Unit Three - Work, Energy, Power

Energy is a concept we are both familiar with, and perplexed by.

We can understand that a hot fire, gives off heat (thermal energy). We can accept that something that is moving must have energy or it wouldn't move. We can accept that wood has a stored energy, and when it is burned it releases that energy.

What we have difficulty seeing is how energy transforms, and moves throughout a system.

In it's most simplest idea, everything has energy, and is made up of energy.

Our goal in this unit is to start to refine the idea of Mechanical Energy, which will involve three concepts: Work, Kinetic Energy, and Gravitational Potential Energy.

Please understand, this concept will evolve drastically as you learn more.

Section 5.1 - Work

"Work" is another word that has very different meanings in the science world and the everyday world.

"Mechanical" Work is done by applying a force over a distance.

For example, pushing a heavy object across a floor requires mechanical work.

To calculate the concept we call WORK, we multiply the applied Force magnitude times the **displacement.**

Work = Force x Displacement or $W = F \Delta d$

Work is a Scalar (magnitude, no direction) even though it has two vectors being multiplied together. (we'll return to this in Calculus)

The SI unit of work is a Newton-Meter (N·m) also called a Joule.

1 Joule = 1 N·m

A new weight training program is based on the amount of WORK you do in a workout session.

Training Plan 1 involves carrying a heavy weight of 50kg up a flight of stairs that rises 5 meters.

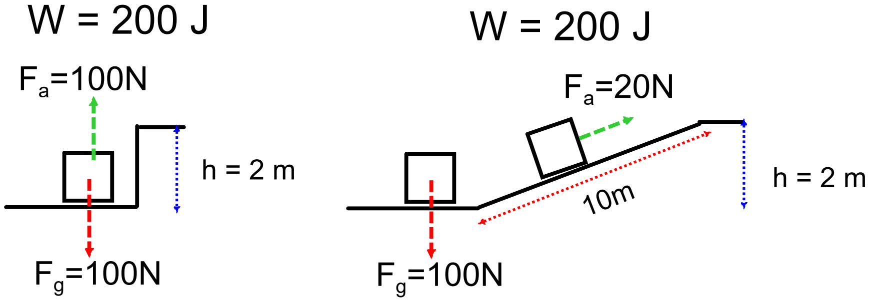
Training Plan 2 involves carrying a medium weight of 20kg up a flight of stairs that rises 12.5 meters.

Training Plan 3 involves carrying a light weight of 5 kg up a flight of stairs that rises 50 meters.

Which training plan involves the most WORK?

$W = F \Delta d$

A Ramp is a simple machine that utilizes the work equation. A ramp increases the distance travelled, which results in a smaller force required.



A wood screw is a ramp that has been wrapped around an axis.

Sample Problem 2

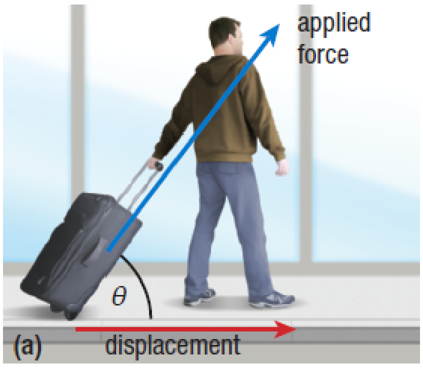
A curler applies a force of 15.0 N on a curling stone and accelerates the stone from rest to a speed of 8.00 m/s in 3.50 s. Assuming that the ice surface is level and frictionless, how much mechanical work does the curler do on the stone?

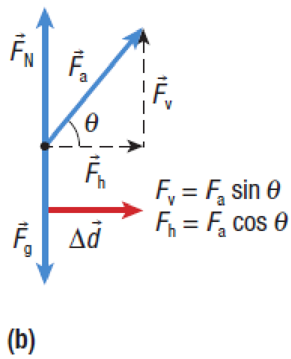
Practice

1. A 0.50 kg laboratory dynamics cart with an initial velocity of 3.0 m/s [right] accelerates for 2.0 s at 1.2 m/s^2 [right] when pulled by a string. Assume there is no friction acting on the cart. T/I
   (a) Calculate the force exerted by the string on the cart.
   (b) Calculate the displacement of the cart.
   (c) Calculate the mechanical work done by the string on the cart.

What happens when the Force and the direction of Displacement are not in the same direction?

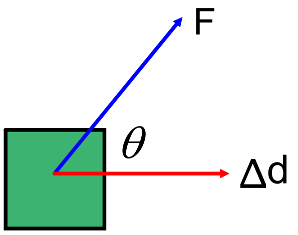
Welcome back the idea of components! Yaaaah!





When the force and the displacement are NOT aligned, we need to use a revised Work equation that uses just the component of Force that is in the direction of the displacement.(Θ is the angle between the force and displacement)

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



LEARNING TIP

Dot Products
The scalar product of two vectors is commonly indicated by placing a dot between the vector symbols (e.g., $W = \vec{F}\cdot\Delta\vec{d}$) and unit symbols (N·m). It is for this reason that a scalar product is sometimes called a dot product. A dot product may also be represented by using scalar symbols without the dot between them (as we do in this book), $W = F\Delta d$.

CASE 1:
An object is displaced by a force that has a component in the direction of the displacement

Sample Problem 1

Calculate the mechanical work done by a custodian on a vacuum cleaner if the custodian exerts an applied force of 50.0 N on the vacuum hose and the hose makes a 30.0° angle with the floor. The vacuum cleaner moves 3.00 m to the right on a level, flat surface. The system diagram for this problem is shown in **Figure 4**.

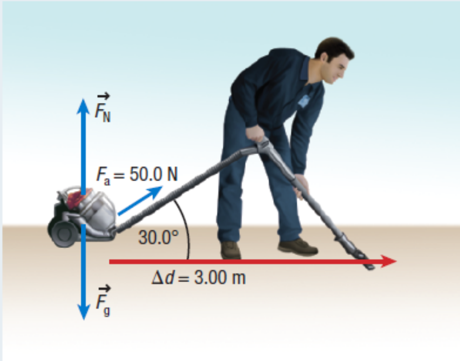


Figure 4

Case 2:
An object is displaced, but there is no force or component of a Force in the direction of the displacement

Sample Problem 2

Ranbir wears his backpack as he walks forward in a straight hallway. He walks at a constant velocity of 0.8 m/s for a distance of 12 m. How much mechanical work does Ranbir do on his backpack?

Consider the system diagram shown in **Figure 5**. Ranbir walks at constant velocity. Thus, there is no acceleration in the direction of displacement and no applied force on the backpack in that direction. The only applied force on the backpack is the force that Ranbir's shoulders apply on the backpack ($\vec{F}_a$) to oppose the force of gravity on the backpack ($\vec{F}_g$, the backpack's weight). However, neither the applied force nor the force of gravity does work on the backpack because both forces are perpendicular to the displacement. Therefore, Ranbir does no mechanical work at all on the backpack.

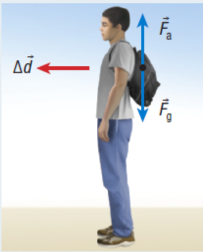


Figure 5

Practice

1. A person cutting a flat lawn pushes a lawnmower with a force of 125 N at an angle of 40.0° below the horizontal for 12.0 m. Determine the mechanical work done by the person on the lawnmower. T/I
2. A father pulls a child on a toboggan along a flat surface with a rope angled at 35.0° above the horizontal. The total mechanical work done by the father over a horizontal displacement of 50.0 m is 2410 J. Determine the work done on the toboggan by the normal force and the force of gravity, and explain your reasoning. T/I

IS Work Done when a Force Fails to Displace an Object?

In some cases, a force is applied on an object, but the object does not move: no displacement occurs. For example, when you stand on a solid floor, your body applies a force on the floor equal to your weight, but the floor does not move. Your body does no work on the floor because the floor is not displaced.

Sample Problem 1

How much mechanical work is done on a stationary car if a student pushing with a 300 N force fails to displace the car?

Given: $F_a = 300$ N; $\Delta d = 0$ m

Required: W

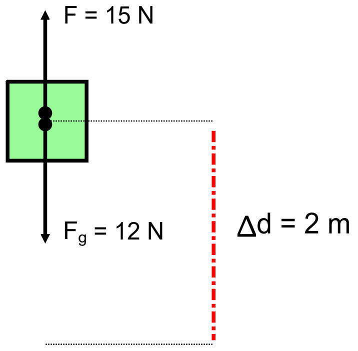
Analysis: $W = F\Delta d$

Positive and Negative Work (Parts vs System)

Sometimes and object has more than one force acting on it.

The act of picking up a book has an applied force [up] to lift the book and a downward force of gravity.

In cases such as this, the TOTAL work done is the algebraic sum of the work done by all of the forces acting on the object.



Work = 15 x 2
= 30 J

Work done by the applied force

Work = -12 x 2
= -24 J

Work done by the gravity force

Total (Net) Work = 30 - 24
= 6 J

Practice

1. Curtis pushes a bowl of cereal along a level counter a distance of 1.3 m. What is the net work done on the bowl if Curtis pushes the bowl with a force of 4.5 N and the force of friction on the bowl is 2.8 N? T/I
2. A crane lifts a 450 kg beam 12 m straight up at a constant velocity. Calculate the mechanical work done by the crane. T/I

Graphing Work Done - Positive and Negative Values - Force vs Distance Graph

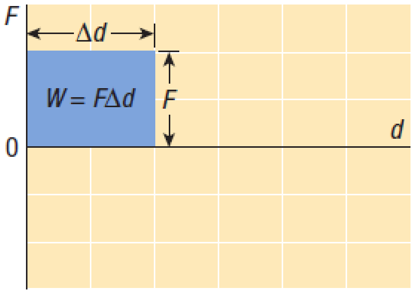


Figure 7 *F–d* graph for a constant force acting through a displacement

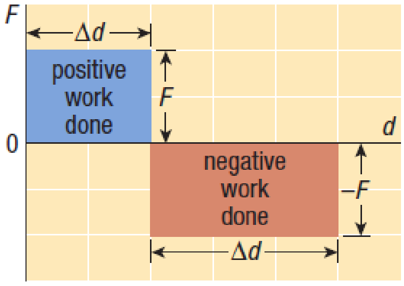


Figure 8 *F–d* graph representing positive and negative work done

The AREA of the bar graph is the amount of WORK done.
(Just like the area of a rectangle is given by base x height)

Work Done by a Changing Force - Force vs Distance Graph

The equation $W = F\Delta d$ or $W = F(\cos\theta)\Delta d$ can be used only to calculate the mechanical work done on an object when the force on the object is constant.
However, in many cases, a force varies in magnitude during a displacement. For example, when a bus driver steadily depresses the accelerator pedal of a bus, the force the engine applied on the wheels increases uniformly. The force is not constant. The work done on an object by a changing force that is in the same direction as the object's displacement may be represented using an F-d graph. Figure 9 shows an F-d graph for a uniformly increasing force. As in the case of a constant force, the work done is equal to the area under the F-d graph. In this case, the work done, W, is equal in value to the product $F_{av}\Delta d$. Fav represents the average force applied to the object as it is displaced.

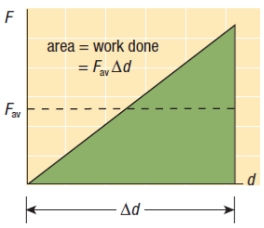


Figure 9 *F–d* graph representing a uniformly increasing force

The AREA under the triangle is the amount of WORK done.

5.1 Questions

1. A 25.0 N applied force acts on a cart in the direction of the motion. The cart moves 13.0 m. How much work is done by the applied force? T/I
2. A tow truck pulls a car from rest onto a level road. The tow truck exerts a horizontal force of 1500 N on the car. The frictional force on the car is 810 N. Calculate the work done by each of the following forces on the car as the car moves forward 12 m: T/I
   (a) the force of the tow truck on the car
   (b) the force of friction
   (c) the normal force
   (d) the force of gravity
3. A child pulls a wagon by the handle along a flat sidewalk. She exerts a force of 80.0 N at an angle of 30.0° above the horizontal while she moves the wagon 12 m forward. The force of friction on the wagon is 34 N. T/I
   (a) Calculate the mechanical work done by the child on the wagon.
   (b) Calculate the total work done on the wagon.
4. A horizontal rope is used to pull a box forward across a rough floor doing 250 J of work over a horizontal displacement of 12 m at a constant velocity. T/I C
   (a) Draw an FBD of the box.
   (b) Calculate the tension in the rope.
   (c) Calculate the force of friction and the work done by the force of friction. Explain your reasoning.
5. A 62 kg person in an elevator is moving up at a constant speed of 4.0 m/s for 5.0 s. T/I C
   (a) Draw an FBD of the person in the elevator.
   (b) Calculate the work done by the normal force on the person.
   (c) Calculate the work done by the force of gravity on the person.
   (d) How would your answers change if the elevator were moving down at 4.0 m/s for 5.0 s?
7. A rope pulls a 2.0 kg bucket straight up, accelerating it from rest at 2.2 m/s^2 for 3.0 s. T/I
   (a) Calculate the displacement of the bucket.
   (b) Calculate the work done by each force acting on the bucket.
   (c) Calculate the total mechanical work done on the bucket.
   (d) Calculate the net force acting on the bucket and the work done by the net force. Compare your answer to the total mechanical work done on the bucket as calculated in (c).
8. In your own words, explain if mechanical work is done in each of the following cases: K/U C
   (a) A heavy box sits on a rough horizontal counter in a factory.
   (b) An employee pulls on the box with a horizontal force and nothing happens.
   (c) The same employee goes behind the box and pushes even harder, and the box begins to move. After a few seconds, the box slides onto frictionless rollers and the employee lets go, allowing the box to move with a constant velocity.

Section 5.1

#1,2,3,7,8