

Energy (cont.)

- Write a sentence using the word energy with its science usage and a sentence using the word energy with its common usage.
- **Science ex: The energy of a train changes as the force from the engine increases the train's speed.**
- **Common ex: The little children had so much energy that they ran and played all afternoon.**

Energy (cont.)

- Since work is measured in joules, energy must also be measured in joules.
- Through the process of doing work, energy can move between the external world and the system.
  - If the external world does work on the system, then *W* is positive and the energy of the system increases.
  - If the system does work on the external world, then *W* is negative and the energy of the system decreases.

Energy (cont.)

- The energy resulting from motion is called **kinetic energy** and is represented by the symbol *KE*.
- In the examples we have considere $\frac{1}{2}mv^2$ e object was changing position and i ergy, , was due to its motion.

Energy (cont.)

- Energy due to changing position is called **translational kinetic energy** and can be represented by the following equation:

$$KE_{trans} = \frac{1}{2}mv^2$$

Power

- Suppose you had a stack of books to move from the floor to a shelf.
  - You could lift the entire stack at once.
  - Or you could move the books one at a time.
- How would the amount of work compare between the two cases?

Power (cont.)

- In both cases, the total force applied and the displacement are the same so the work is the same. However, the time needed is different.
- Recall, that work causes a change in energy. The rate at which energy is transformed is power.

Power (cont.)

- **Power** is the work done, divided by the time taken to do the work.

- **In other words, power is the rate at which the external force changes the energy of the system. It is represented by the following equation.**

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

Power (cont.)

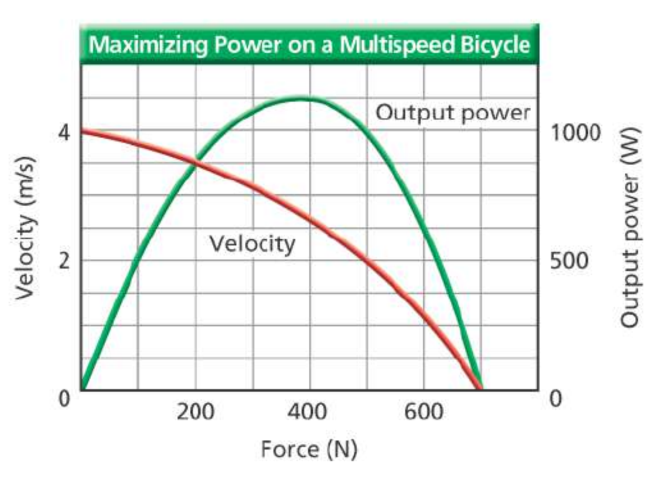
- Consider two forklifts, both using the same amount of force to lift identical loads. One accomplishes the task in 5 seconds, the other in 10 seconds.
- Even though the same work is accomplished by both, the forklift that took less time, has more power.

Power (cont.)

- Power is measured in watts (W). One **watt** is 1 Joule of energy transferred in 1 second.
- A watt is a relatively small unit of power. For example, a glass of water weighs about 2 N. If you lift the glass 0.5 m in 1 s, you are doing work at the rate of 1 W.
- Because a watt is such a small unit, power often is measured in kilowatts (kW). One kilowatt is equal to 1000 W.

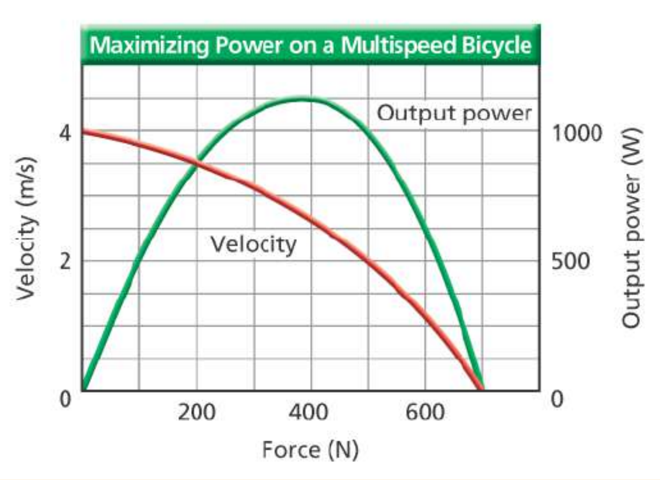
Power (cont.)

- When force and displacement are in the same direction, $P = Fd/t$. However, because the ratio d/t is the speed, power also can be calculated using $P = Fv$.
- **When riding a multi-speed bicycle, you need to choose the correct gear. By considering the equation, *P* = *Fv*, you can see that either zero force or zero speed results in no power delivered.**



Power (cont.)

- The muscles cannot exert extremely large forces, nor can they move very fast. Thus, some combination of moderate force and moderate speed will produce the largest amount of power.



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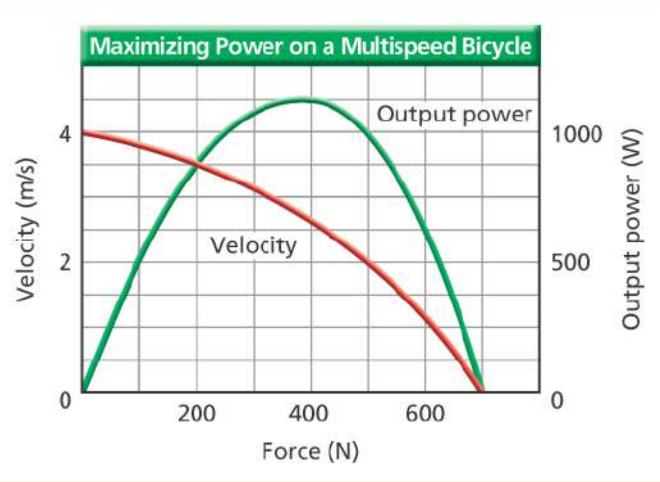
Power (cont.)

- The adjoining animation shows that the maximum power output is over 1000 W when the force is about 400 N and speed is about 2.6 m/s.

- **All engines—not just humans—have these limitations.**



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Section Check

If a constant force of 10 N is applied perpendicular to the direction of motion of a ball, moving at a constant speed of 2 m/s, what will be the work done on the ball?

A. 20 J

B. 0 J

C. 10 J

D. Data insufficient

Section Check

Answer

Reason: Work is equal to a constant force exerted on an object in the direction of motion, times the object's displacement. Since the force is applied perpendicular to the direction of motion, the work done on the ball would be zero.

Section Check

Three friends, Brian, Robert, and David, participated in a 200-m race. Brian exerted a force of 240 N and ran with an average velocity of 5.0 m/s, Robert exerted a force of 300 N and ran with an average velocity of 4.0 m/s, and David exerted a force of 200 N and ran with an average velocity of 6.0 m/s. Whom amongst the three delivered the most power?

Section Check

A. Brian

B. Robert

C. David

D. All three delivered the same power

Answer

Reason: The equation of power in terms of work done is:

$P = W/t$

Also since $W = Fd$

$\therefore\ P = Fd/t$

Also $d/t = v$

$\therefore\ P = Fv$

Answer

Now, since the product of force and velocity was the same for all three participants:

Power delivered by Brian → $P = (240\ N)\ (5.0\ m/s) = 1.2\ kW$

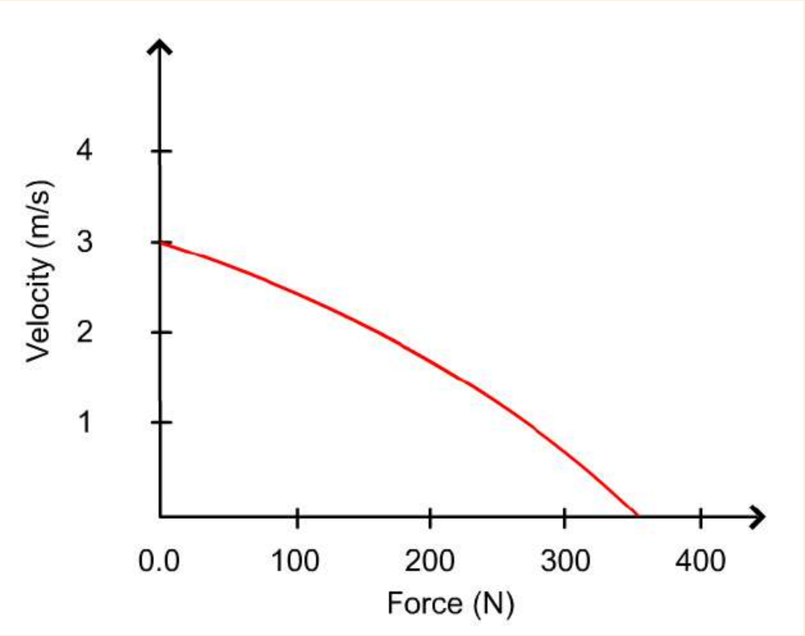
Power delivered by Robert → $P = (300\ N)\ (4.0\ m/s) = 1.2\ kW$

Power delivered by David → $P = (200\ N)\ (6.0\ m/s) = 1.2\ kW$

All three players delivered the same power.

Section Check

A graph of the force exerted by an athlete versus the velocity with which he ran in a 200-m race is given at right. What can you conclude about the power produced by the athlete?



Section Check

The options are:

A. As the athlete exerts more and more force, the power decreases.

B. As the athlete exerts more and more force, the power increases.

C. As the athlete exerts more and more force, the power increases to a certain limit and then decreases.

D. As the athlete exerts more and more force, the power decreases to a certain limit and then increases.

Section Check

Answer

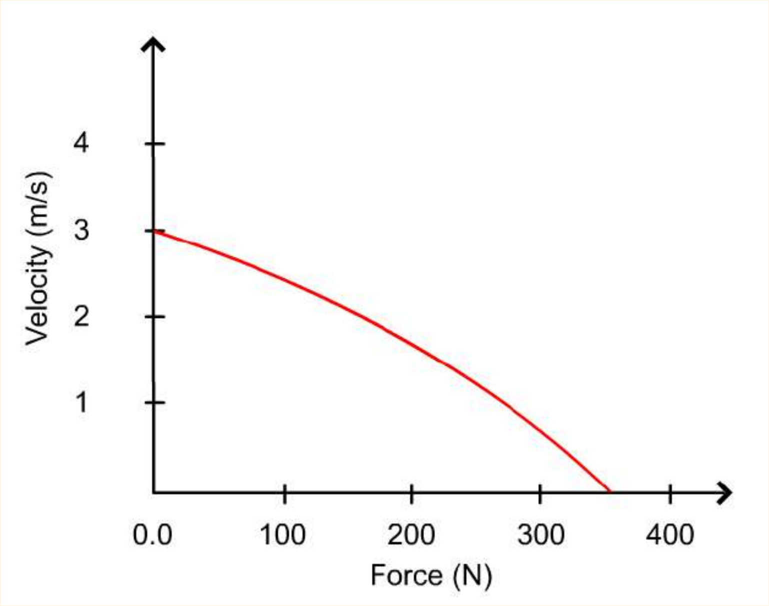
Reason: From the graph, we can see that as the velocity of the athlete increases, the force exerted by the athlete decreases.

Power is the product of velocity and force. Thus, some combination of moderate force and moderate speed will produce the maximum power.

Section Check

Answer

Reason: This can be understood by looking at the graph.



Section Check

Answer

By considering the equation $P = Fv$, we can see that either zero force or zero speed results in no power delivered. The muscles of the athlete cannot exert extremely large forces, nor can they move very fast. Hence, as the athlete exerts more and more force, the power increases to a certain limit and then decreases.

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Education

Click the mouse button or press the space bar to continue.

Machines

MAIN IDEA

Machines make tasks easier by changing the magnitude or the direction of the force exerted.

Essential Questions

- What is a machine, and how does it make tasks easier?
- How are mechanical advantage, the effort force and the resistance force related?
- What is a machine's ideal mechanical advantage?
- What does the term efficiency mean?

Review Vocabulary

- work **a force applied through a distance**

New Vocabulary

- **Machine** – a device that makes tasks easier by changing either the magnitude or the direction of the applied force.
- **Effort force** – force exerted by a user on a machine
- **Resistance force** – force exerted by the machine
- **Mechanical advantage** – ratio of resistance force to effort force
- **Ideal mechanical advantage** – equal to the displacement of the effort force divided by the displacement of the resistance force
- **Efficiency** – the ratio of output work to input work
- **Compound machine** – machine consisting of two or more simple machines linked in such a way that the resistance force of one machine becomes the effort force of the second.

Machines

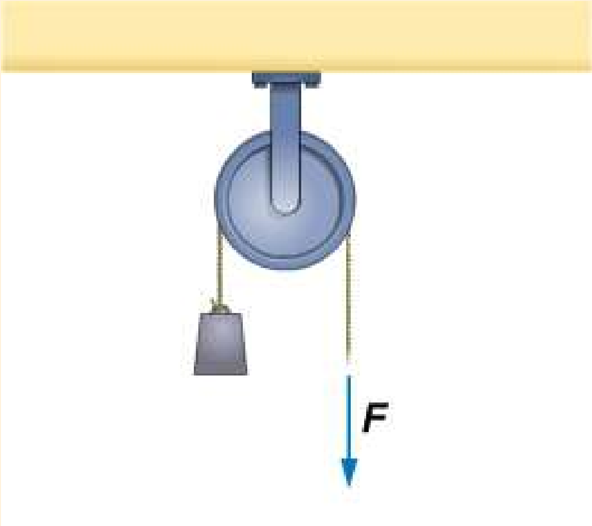
- Everyone uses machines every day. Some are simple tools, such as bottle openers and screwdrivers, while others are complex, such as bicycles and automobiles.
- Machines, whether powered by engines or people, make tasks easier.
- A **machine** is a device that makes tasks easier by changing either the **magnitude** or the **direction** of a force to match the force.

Machines (cont.)

Click image to view movie.

Machines (cont.)

- In a fixed pulley, such as the one shown in the figure here, the forces, F_e and F_r, are equal, and consequently *MA* is 1.



- **The fixed pulley is useful, not because the effort force is lessened, but because the direction of the effort force is changed.**

View Movie

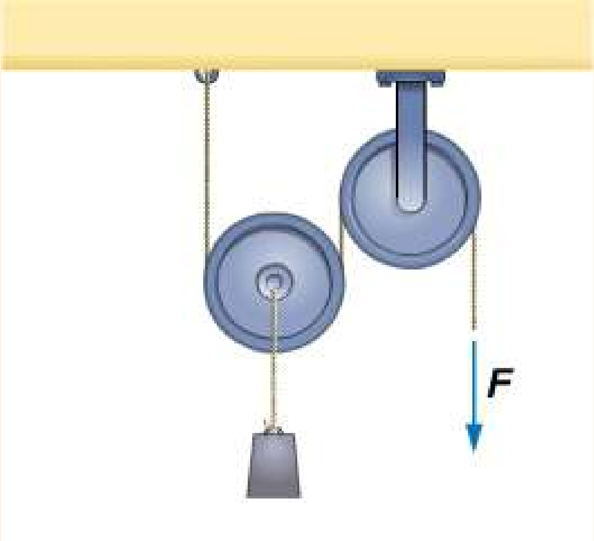
Machines (cont.)

- An effort force is exerted by a **user** on a **machine**
- A resistance force is exerted by a **machine**.

Machines (cont.)

- Many machines, such as the pulley system shown in the figure, have a mechanical advantage greater than 1.

- **When the mechanical advantage is greater than 1, the machine increases the force applied by a person.**



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Machines (cont.)

- Get it? Calcuate: A machine has a mechanical advantage of 3. If the input force is 2N, what is the output force?

2 x 3 = 6N (output force)

Machines (cont.)

- A machine can increase force, but it cannot increase energy. An ideal machine transfers all the energy, so the output work equals the input work: $W_o = W_i$ or $F_r d_r = F_e d_e$.
- This equation can be rewritten as $F_r / F_e = d_e / d_r$.

(**Resistance force/ effort force**) = (displacement of effort force/ displacement of resistance force)

Machines (cont.)

- Therefore, for an ideal machine, **ideal mechanical advantage**, *IMA*, is equal to the **displacement of the effort force, divided by the displacement of the load.**

- **The ideal mechanical advantage can be represented by the following equation.**

$$IMA = \frac{d_e}{d_r}$$

Machines (cont.)

- In a real machine, not all of the input work is available as output work. Energy removed from the system means that there is less output work from the machine.
- Consequently, the machine is less efficient at accomplishing the task.

Machines (cont.)

- The **efficiency** of a machine, e, is defined as the ratio of output work to input work.

$$e = \frac{W_o}{W_i} \times 100\%$$

- The efficiency of a machine (in %) is equal to the output work, divided by the input work, multiplied by 100.

Machines (cont.)

- An ideal machine has equal output and input work, $W_o/W_i = 1$, and its efficiency is 100 percent. All real machines have efficiencies of less than 100 percent because **some energy is always lost through heat or sound, not all of the input work is available as output work.**

- Efficiency can be expressed in terms of the mechanical advantage and ideal mechanical advantage.

Machines (cont.)

- Efficiency, $e = W_o/W_i$, can be rewritten as follows:

$$\frac{W_o}{W_i} = \frac{F_r d_r}{F_e d_e}$$

Machines (cont.)

- Because $MA = F_r/F_e$ and $IMA = d_e/d_r$, the following expression can be written for efficiency.

$$e = \frac{MA}{IMA} \times 100\%$$

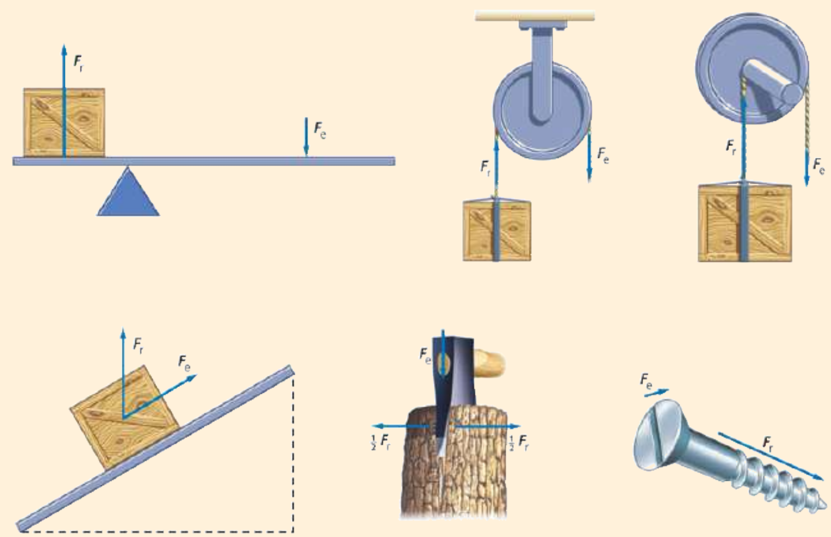
- **The efficiency of a machine (in %) is equal to its mechanical advantage, divided by the ideal mechanical advantage, multiplied by 100.**

Machines (cont.)

- A machine's design determines its ideal mechanical advantage. An efficient machine has an *MA* almost equal to its *IMA*. A less-efficient machine has a small *MA* relative to its *IMA*.
- To obtain the same resistance force, a greater force must be exerted in a machine of lower efficiency than in a machine of higher efficiency.

Compound Machines

- **Most machines, no matter how complex, are combinations of one or more of the six simple machines**: the lever, pulley, wheel and axle, inclined plane, wedge, and screw. These machines are shown in the figure.



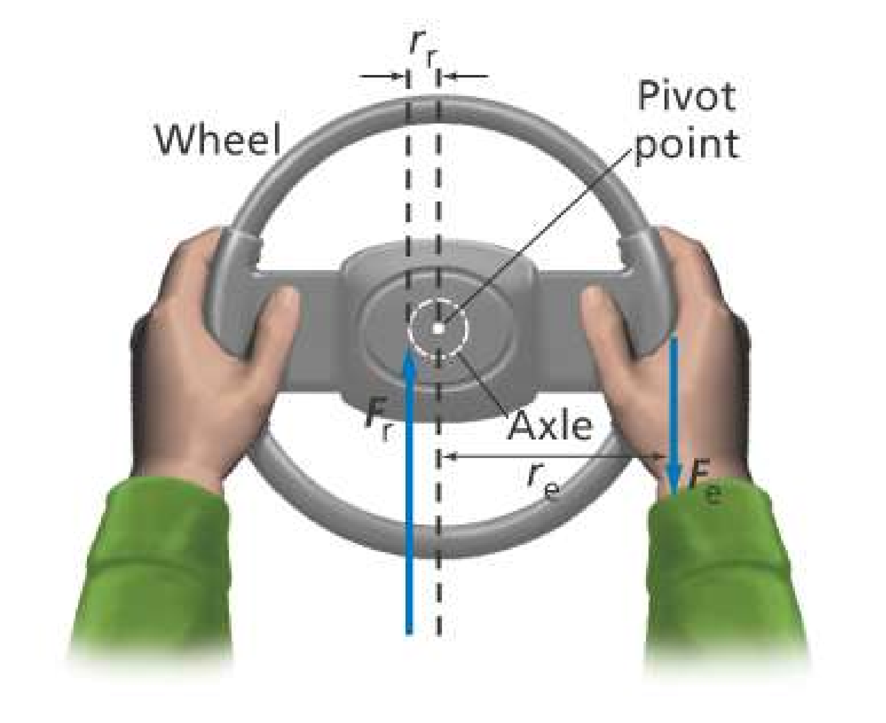
- **Both are designed to make a task easier.**

Compound Machines (cont.)

- The *IMA* of all compound machines is the ratio of the displacement of the effort force to the displacement of the resistance force.
- For machines, such as the lever and the wheel and axle, this ratio can be replaced by the ratio of the displacements between the place where the force is applied and the pivot point.

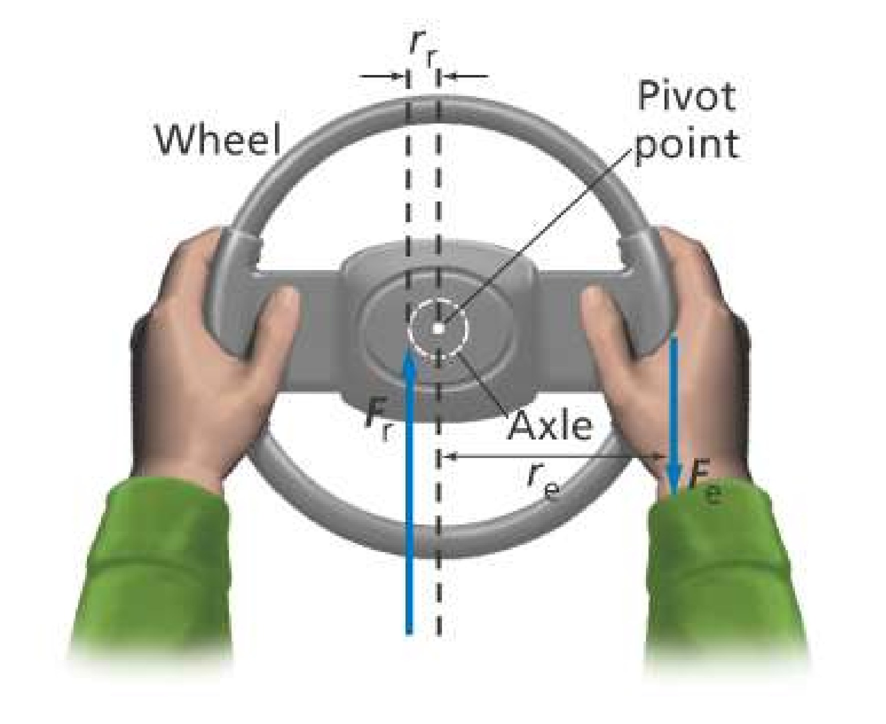
Compound Machines (cont.)

- A common version of the wheel and axle is a steering wheel, such as the one shown in the figure at right. The *IMA* is the ratio of the radii of the wheel and axle.



Compound Machines (cont.)

- A machine consisting of two or more simple machines linked in such a way that the resistance force of one machine becomes the effort force of the second is called a **compound machine**.



Compound Machines (cont.)

- In a bicycle, the pedal and the front gear act like a wheel and axle. **The effort force is the force that the rider exerts on the pedal, $F_{\text{rider on pedal}}$.**
- The resistance is the **force that the front gear exerts on the chain, $F_{\text{gear on chain}}$.**

Compound Machines (cont.)

- The chain exerts an effort force on the rear gear, $F_{\text{chain on gear}}$, equal to the force exerted on the chain.
- **The resistance force is the force that the wheel exerts on the road, $F_{\text{wheel on road}}$.**

Compound Machines (cont.)

- According to Newton's third law, the ground exerts an equal forward force on the wheel, which accelerates the bicycle forward.

- **The *MA* of a compound machine is the product of the *MA*s of the simple machines from which it is made.**

Compound Machines (cont.)

- So for a simple machine, the mechanical advantage is the ratio of the resistance force and the effort force. For a compound machine, the mechanical advantage is found the same way for each individual machine, but the total mechanical advantage is the produce of the mechanical advantage for each individual machine.

Compound Machines (cont.)

- In the case of the bicycle, $MA = MA_{\text{machine 1}} \times MA_{\text{machine 2}}$.

$$MA = \left(\frac{F_{\text{gear on chain}}}{F_{\text{rider on pedal}}}\right)\left(\frac{F_{\text{chain on gear}}}{F_{\text{gear on chain}}}\right)\left(\frac{F_{\text{wheel on road}}}{F_{\text{chain on gear}}}\right) = \frac{F_{\text{wheel on road}}}{F_{\text{rider on pedal}}}$$

Compound Machines (cont.)

- **The *IMA* of each wheel-and-axle machine is the ratio of the distances moved.**

For the pedal gear, $IMA = \dfrac{\text{pedal radius}}{\text{front gear radius}}$

For the rear wheel, $IMA = \dfrac{\text{rear gear radius}}{\text{wheel radius}}$

Compound Machines (cont.)

- For the bicycle, then,

$$IMA = \left(\frac{\text{pedal radius}}{\text{front gear radius}}\right)\left(\frac{\text{rear gear radius}}{\text{wheel radius}}\right)$$

$$= \left(\frac{\text{rear gear radius}}{\text{front gear radius}}\right)\left(\frac{\text{pedal radius}}{\text{wheel radius}}\right)$$

Compound Machines (cont.)

- Because both gears use the same chain and have teeth of the same size, you can count the number of teeth to find the *IMA*, as follows.

$$IMA = \left(\frac{\text{teeth on rear gear}}{\text{teeth on front gear}}\right)\left(\frac{\text{pedal arm length}}{\text{wheel radius}}\right)$$

Compound Machines (cont.)

- Shifting gears on a bicycle is a way of adjusting the ratio of gear radii to obtain the desired *IMA*.
- If the pedal of a bicycle is at the top or bottom of its circle, no matter how much downward force you exert, the pedal will not turn.

Compound Machines (cont.)

- The force of your foot is most effective when the force is exerted perpendicular to the arm of the pedal; that is, when the torque is largest.
- Whenever a force on a pedal is specified, assume that it is applied perpendicular to the arm.

Compound Machines (cont.)

- Get it? Explain what are the unites of the MA and IMA for the bicycle?

- **Both are dimensionless quantities and have not units.**

Compound Machines (cont.)

- On a multi-gear bicycle, the rider can change the *MA* of the machine by choosing the size of one or both gears.
- When accelerating or climbing a hill, the rider increases the ideal mechanical advantage to increase the force that the wheel exerts on the road.

Compound Machines (cont.)

- To increase the *IMA*, the rider needs to make the rear gear radius large compared to the front gear radius.
- For the same force exerted by the rider, a larger force is exerted by the wheel on the road. However, the rider must rotate the pedals through more turns for each revolution of the wheel.

Compound Machines (cont.)

- On the other hand, less force is needed to ride the bicycle at high speed on a level road.
- An automobile transmission works in the same way. To accelerate a car from rest, large forces are needed and the transmission increases the *IMA*.

Compound Machines (cont.)

- At high speeds, however, the transmission reduces the IMA because smaller forces are needed.
- Even though the speedometer shows a high speed, the tachometer indicates the engine's low angular speed.

Try it!

- A 45.6 cm wheel is attached to an axle with a radius of 8.95 cm. When an effort force of 265 N turns the axle, the wheel moves a linear distance of 16.3 cm. The efficiency of the wheel and axle is 85.6 percent.
  - A. What is the IMA of the wheel and axle?
  - B. What is the MA of the wheel and axle?
  - C. What is the resistance force?
  - D. How far did the axle turn when the wheel moved 16.3cm?

Machines

Try it!

1. Analyze and Sketch the Problem

Known: Re = **8.95 cm** Rr = **45.6 cm** Fe = **265N**

e = **85.6%** Dr = **16.3 cm**

Unknowns: **IMA** = ? **MA** = ? **Fr** = ? **De** = ?

2. Solve for the unkowns:

A. $IMA = \frac{Re}{Rr} = \frac{8.95}{45.6} = 0.196$

Try it!

b. $e = \frac{MA}{IMA} x\ 100$ rearrange to solve for MA

$$MA = \left(\frac{e}{100}\right) x\ IMA = \left(\frac{85.6}{100}\right) x\ 0.196 = 0.168$$

c. $MA = \frac{Fr}{Fe}$ rearrange to solve for Fr

$$Fr = (MA)(Fe) = (0.168)(265) = 44.5N$$

d. $IMA = \frac{De}{Dr}$ rearrange for De

$De = (IMA)(Dr) = (0.168)(16.3)$ = 3.19 cm

Try it!

3. Evaluate the answer

Are the units correct? **IMA and MA have no units. The force is in newtons, and the distance is in cm.**

Machines

Get it? Explain why your car needs multiple gears.

Gears are needed to apply different amounts of forces for different requirements.

The Human Walking Machine

- Movement of the human body is explained by the same principles of force and work that describe all motion.
- Simple machines, in the form of levers, give humans the ability to walk and run. The lever systems of the human body are complex.

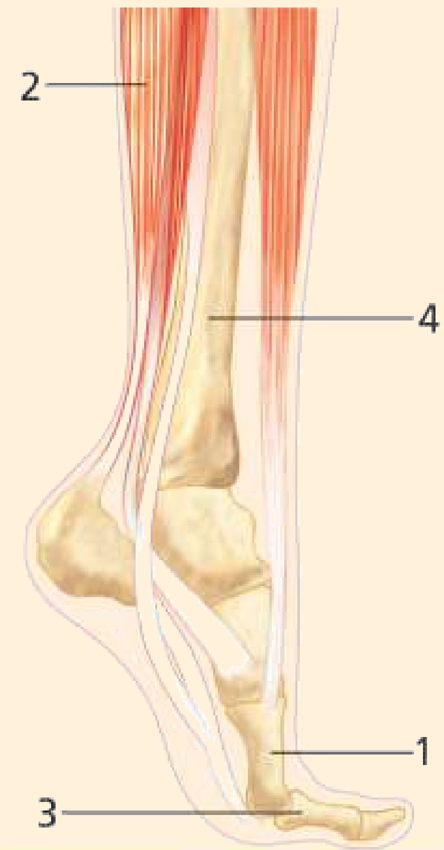
The Human Walking Machine (cont.)

- **However each system has the following four basic parts.**

1. a rigid bar (bone)
2. source of force (muscle contraction)
3. a fulcrum or pivot (movable joints between bones)
4. a resistance (the weight of the body or an object being lifted or moved).

The Human Walking Machine (cont.)

- Lever systems of the body are not very efficient, and mechanical advantages are low.
- This is why walking and jogging require energy (burn calories) and help people lose weight.

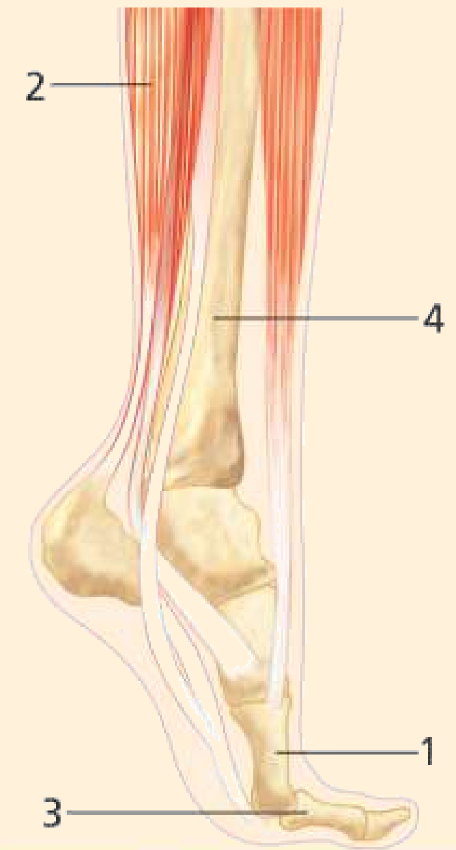


The Human Walking Machine (cont.)

- When a person walks, the hip acts as a fulcrum and moves through the arc of a circle, centered on the foot.
- The center of mass of the body moves as a resistance around the fulcrum in the same arc.

The Human Walking Machine (cont.)

- The length of the radius of the circle is the length of the lever formed by the bones of the leg.



The Human Walking Machine (cont.)

- Athletes in walking races increase their velocity by swinging their hips upward to increase this radius.
- A tall person’s body has lever systems with less mechanical advantage than a short person’s does.

The Human Walking Machine (cont.)

- Although tall people usually can walk faster than short people can, a tall person must apply a greater force to move the longer lever formed by the leg bones.
- Walking races are usually 20 or 50 km long. Because of the inefficiency of their lever systems and the length of a walking race, very tall people rarely have the stamina to win.

Section Check

How can a simple machine, such as a screwdriver, be used to turn a screw?

Section Check

Answer

You transfer energy to the screwdriver, which in turn transfers energy to the screw.

Answer

Reason: When you use a screwdriver to turn a screw, you rotate the screwdriver, thereby doing work on the screwdriver. The screwdriver turns the screw, doing work on it. The work that you do is the input work, W_i. The work that the machine does is called output work, W_0.

Section Check

Answer

Reason: Recall that work is the transfer of energy by mechanical means. You put work into a machine, such as the screwdriver. That is, you transfer energy to the screwdriver. The screwdriver, in turn, does work on the screw, thereby transferring energy to it.

Section Check

How can you differentiate between the efficiency of a real machine and an ideal machine?

A. The efficiency of an ideal machine is 100%, whereas efficiency of a real machine can be more than 100%.

B. The efficiency of a real machine is 100%, whereas efficiency of an ideal machine can be more than 100%.

C. The efficiency of an ideal machine is 100%, whereas efficiency of a real machine is less than 100%.

D. The efficiency of a real machine is 100%, whereas efficiency of an ideal machine is less than 100%.

Answer

Reason: The efficiency of a machine (in percent) is equal to the output work, divided by the input work, multiplied by 100.

Efficiency of a machine = $\frac{W_o}{W_i} \times 100$

For an ideal machine, $W_o = W_i$.

Hence, efficiency of an ideal machine = 100%.

For a real machine, $W_i > W_o$.

Hence, efficiency of a real machine is less than 100%.

Section Check

What is a compound machine? Explain how a series of simple machines combine to make a bicycle a compound machine.

Section Check

Answer

A compound machine consists of two or more simple machines linked in such a way that the resistance force of one machine becomes the effort force of the second machine.

Answer

In a bicycle, the pedal and the front gear act like a wheel and an axle. The effort force is the force that the rider exerts on the pedal, $F_{\text{rider on pedal}}$. The resistance force is the force that the front gear exerts on the chain, $F_{\text{gear on chain}}$. The chain exerts an effort force on the rear gear, $F_{\text{chain on gear}}$, equal to the force exerted on the chain by the gear. This gear and the rear wheel act like another wheel and axle. The resistance force here is the force that the wheel exerts on the road, $F_{\text{wheel on road}}$.

Click here to go back to the chapter menu.

Resources

Physics Online

Study Guide

Chapter Assessment Questions

Standardized Test Practice

Study Guide

- Work is done when a force is applied through a displacement. Work is the product of the force exerted on a system and the component of the distance through which the system moves that is parallel to the force.

$$W = Fd\cos\theta$$

The work done can be determined by calculating the area under a force-displacement graph.

Energy and Work

Study Guide

- Energy is the ability of a system to produce a change in itself or its environment. A moving object has kinetic energy. Objects that are changing position have translational energy.

$$KE_{trans} = \frac{1}{2}mv^2$$

Energy and Work

Study Guide

- The work done on a system is equal to the change in energy of the system. This is called the work-energy theorem.

$$W = \Delta E$$

- Power is the rate at which energy is transformed. When work causes the change in energy, power is equal to the rate of work done.

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

Machines

Study Guide

- Machines, whether powered by engines or humans, do not change the amount of work done, but they do make the task easier by changing the magnitude or direction of the effort force.

Study Guide

- The mechanical advantage, *MA*, is the ratio of resistance force to effort force.

$$MA = \frac{F_r}{F_e}$$

- **The ideal mechanical advantage, *IMA*, is the ratio of the distances moved.**

$$IMA = \frac{d_e}{d_r}$$

Study Guide

- The efficiency of a machine is the ratio of output work to input work.

$$e = \frac{W_o}{W_i} \times 100\%$$

Study Guide

- The efficiency of a machine can be found from the real and ideal mechanical advantages. In all real machines, *MA* is less than *IMA*, and *e* is less than 100 percent.

$$e = \frac{MA}{IMA} \times 100\%$$

Chapter Assessment

Juan pulled a crate with a rope angled 25° above the horizontal, applying a constant force of 40 N over a distance of 100 m. Find the work performed by Juan.

A. (40 N) (100 m)

B. (40 N) (100 m) sin 25°

C. (40 N) (100 m) cos 25°

D. (40 N) (100 m) tan 25°

Chapter Assessment

Reason: When force is applied at an angle, work is equal to the product of force and displacement times the cosine of the angle between the force and the direction of the displacement.

That is, $W = Fd \cos \theta = (40\ \text{N})\ (100\ \text{m}) \cos 25°$

Chapter Assessment

Three motors, A, B, and C were tested to lift water from a tank to the top of a building. The results are as follows.

Motor A of mass 1.0 kg lifted the water in 120 s. Motor B of mass 1.5 kg lifted the same amount of water in 135 s. Motor C of mass 2.0 kg lifted the same amount of water in 150 s.

Which of the motors produced the most power?

Chapter Assessment

A. Motor A

B. Motor B

C. Motor C

D. All three motors produce the same power.

Chapter Assessment

Reason: Power is equal to the work done, divided by the time taken to do work ($P = W/t$).

Since all three motors are doing the same work, the motor doing the work in the least time (that is, Motor A) produces the most power.

Chapter Assessment

While riding a multi-speed bicycle, the muscles in Jack's body exert a constant force of 400 N. If he covers a distance of 200 m in 1 minute, what is the power delivered by Jack?

A. $P = \dfrac{(400\text{ N})(200\text{ m})}{60\text{ s}}$

B. $P = \dfrac{(400\text{ N})}{(200\text{ m})(60\text{ s})}$

C. $P = \dfrac{(400\text{ N})(60\text{ s})}{(200\text{ m})}$

D. $P = \dfrac{(60\text{ s})}{(400\text{ N})(200\text{ m})}$

Chapter Assessment

Reason: **Power is equal to the work done, divided by the time taken to do work.**

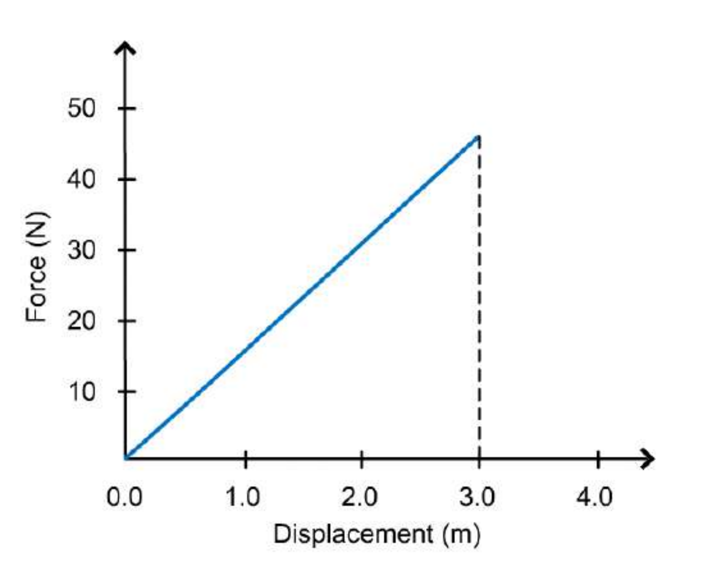
$$P = \frac{W}{t}$$

Since $W = Fd$,

$$P = \frac{Fd}{t} = \frac{(400\ \text{N})(200\ \text{m})}{60\ \text{s}}$$

Chapter Assessment

John is pushing a huge table in his house. As John pushes the table farther and farther, he applies more and more force. A graph of force (N) applied by John versus the displacement (m) of the table is given. What work does John do on the table?



Chapter Assessment

A. $(45\ \text{N})(3.0\ \text{m})$

B. $-(45\ \text{N})(3.0\ \text{m})$

C. $\frac{1}{2}(45\ \text{N})(3.0\ \text{m})$

D. $-\frac{1}{2}(45\ \text{N})(3.0\ \text{m})$

Chapter Assessment

Reason: **The area under the force-displacement graph is equal to the work done by that force, even if the force changes. Therefore, the work done by John in pushing the table is the area of a triangle:**

$$\frac{1}{2}(\text{base})(\text{altitude})$$

$$\text{That is, } W = \frac{1}{2}(45\,\text{N})(3.0\,\text{m}).$$

Chapter Assessment

Explain why the output work of a simple machine can never be greater than the input work.

Answer: A simple machine is not a source of energy. It only transfers the energy supplied to it. Therefore, the substance to which a machine transfers energy cannot receive more energy than the amount of energy put into it. Hence, the output work of a simple machine can never be greater than the input work.

Standardized Test Practice

A pulley system consists of two fixed pulleys and two movable pulleys that lift a load that has a weight of 300 N. If the effort force used to lift the load is 100 N, what is the mechanical advantage of the system?

A. $\frac{1}{3}$

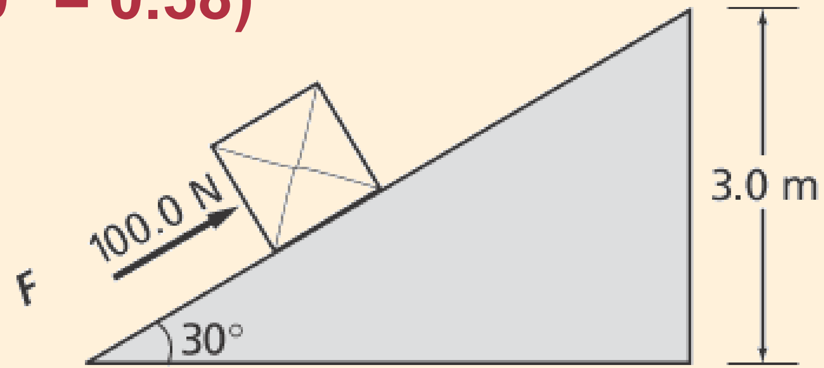
B. $\frac{3}{4}$

C. 3

D. 6

Standardized Test Practice

The box in the diagram is being pushed up the ramp with a force of 100.0 N. If the height of the ramp is 3.0 m, what is the work done on the box? (sin 30° = 0.50, cos 30° = 0.87, tan 30° = 0.58)



A. 150 J

B. 260 J

C. 450 J

D. 600 J

Standardized Test Practice

A compound machine used to raise heavy boxes consists of a ramp and a pulley. The efficiency of pulling a 100-kg box up the ramp is 50%. If the efficiency of the pulley is 90%, what is the overall efficiency of the compound machine?

A. 40%

B. 45%

C. 50%

D. 70%

Standardized Test Practice

A skater with a mass of 50.0 kg slides across an icy pond with negligible friction. As he approaches a friend, both he and his friend hold out their hands, and the friend exerts a force in the direction opposite to the skater's movement, which lowers the skater's speed from 2.0 m/s to 1.0 m/s. What is the change in the skater's kinetic energy?

A. 25 J

B. 75 J

C. 100 J

D. 150 J

Standardized Test Practice

A 20.0-N block is attached to the end of a rope, and the rope is looped around a pulley system. If you pull the opposite end of the rope a distance of 2.00 m, the pulley system raises the block a distance of 0.40 m. What is the pulley system's ideal mechanical advantage?

A. 2.5

B. 4.0

C. 5.0

D. 10.0

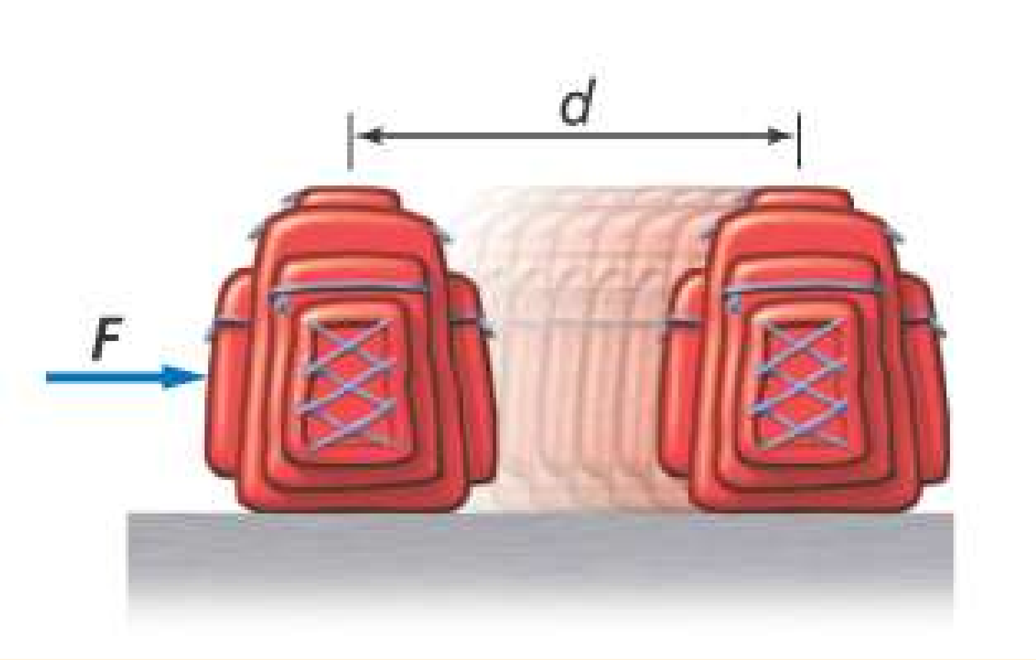
Standardized Test Practice

Test-Taking Tip

Beat the Clock and then Go Back

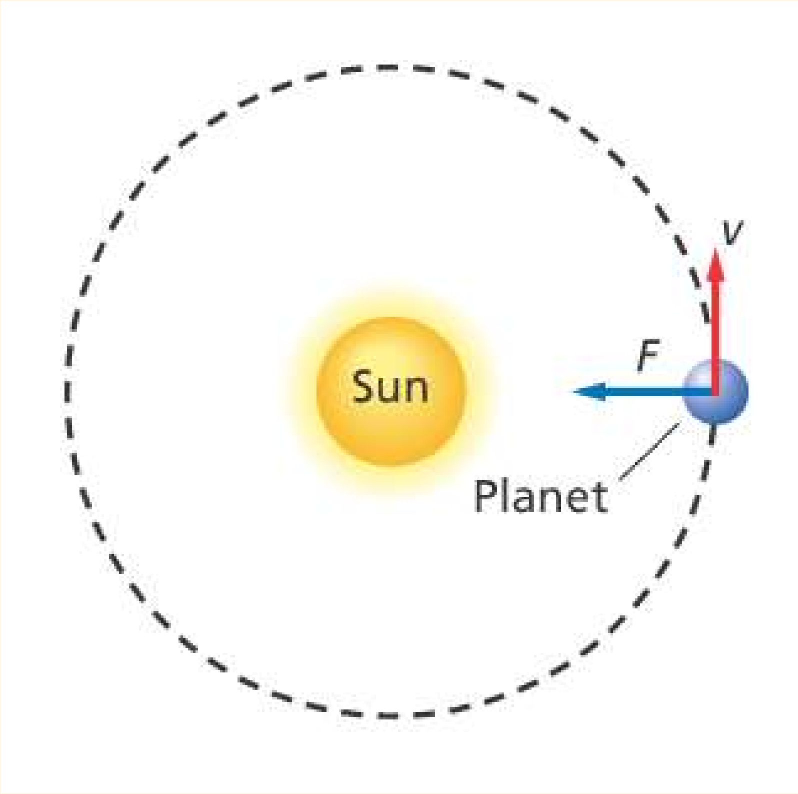
As you take a practice test, pace yourself to finish each section just a few minutes early so you can go back and check over your work.

A Constant Force Exerted on the Backpack

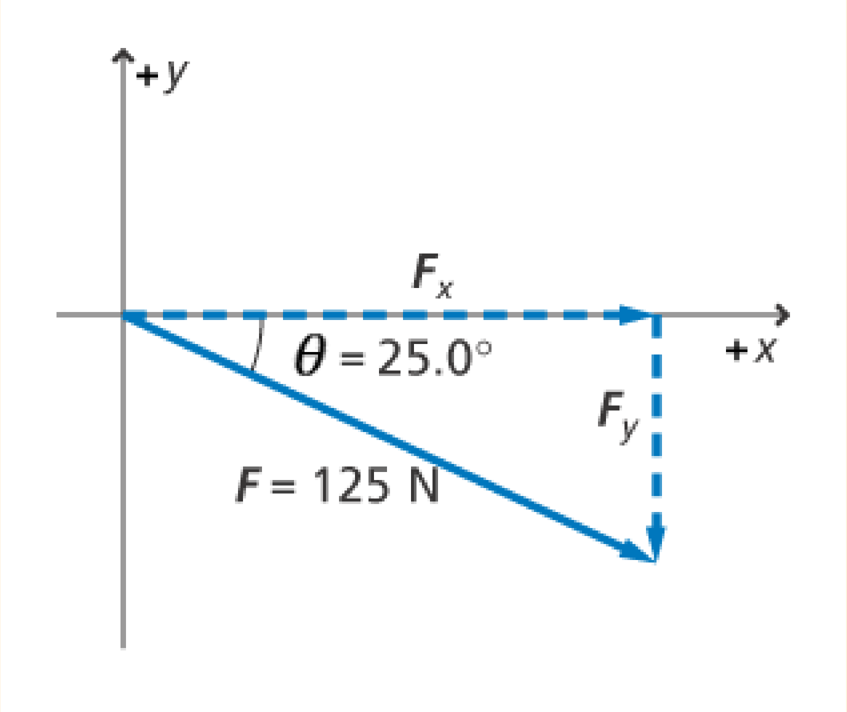


Chapter Resources

Motion of the Planet Around the Sun

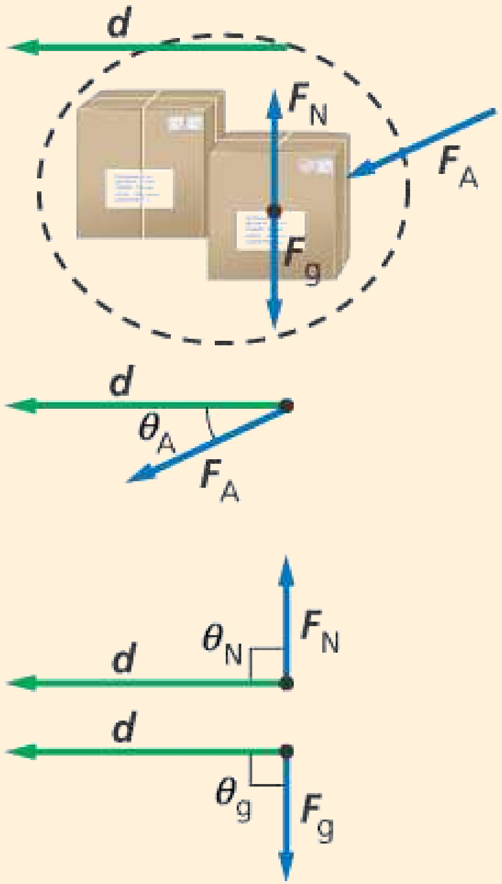


Constant Force Exerted at an Angle

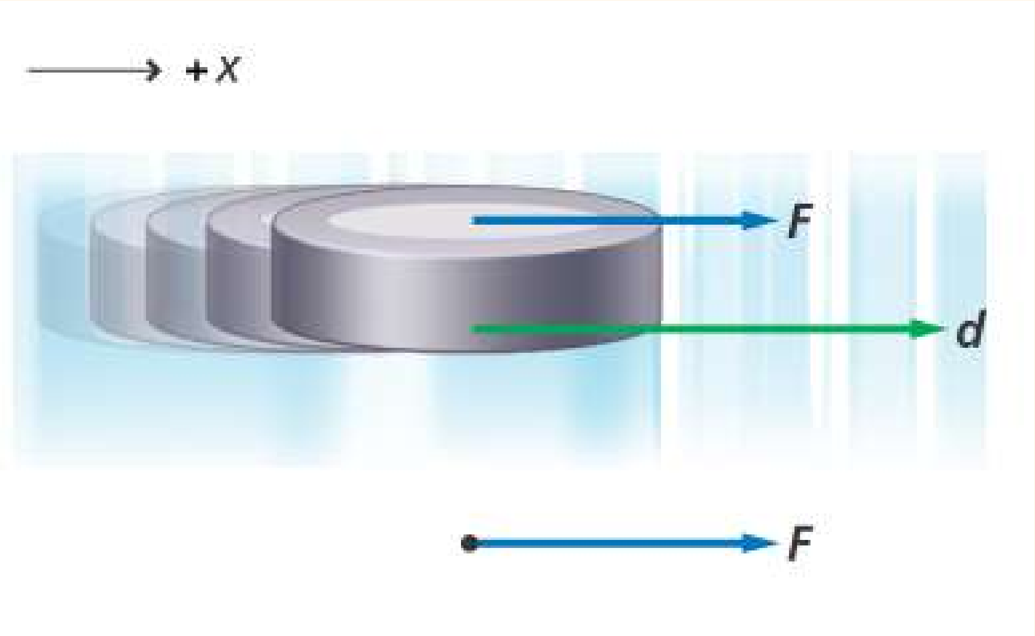


Chapter Resources

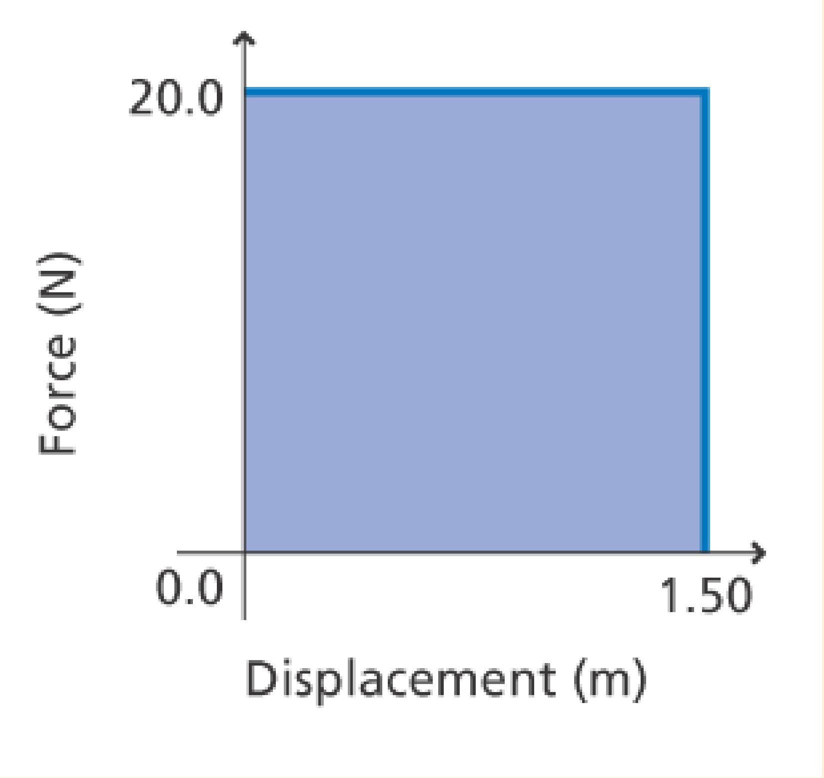
Work Diagram



Work and Energy

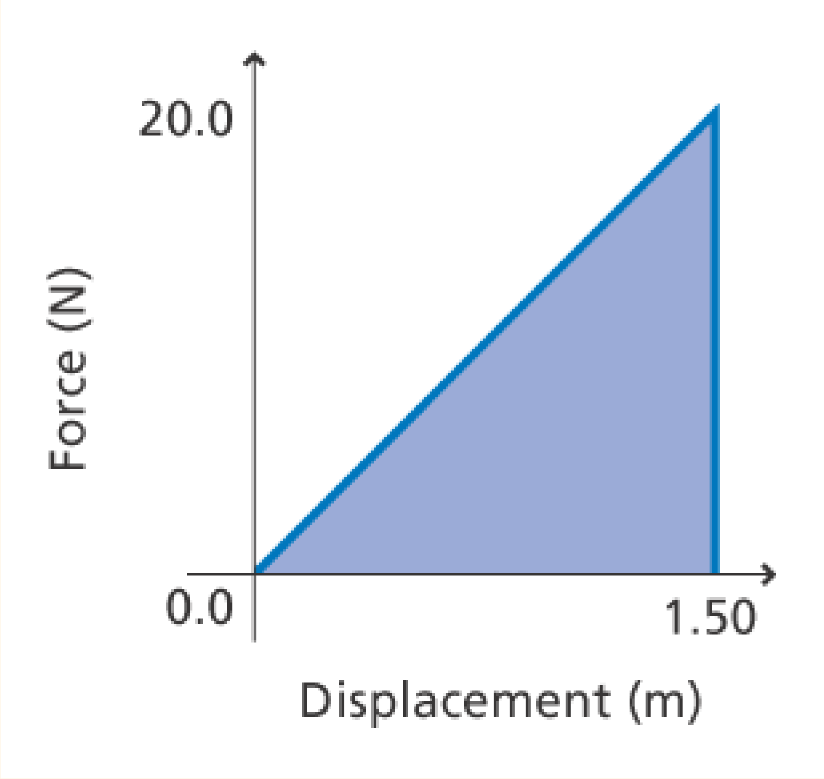


Work Done by a Force



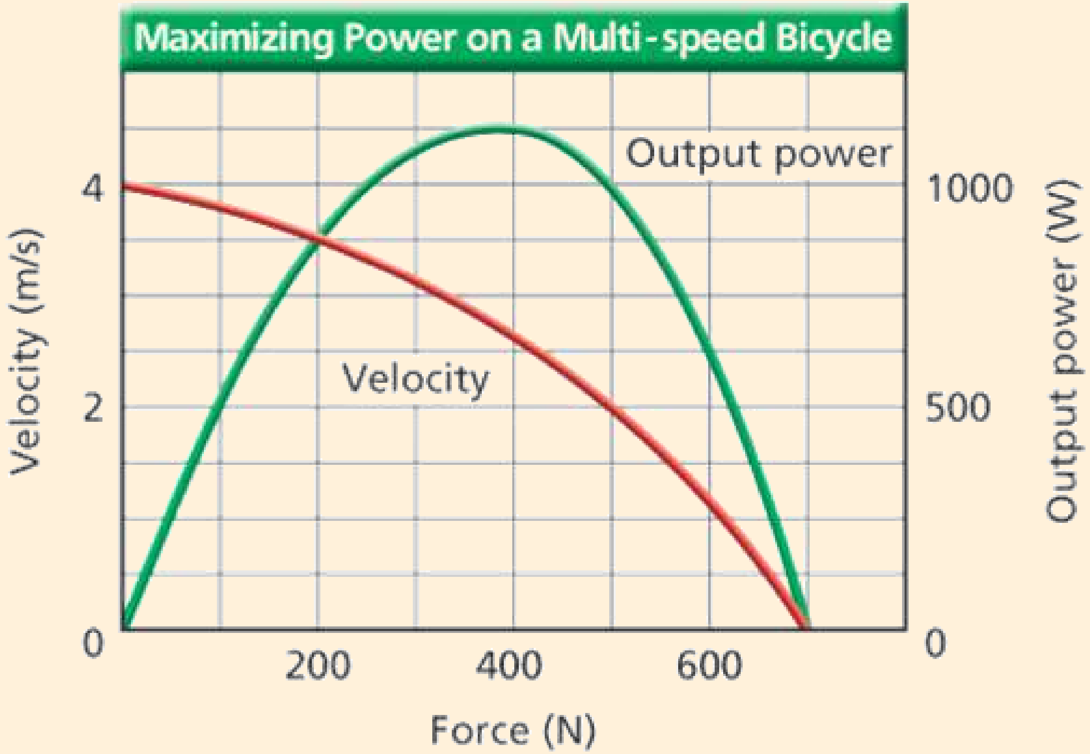
Chapter Resources

Work Done by a Force



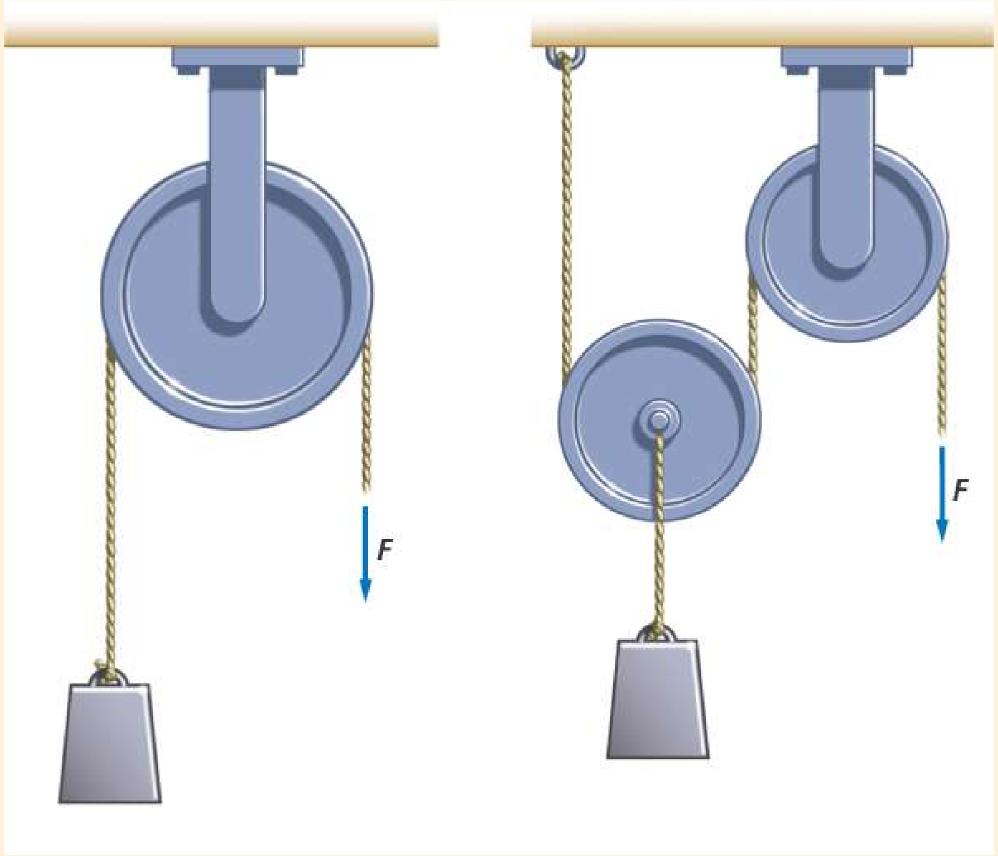
Chapter Resources

Maximizing Power on a Multi-speed Bicycle



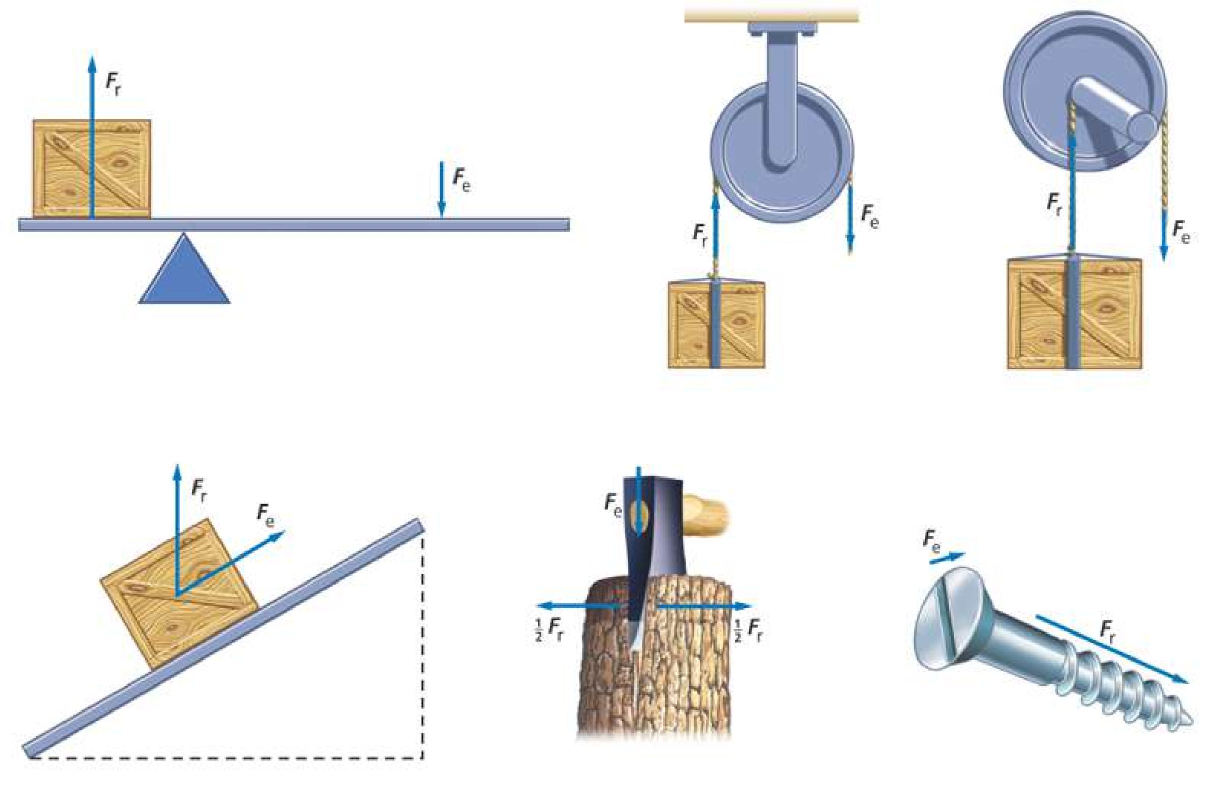
Chapter Resources

A Pulley System

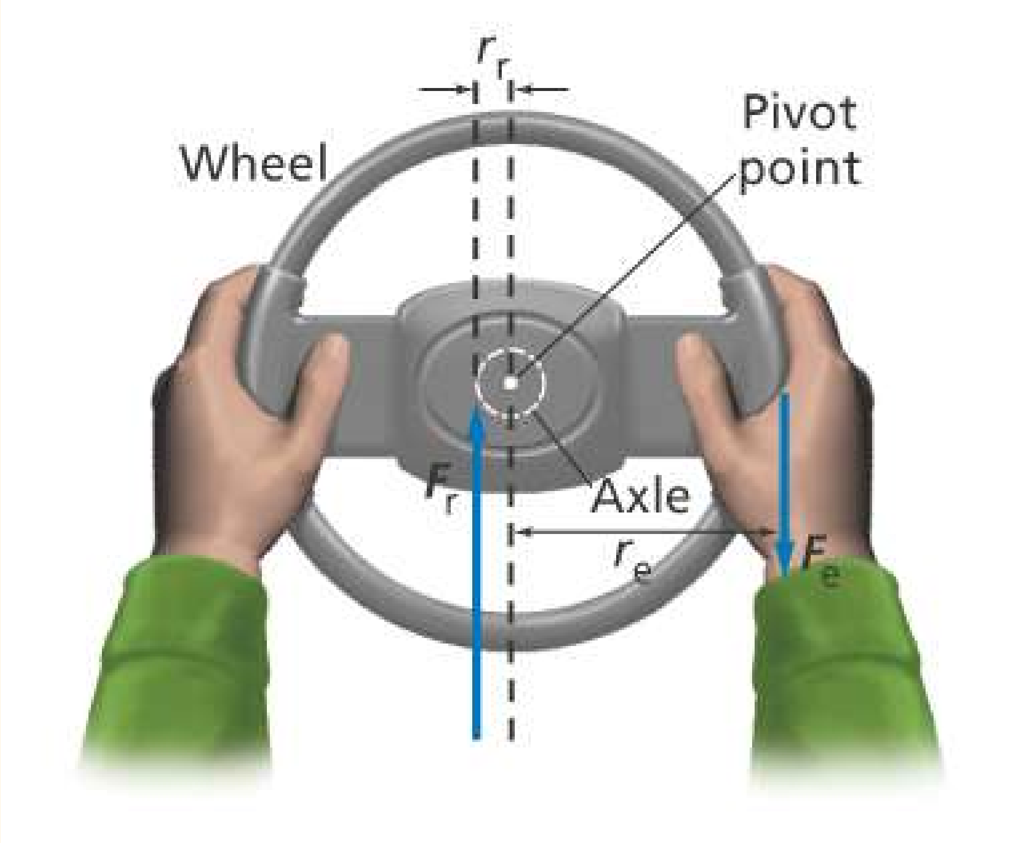


Chapter Resources

Examples of Simple Machines

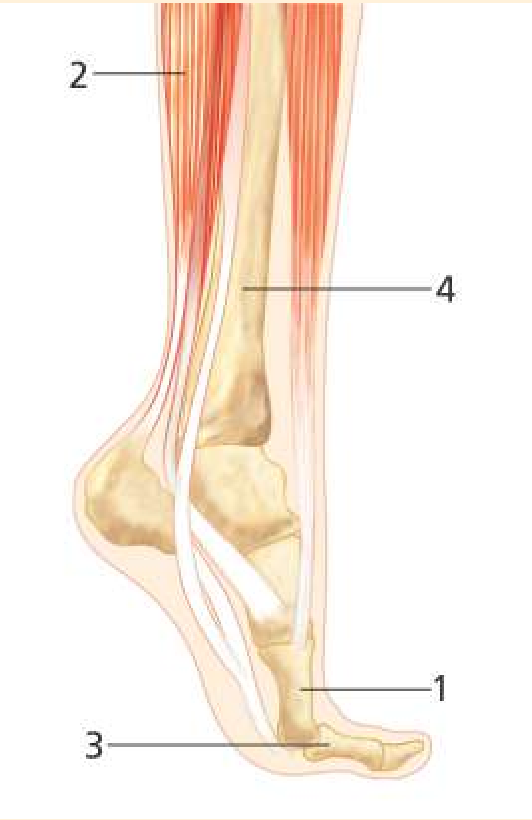


A Steering Wheel



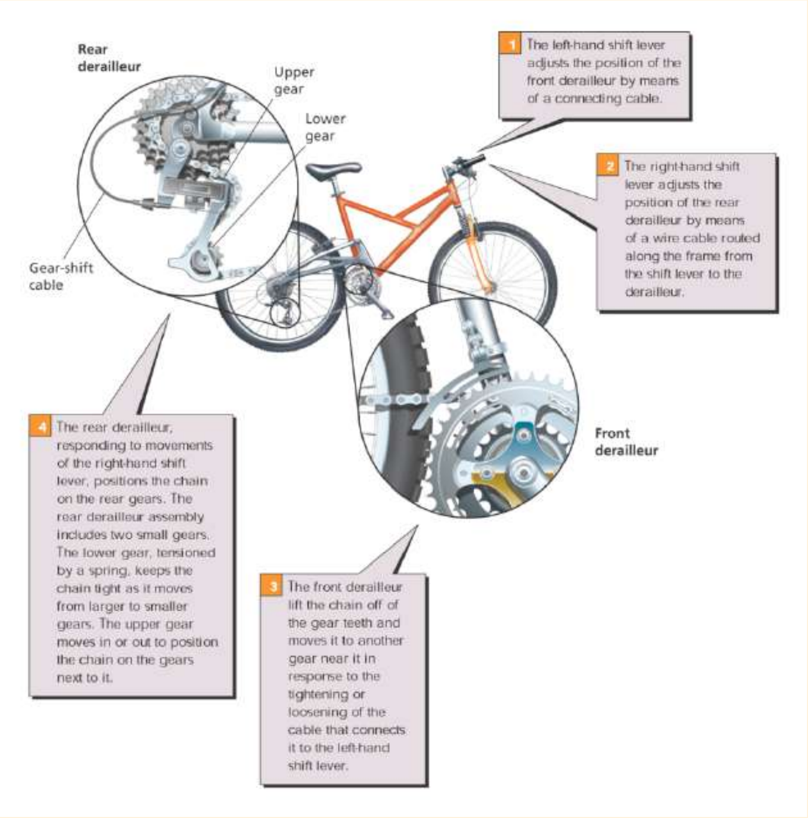
Chapter Resources

The Human Walking Machine



Chapter Resources

Bicycle Gear Shifters



Work and Energy

A 105-g hockey puck is sliding across the ice. A player exerts a constant 4.50-N force over a distance of 0.150 m. How much work does the player do on the puck? What is the change in the puck's energy?

Mechanical Advantage

You examine the rear wheel on your bicycle. It has a radius of 35.6 cm and has a gear with a radius of 4.00 cm. When the chain is pulled with a force of 155 N, the wheel rim moves 14.0 cm. The efficiency of this part of the bicycle is 95.0 percent.

Mechanical Advantage

A. What is the *IMA* of the wheel and gear?

B. What is the *MA* of the wheel and gear?

C. What is the resistance force?

D. How far was the chain pulled to move the rim 14.0 cm?