

**Module 4: Energy**  
**Topic 1 Content: Work and Power**



Physics uses a specific definition for work, and by looking at several examples, you'll be able to determine just how it is applied.

## Module 4: Energy

### Topic 1 Content: Work and Power



The man does work.



The waitress does no work.



The woman does negative work.



The mother does work.



The weight lifter does no work.



Friction does negative work.

See if work is done or not!

Example one: A man lifts a box from the floor onto a shelf. The man does work as he lifts the box.

Example two: A waitress carries a tray full of food across the restaurant. The waitress does no work carrying the tray.

Example three: A woman takes a box from a shelf and places it on the floor. The woman does negative work while lowering the box.

Example four: A sled on ice skates is pushed from behind by a mother so that the sled starts moving. The mother does work while pushing the sled.

Example five: A weight lifter holds weight over his head. The weight lifter does no work.

Example six: A baseball player slides into third base. Friction does negative work while acting on the baseball player.

## Module 4: Energy

### Topic 1 Content: Work and Power

The image contains six examples of work and power scenarios, each with a diagram and a text description:

- Example 1:** A blue arrow labeled 'F' points up, and a black arrow labeled 'd' points up. Text: "The man does work."
- Example 2:** A blue arrow labeled 'F' points up, and a black arrow labeled 'd' points right. Text: "The waitress does no work."
- Example 3:** A blue arrow labeled 'F' points up, and a black arrow labeled 'd' points down. Text: "The woman does negative work."
- Example 4:** A blue arrow labeled 'F' points right, and a black arrow labeled 'd' points right. Text: "The mother does work."
- Example 5:** A blue arrow labeled 'F' points up, and a black circle with a diagonal slash contains a 'd'. Text: "The weight lifter does no work"
- Example 6:** A blue arrow labeled 'F' points right, and a black arrow labeled 'd' points left. Text: "Friction does negative work"

Do you see a pattern here? Perhaps it will be useful to look at the applied force or forces in each situation.

In example one, the man applies a force to the box in an upward direction. At the same time, the box moves up, in the same direction.

In example two, the waitress must apply a force up on the tray as she carries it, but the direction of motion is forward perpendicular to the direction of the force.

In example three, while the box is being lowered, the woman is still applying an upward force to keep the box from falling. The force points opposite the direction of motion.

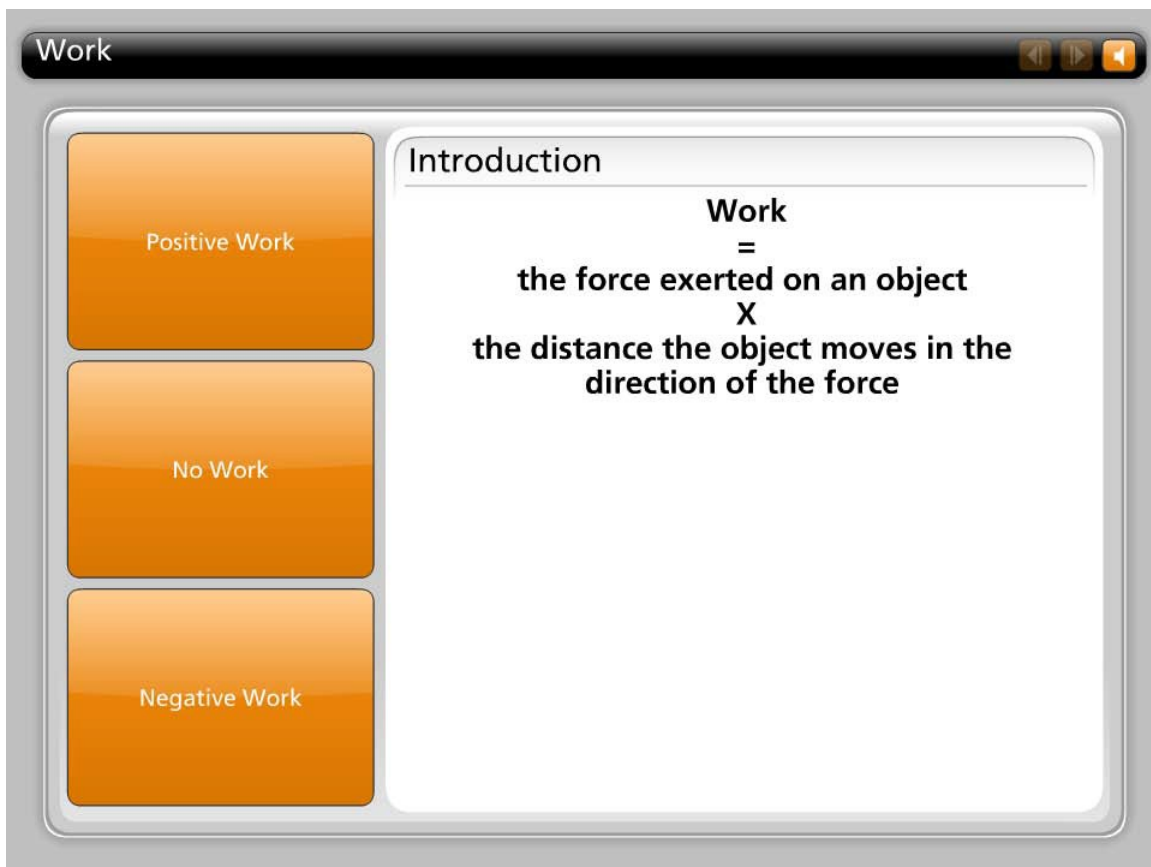
In example four, the mother pushes forward, and the sled moves forward in the same direction as the force.

In example five, the weight lifter does not move the weight any distance, so no work is done.

And in example six, friction provides a force opposite the direction of motion, bringing the baseball player to a stop.

## Module 4: Energy

### Topic 1 Content: Work and Power



The screenshot shows a software window titled "Work" with a navigation bar at the top containing back, forward, and home icons. On the left side, there are three orange buttons labeled "Positive Work", "No Work", and "Negative Work". The main content area is titled "Introduction" and contains the following text:

**Work**  
=  
the force exerted on an object  
X  
the distance the object moves in the  
direction of the force

In physics, work is the product of the force exerted on an object and the distance the object moves in the direction of the force.

## Module 4: Energy

### Topic 1 Content: Work and Power

The screenshot shows a software window titled "Work" with three buttons on the left: "Positive Work" (dark blue), "No Work" (orange), and "Negative Work" (orange). The "Positive Work" button is selected. The main content area is titled "Positive Work" and contains a diagram. The diagram shows two horizontal arrows pointing to the right. The top arrow is thicker and labeled with the letter "F" to its right. The bottom arrow is thinner and labeled with the letter "d" to its right. Below the arrows, the text "positive work" is written in a serif font.

As you can see, when the force is in the same direction that the object moves, work is done.

## Module 4: Energy

### Topic 1 Content: Work and Power

The image shows a software interface for learning about work. It has a title bar that says "Work" and three navigation buttons (back, forward, home). On the left, there are three buttons: "Positive Work" (orange), "No Work" (blue), and "Negative Work" (orange). The "No Work" button is currently selected. To the right of the buttons is a large white area with a blue border. Inside this area, there is a diagram showing a vertical arrow pointing upwards labeled "F" and a horizontal arrow pointing to the right labeled "d". Below the arrows, the text "no work" is written in a large, black, serif font.

When the force is perpendicular to the displacement, there is no work done. Also, when the object does not move, no work is done.

## Module 4: Energy

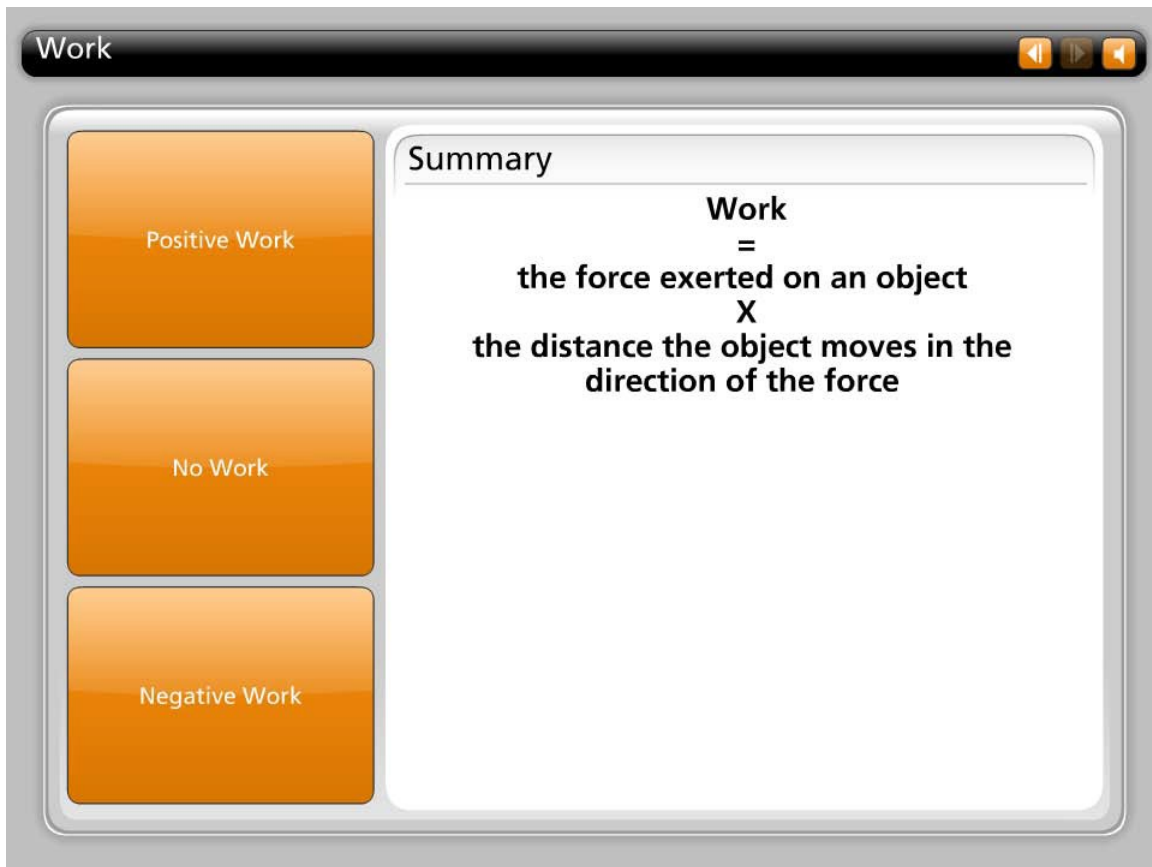
### Topic 1 Content: Work and Power

The image shows a software interface with a title bar labeled "Work" and three navigation buttons. On the left, there are three buttons: "Positive Work" (orange), "No Work" (orange), and "Negative Work" (dark blue). The "Negative Work" button is selected. The main content area is titled "Negative Work" and contains a diagram. The diagram shows a force vector  $F$  pointing to the left and a displacement vector  $d$  pointing to the right. Below the diagram, the text "negative work" is displayed.

Finally, when the force is applied opposite the direction of motion, this results in negative work.

## Module 4: Energy

### Topic 1 Content: Work and Power



The image shows a presentation slide titled "Work". On the left side, there are three orange buttons labeled "Positive Work", "No Work", and "Negative Work". On the right side, under the heading "Summary", the definition of work is given as:

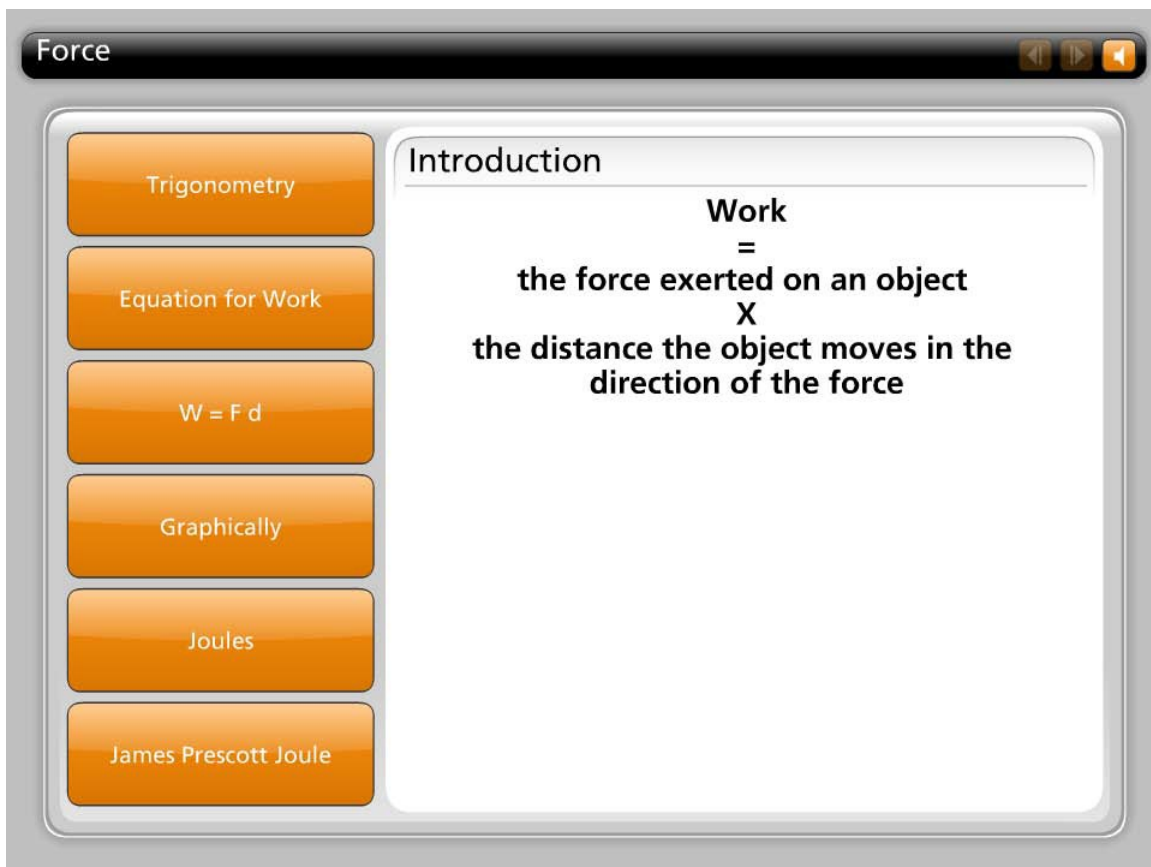
$$\text{Work} = \text{the force exerted on an object} \times \text{the distance the object moves in the direction of the force}$$

As you can see, this very specific definition is likely different from what you thought before studying physics. Most of the time, if you have a good work out, or work hard on your homework or at your job, you don't really accomplish any work as defined in physics.



## Module 4: Energy

### Topic 1 Content: Work and Power



The screenshot shows a software window titled "Force" with a sidebar menu on the left and a main content area on the right. The sidebar menu contains the following items: Trigonometry, Equation for Work,  $W = F d$ , Graphically, Joules, and James Prescott Joule. The main content area is titled "Introduction" and contains the following text:

**Work**  
=  
the force exerted on an object  
**X**  
the distance the object moves in the  
direction of the force

Given that work is the product of the force exerted on an object and the distance the object moves in the direction of the force, you need a method to deal with forces and displacements at any angle.

## Module 4: Energy

### Topic 1 Content: Work and Power

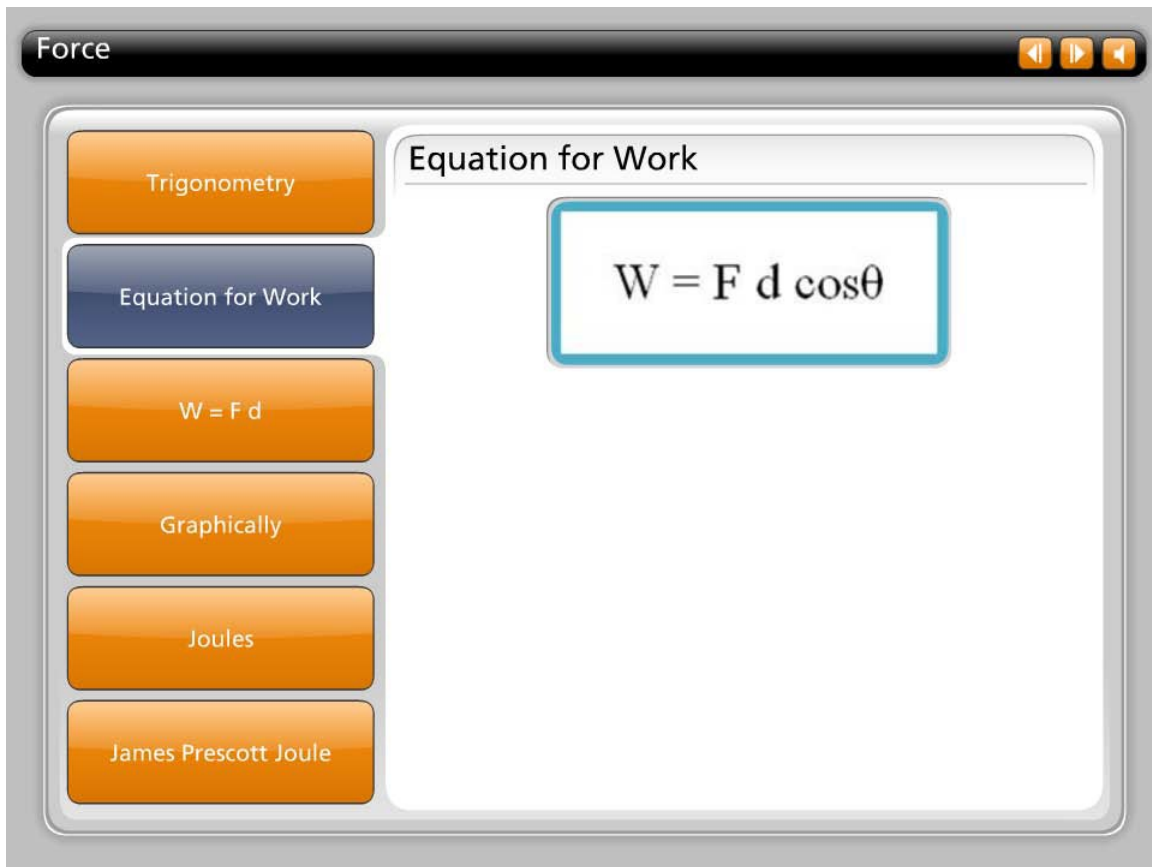
The screenshot shows a software window titled "Force" with a navigation bar on the left containing buttons for "Trigonometry", "Equation for Work", "W = F d", "Graphically", "Joules", and "James Prescott Joule". The "Trigonometry" button is selected, and the main content area displays a table of cosine values for 0°, 90°, and 180°. The table is enclosed in a blue border with a search icon in the bottom right corner.

0°	90°	180°
$\cos(0^\circ) = 1$	$\cos(90^\circ) = 0$	$\cos(180^\circ) = -1$

If you consider the angle between the force vector and the displacement vector, when the angle is zero, you get positive work, when the angle is ninety degrees, you get no work, and when the angle is one hundred eighty degrees, you get negative work. If you remember your trigonometry, you should recognize that the cosine function is equal to one when the angle is zero. It is zero when the angle is ninety degrees, and it is negative one when the angle is one hundred eighty degrees.

## Module 4: Energy

### Topic 1 Content: Work and Power



The screenshot shows a software window titled "Force" with a navigation menu on the left and a main content area on the right. The navigation menu contains the following items: "Trigonometry", "Equation for Work" (highlighted in blue), "W = F d", "Graphically", "Joules", and "James Prescott Joule". The main content area is titled "Equation for Work" and displays the equation  $W = F d \cos\theta$  inside a blue-bordered box.

This lets us see that, in order to handle forces at any angle, our equation for work will be force times distance times the cosine of the angle between the two vectors, or work equals  $f d \cos\theta$ .

## Module 4: Energy

### Topic 1 Content: Work and Power

The image shows a software window titled "Force" with a navigation menu on the left and a main content area on the right. The navigation menu contains six buttons: "Trigonometry", "Equation for Work", "W = F d", "Graphically", "Joules", and "James Prescott Joule". The "W = F d" button is currently selected and highlighted in a darker blue. The main content area displays the equation  $W = F d$  in a large, black, serif font, centered within a light blue rectangular frame. Above the frame, the text "W = F d" is also visible in a smaller font. The window has a standard operating system title bar with a close, maximize, and minimize button on the right.

In the simplest case, when the force and the displacement are in the same direction, this simplifies to work equals force times distance.

## Module 4: Energy

### Topic 1 Content: Work and Power

Force

Trigonometry

Equation for Work

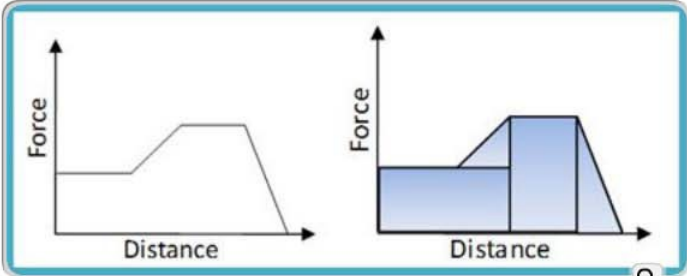
$W = F d$

Graphically

Joules

James Prescott Joule

Graphically



The image displays two side-by-side graphs of Force versus Distance. Both graphs have 'Force' on the vertical axis and 'Distance' on the horizontal axis. The left graph shows a piecewise linear function: it starts with a horizontal line at a constant force, then a line with a positive slope (increasing force), followed by a horizontal line at a higher constant force, and finally a line with a negative slope (decreasing force). The right graph shows the same piecewise linear function, but the area under the curve is shaded in light blue, representing the work done. A magnifying glass icon is visible in the bottom right corner of the graph area.

You could also look at this relationship graphically.

This graph shows a non constant force being applied over a distance. Since work is force times distance, the area under the graph will equal the work done.

## Module 4: Energy

### Topic 1 Content: Work and Power

The screenshot shows a software window titled "Force" with a sidebar on the left containing buttons for "Trigonometry", "Equation for Work", "W = F d", "Graphically", "Joules", and "James Prescott Joule". The "Joules" button is selected. The main content area displays the following equations:

$$1 \text{ Joule} = 1 \text{ N m}$$
$$1 \text{ N} = 1 \frac{\text{kg m}}{\text{s}^2}$$
$$1 \text{ Joule} = 1 \left( \frac{\text{kg m}}{\text{s}^2} \right) \text{ m} = 1 \frac{\text{kg m}^2}{\text{s}^2}$$

The units for work are Joules. Work is equal to force in Newtons times distance in meters times cosine theta, which has no units. A Newton times a meter is defined to be a Joule.

Since a Newton is equal to a kilogram meter per second squared, you can also see that a Joule is equal to a kilogram meter squared per second squared.

Work is also a scalar quantity. Remember that vectors have magnitude and direction, while scalars only have magnitude.

There are two methods of vector multiplication, the dot product and the cross product. The dot product gives a scalar result and the cross product gives a vector result.

When you calculate work you are multiplying the magnitude of the force times the magnitude of the displacement times the cosine of the angle between them. This gives a scalar result.

## Module 4: Energy

### Topic 1 Content: Work and Power

Force

Trigonometry

Equation for Work

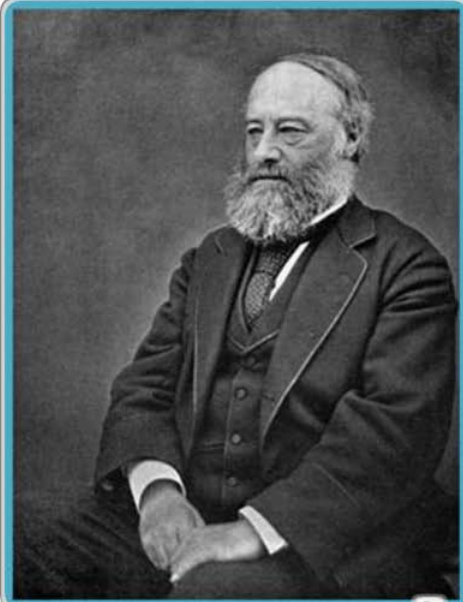
$W = F d$

Graphically

Joules

James Prescott Joule

James Prescott Joule

A black and white portrait of James Prescott Joule, an elderly man with a full white beard, wearing a dark suit and a white shirt with a tie. He is seated and looking slightly to the right of the camera.

The Joule is named after physicist James Prescott Joule who first measured the relationship between mechanical energy and heat. This work, along with his study of heat generated in electric circuits led to the development of the law of conservation of energy. Joule also worked with Lord Kelvin to develop the absolute temperature scale.

# Module 4: Energy

## Topic 1 Content: Work and Power

Examples

Introduction


A Man Lifting a Box

Woman Lowering a Box

Mother Pushing Sled

Force Applied at an Angle

Several Forces Acting at the Same Time



The interface shows a sidebar with five orange buttons: 'A Man Lifting a Box', 'Woman Lowering a Box', 'Mother Pushing Sled', 'Force Applied at an Angle', and 'Several Forces Acting at the Same Time'. The main content area, titled 'Introduction', contains a grid of six images: a man lifting a box, a woman lowering a box, a mother pushing a sled, a waiter carrying a tray, a person pushing a shopping cart, and a person lifting a barbell. A search icon is visible in the bottom right corner of the image grid.

You'll now look back at a few of our earlier examples, but you will add values so that you can calculate work.



## Module 4: Energy

### Topic 1 Content: Work and Power

Examples

A Man Lifting a Box

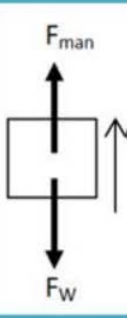
Woman Lowering a Box

Mother Pushing Sled

Force Applied at an Angle

Several Forces Acting at the Same Time

A Man Lifting a Box



The diagram shows a square box with an upward-pointing arrow labeled  $F_{man}$  and a downward-pointing arrow labeled  $F_w$ . To the right of the box, a vertical arrow labeled  $d$  points upwards, indicating the displacement.

$$F_{man} = F_w = mg = (15)(9.8)F$$
$$F_{man} = 147N$$
$$W = Fd \cos(\theta) = 147(1.2)(\cos(0))$$
$$W = 176.4J$$

Example one had a man lifting a box. Let's say that the box has a mass of fifteen kilograms and is lifted to a shelf that is one point two meters high.

The force the man must exert on the box to move it at a constant velocity is the same as the gravitational force on the box, or one hundred forty seven Newtons.

The work done by the man is the force times the distance times the cosine of the angle between the force and the displacement vectors. Since the force and the displacement are in the same direction, this angle is zero and the cosine of zero is one. So our equation basically simplifies to work is force times distance. Substituting and solving you see that the work done is one hundred seventy six point four Joules.

## Module 4: Energy

### Topic 1 Content: Work and Power

Examples

A Man Lifting a Box

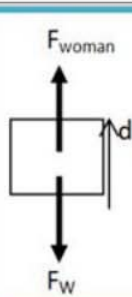
Woman Lowering a Box

Mother Pushing Sled

Force Applied at an Angle

Several Forces Acting at the Same Time

#### Woman Lowering a Box



The diagram shows a rectangular box with two vertical force vectors: an upward arrow labeled  $F_{\text{woman}}$  and a downward arrow labeled  $F_w$ . To the right of the box, a vertical line with a downward-pointing arrow is labeled  $d$ , representing the displacement of the box.

$$F_{\text{woman}} = F_w = mg = (15)(9.8)F$$
$$F_{\text{woman}} = 147\text{ N}$$
$$W = Fd \cos(\theta) = 147(1.2)(\cos(180))$$
$$W = -176.4\text{ J}$$

You also had an example of the woman lowering the box to the floor. If you assume the same box and the same shelf, the woman still must provide an upward force of one hundred forty seven Newtons to keep the box from falling as he lowers it. The force is up but the displacement is down, with an angle of one hundred eighty degrees between them. The cosine of one hundred eighty degrees is negative one. The amount of work therefore works out to negative one hundred seventy six point four Joules.

## Module 4: Energy

### Topic 1 Content: Work and Power

Examples

A Man Lifting a Box

Woman Lowering a Box

Mother Pushing Sled

Force Applied at an Angle

Several Forces Acting at the Same Time

#### Mother Pushing Sled

$$W = Fd\cos\theta = (50)(2)\cos(0) = 100 \text{ J}$$

Another earlier example had a mother pushing a sled, to get it moving. Let's say that the sled has a mass of seventy five kilograms and the mother pushes with a force of fifty Newtons over a distance of two meters to get it moving.

In this case, there are three forces acting on the sled. The gravitational force pulls down, the normal force pushes up, perpendicular to the surface, and the mother's push acts to the right.

You are interested in the amount of work done by the mother, so you are only interested in the push force of fifty Newtons. This is also the only force acting in the direction of motion.

The normal force and the gravitational force are both perpendicular to the displacement. So no work is done by either of these forces. Only the fifty Newton force of the mother on the sled does any work.

The work done is the force times the distance times the cosine of the angle between them. The angle is zero, which makes the cosine equal to one. This results in one hundred Newtons of work being done by the mom.

## Module 4: Energy

### Topic 1 Content: Work and Power

Examples

A Man Lifting a Box

Woman Lowering a Box

Mother Pushing Sled

Force Applied at an Angle

Several Forces Acting at the Same Time

#### Force Applied at an Angle

$$W = Fd\cos\theta$$
$$W = (45)(15)(\cos 60) = 337.5 \text{ N}$$

Now let's see what happens when the force is applied at an angle to the direction of motion.

Jacob, a stage manager, pushes a broom across a fifteen meter wide stage at a constant speed by applying a forty five Newton force along the handle of the broom, which makes an angle of sixty degrees to the horizontal. How much work does Jacob do on the broom?

A free body diagram of the broom demonstrates that there are several forces acting on the broom. You are only interested in the force applied by Jacob.

This force is at an angle of sixty degrees to the displacement. When you substitute these values into the work equation you see that work equals three hundred thirty seven point five Joules.

This is the work done by Jacob, which answers the original question. But it is interesting to note that there are other forces also acting on the broom. The normal force and the gravitational force both are acting perpendicular to the displacement of the broom, so no work is done by them, but friction acts opposite the direction of motion and therefore will do negative work.

## Module 4: Energy

### Topic 1 Content: Work and Power

Examples

A Man Lifting a Box

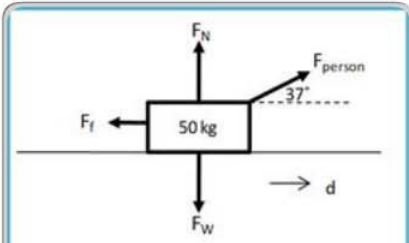
Woman Lowering a Box

Mother Pushing Sled

Force Applied at an Angle

Several Forces Acting at the Same Time

#### Several Forces Acting at the Same Time



$W_G = mg \, d \cos 90^\circ = 0$   
 $W_N = F_N \, d \cos 90^\circ = 0$   
Work done by Ellen:  
 $W_P = F_P \, d \cos \theta = (100)(40) \cos 37^\circ = 3200 \text{ J}$   
Work done by friction:  
 $W_f = F_f \, d \cos 180^\circ = (50)(40)(-1) = -2000 \text{ J}$   
Friction does negative work!  
Total Work done:  
 $3200 \text{ J} + (-2000 \text{ J}) = 1200 \text{ J}$

To see how you account for the work done by several forces acting at the same time, let's look at another example.

Suppose Ellen pulls a fifty kilogram crate forty meters along a horizontal floor by applying a constant force of one hundred Newtons at an angle of thirty seven degrees above the horizontal. If the constant force of friction is fifty Newtons, what is work done on crate by each force? What is the total work done on the crate?

There are four forces acting on the crate. Ellen's pull force, Friction, the normal force, and the gravitational force.

Both the normal force and gravitational force do no work as they are perpendicular to motion.

Ellen applies a force of one hundred Newtons to the crate at an angle of thirty seven degrees as it moves a horizontal distance of forty meters. This results in thirty two hundred Joules of work done by Ellen.

Friction applies a force of fifty Newtons directly opposite the direction of motion, or at an angle of one hundred eighty degrees. This gives us negative two thousand Joules of work done by friction.

The total work done to the crate is thirty two hundred plus negative two thousand, or twelve hundred Joules.

## Module 4: Energy

### Topic 1 Content: Work and Power

Examples

A Man Lifting a Box

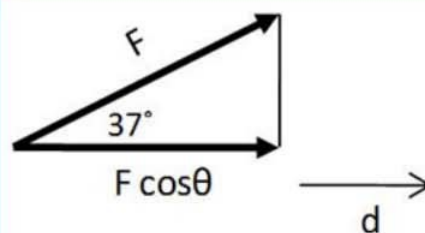
Woman Lowering a Box

Mother Pushing Sled

Force Applied at an Angle

Several Forces Acting at the Same Time

Summary

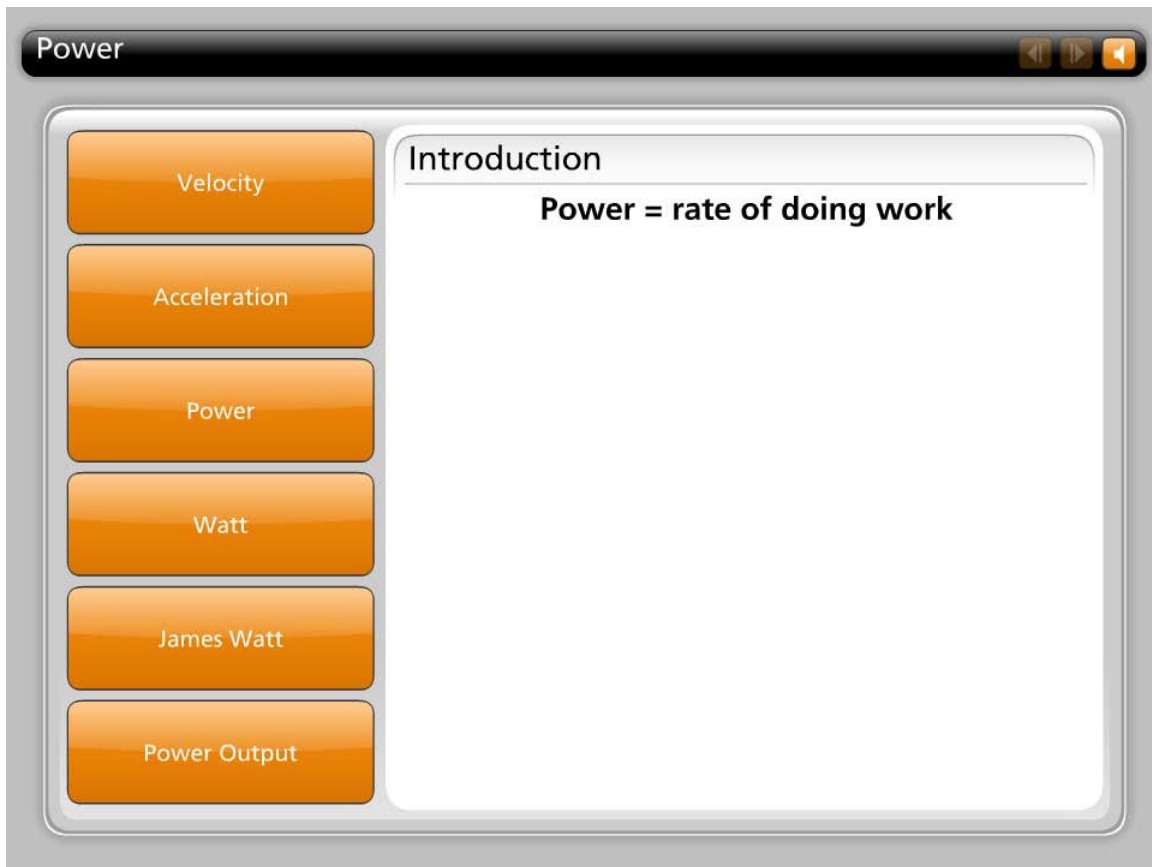


$W = (F d) \cos \theta = F d \cos \theta$   
 $W = (F \cos \theta) d = F d \cos \theta$

When looking at forces applied at an angle, you could also calculate the component of the force that acts in the direction of motion, then multiply this by the displacement. But whether you multiply force by displacement, then multiply by the cosine of the angle, or multiply the force by the cosine of the angle to get the horizontal component, then multiply by the displacement, you wind up with  $F d \cos \theta$ .

## Module 4: Energy

### Topic 1 Content: Work and Power



The image shows a presentation slide titled "Power". On the left side, there is a vertical list of six orange buttons with white text: "Velocity", "Acceleration", "Power", "Watt", "James Watt", and "Power Output". The "Power" button is currently selected. The main content area on the right is titled "Introduction" and contains the text "Power = rate of doing work".

Another quantity you are interested in measuring is power. Power is the rate of doing work.

## Module 4: Energy

### Topic 1 Content: Work and Power

The screenshot shows a software interface with a title bar labeled "Power" and navigation icons. On the left is a vertical sidebar with six buttons: "Velocity" (highlighted in blue), "Acceleration", "Power", "Watt", "James Watt", and "Power Output". The main content area is titled "Velocity" and contains the text "velocity = rate that position changes" and the equation  $v = \frac{\Delta x}{t}$ . A search icon is located at the bottom right of the content area.

Remember that velocity is the rate of change in position. You write velocity as change in position divided by time.



## Module 4: Energy

### Topic 1 Content: Work and Power

The screenshot shows a software window titled "Power" with a sidebar on the left containing six buttons: "Velocity", "Acceleration" (highlighted in blue), "Power", "Watt", "James Watt", and "Power Output". The main content area is titled "Acceleration" and contains the text "acceleration = rate that velocity changes" and the equation  $a = \frac{\Delta v}{t}$ . A magnifying glass icon is located at the bottom right of the text box.

Acceleration is the rate of change in velocity. You write acceleration as change in velocity divided by time.

## Module 4: Energy

### Topic 1 Content: Work and Power

The screenshot shows a software window titled "Power" with a navigation bar at the top containing three icons: a double left arrow, a right arrow, and a double right arrow. On the left side, there is a vertical list of six orange buttons: "Velocity", "Acceleration", "Power" (which is highlighted in a darker blue), "Watt", "James Watt", and "Power Output". The main content area on the right is titled "Power" and contains a large blue-bordered box with the equation  $P = \frac{W}{t}$  displayed in the center.

Anytime you talk about rate, you mean the change in that quantity divided by the time required for that change to happen. This is also true for power. Power is work divided by time.

## Module 4: Energy

### Topic 1 Content: Work and Power

The screenshot shows a software window titled "Power" with a sidebar of buttons: Velocity, Acceleration, Power, Watt (selected), James Watt, and Power Output. The main content area, titled "Watt", contains the following equations:

$$1 \text{ Watt} = 1 \frac{\text{Joule}}{\text{second}}$$
$$1 \text{ Joule} = 1 \text{ N m} = 1 \frac{\text{kg m}^2}{\text{s}^2}$$
$$1 \text{ Watt} = 1 \left( \frac{\text{kg m}^2}{\text{s}^2} \right) \left( \frac{1}{\text{s}} \right) = 1 \frac{\text{kg m}^2}{\text{s}^3}$$

A Watt is defined as one Joule per second. Power is expressed in Watts.

Since a Joule is equal to a kilogram meter squared per second squared, if you divide this again by seconds, you see that a Watt is a kilogram meter squared per second cubed in standard units.

## Module 4: Energy

### Topic 1 Content: Work and Power

Power

Velocity

Acceleration

Power

Watt

James Watt

Power Output

James Watt

A portrait of James Watt, a Scottish inventor and engineer, shown in a dark coat and white cravat, sitting at a desk with papers and a quill pen.

The Watt is named in honor of James Watt, a Scottish inventor and engineer whose improvement of the efficiency of the steam engine made it a powerful tool in the industrial revolution.

Image Source: <http://en.wikipedia.org>

## Module 4: Energy

### Topic 1 Content: Work and Power

The screenshot shows a software window titled "Power" with a sidebar on the left containing buttons for "Velocity", "Acceleration", "Power", "Watt", "James Watt", and "Power Output". The "Power Output" button is selected. The main area displays the formula  $P = \frac{W}{t} = \frac{3200 J}{16 s} = 200 \text{ Watts}$  in a blue-bordered box. Below the box, the values  $W = 3200 J$  and  $t = 16 s$  are listed.

Looking back at our last example where Ellen did thirty two hundred Joules of work pulling the box, if this took sixteen seconds to accomplish, what was Ellen's power output?

Since power is work divided by time, you see that Ellen delivered two hundred watts of power.

## Module 4: Energy

### Topic 1 Content: Work and Power

Power

Velocity

Acceleration

Power

Watt

James Watt

Power Output

### Summary

$Work = F d \cos\theta$   
measured in Joules

positive work      no work      negative work

$Power = \frac{Work}{time}$   
measured in Watts

In summary, work is the product of the force on an object and the distance the object moves in the direction of the force. Work is measured in Joules.

In the simplest case, when force and displacement are in the same direction work equals force times distance.

When force and displacement are not in the same direction, work equals force times distance times cosine theta.

Theta is the angle between the force and displacement vectors. If the force and displacement are in the same direction, then positive work is done. If the force is perpendicular to the displacement, no work is done. If the force points opposite the direction of motion, then negative work is done, and if the force is at an angle, the cosine will help you to calculate the work done.

Power is simply work divided by time. Power is measured in Watts.