Conceptual Physics
Energy

Lana Sheridan

De Anza College

July 12, 2017

Last time

- Newton's third law
- momentum
- impulse
- momentum conservation

Overview

- energy
- work
- kinetic energy
- potential energy
- energy conservation
- energy transfer
- simple machines
- efficiency

Energy

Energy is almost impossible to clearly define, yet everyone has a good intuitive notion of what it is.

Energy is a property of physical systems. It tells us something about the states or configurations the system can be in. In fact, it is possible to find the dynamics of a system purely from understanding the distribution of energy in the system.

Energy

Energy is almost impossible to clearly define, yet everyone has a good intuitive notion of what it is.

Energy is a property of physical systems. It tells us something about the states or configurations the system can be in. In fact, it is possible to find the dynamics of a system purely from understanding the distribution of energy in the system.

Importantly, it can neither be created or destroyed, but it can be transferred between systems, and take different forms.

Types of Energy

- motional energy (kinetic)

- energy as a result of object's configurations or stored energy (potential)

- heat, light, sound - can carry away energy from a mechanical system

Types of Energy

Work is a kind of energy transfer to an object.

Work is written with the symbol, W, and its units are Joules, J.

$1\ \text{J} = 1\ \text{N m}$.

Types of Energy

Work is a kind of energy transfer to an object.

Work is written with the symbol, W, and its units are Joules, J.

$1\ \text{J} = 1\ \text{N m}$.

Work is defined as

$$\text{Work} = \text{Force} \times \text{distance}$$

Types of Energy

Work is a kind of energy transfer to an object.

Work is written with the symbol, W, and its units are Joules, J.

$1 \text{ J} = 1 \text{ N m}$.

Work is defined as

$$\text{Work} = \text{Force} \times \text{distance}$$

(We will make this more precise in a minute.)

Work is a scalar quantity (not a vector).

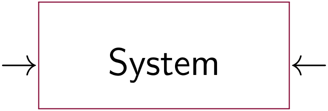
Systems and Environments

To make some predictions about physical objects, you must identify a *system* of interest. Some object (or collection of objects).

System

Systems and Environments

To make some predictions about physical objects, you must identify a *system* of interest. Some object (or collection of objects).

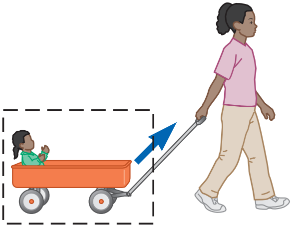


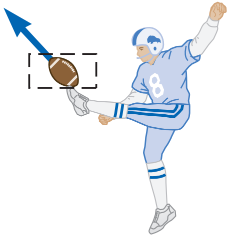
Everything outside the system is the system's *environment*.

Energy can be transferred from the environment to the system, or vice versa.

Forces on systems

Force type examples:





We can choose the system to be what is inside the dotted lines and the environment to be what is outside.

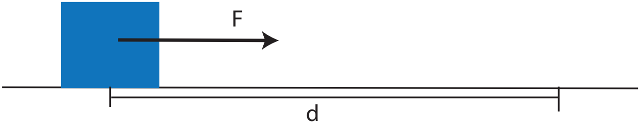
[1]Serway & Jewett

Work

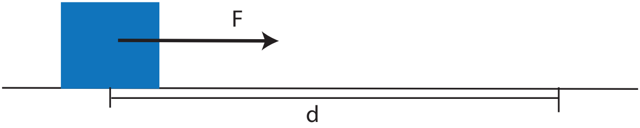
Let's consider how the environment can effect the system by exchanging energy with it.

Take the *system* to be a block.

An external force F (from the *environment*) acts on it.



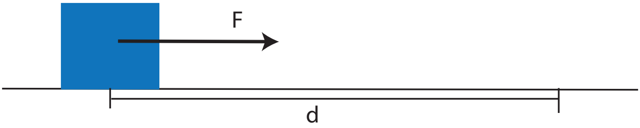
Work



This force affects the block: it can accelerate it.

It can also change the energy of the block.

Work

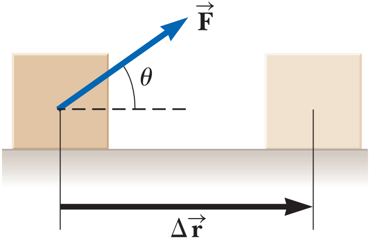


If the force is constant and moves the block through a distance d in the direction of the force, we say the force F has done work on the block:

$$W = F\, d$$

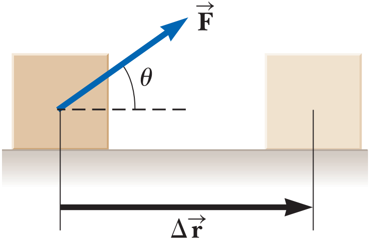
Work

Consider a more general case where the force is not pointed in the same direction as the movement of the block.



In this case, we must generalize the expression for work.

Work



For a constant force applied at an angle θ to the direction of the displacement of the block Work is defined as:

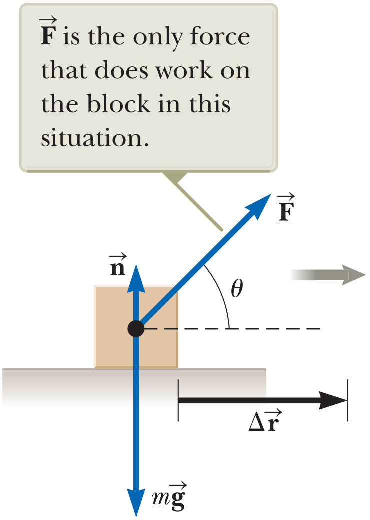
$$W = F\, d \cos\theta$$

Work

If there are several forces acting on a system, each one can have an associated work.

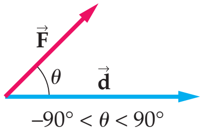
In other words, we can ask what is the work done on the system by each force separately. The *net work* is the work done by the net force (if the system can be modeled as a particle). It is also the sum of all the individual works.

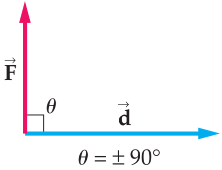
Work done by individual forces

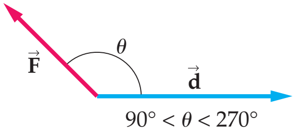


More about Work

Work can be positive or negative!







$W = Fd\cos\theta > 0$

positive work

$W = Fd\cos\theta = 0$

zero work

$W = Fd\cos\theta < 0$

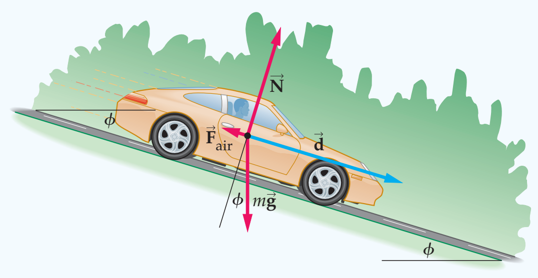
negative work

For work done *on* a system:

- Positive $\Rightarrow$ energy is transferred *to* the system.
- Negative $\Rightarrow$ energy is transferred *from* the system.

Question

A car coasts down a hill that makes an angle ϕ to the horizontal.



The work done by the weight ($m\mathbf{g}$ force) is

(A) positive

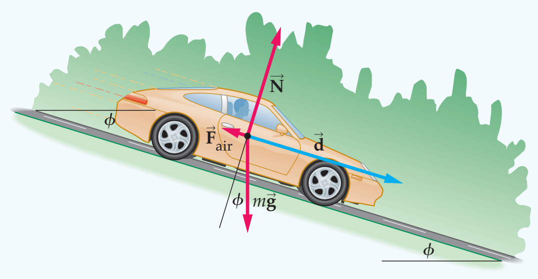
(B) negative

(C) zero

(D) cannot be determined

Question

A car coasts down a hill that makes an angle ϕ to the horizontal.



The work done by the weight ($m\mathbf{g}$ force) is

(A) positive ←

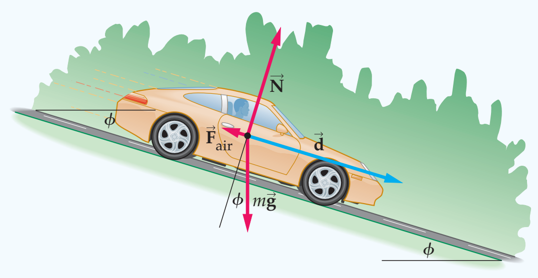
(B) negative

(C) zero

(D) cannot be determined

Question

A car coasts down a hill that makes an angle ϕ to the horizontal.



The work done by the normal force, **N**, is

(A) positive

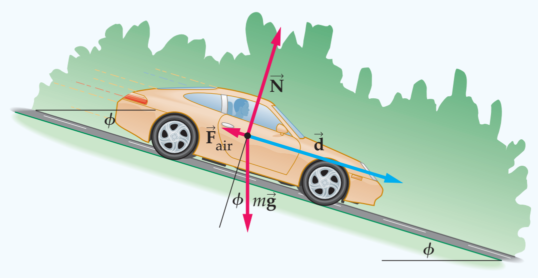
(B) negative

(C) zero

(D) cannot be determined

Question

A car coasts down a hill that makes an angle ϕ to the horizontal.



The work done by the normal force, **N**, is

(A) positive

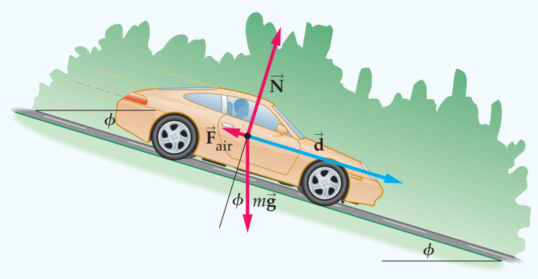
(B) negative

(C) zero ←

(D) cannot be determined

Question

A car coasts down a hill that makes an angle ϕ to the horizontal.



The work done by the air resistance ($\mathbf{F}_{air}$ force) is

(A) positive

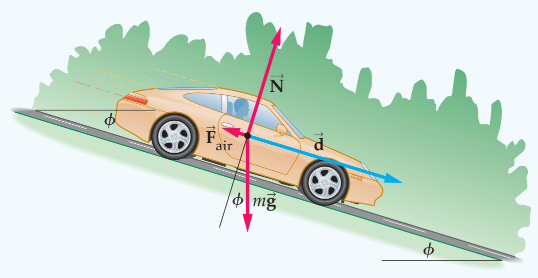
(B) negative

(C) zero

(D) cannot be determined

Question

A car coasts down a hill that makes an angle ϕ to the horizontal.



The work done by the air resistance ($\mathbf{F}_{air}$ force) is

(A) positive

(B) negative ←

(C) zero

(D) cannot be determined

Question

The gravitational force exerted by the Sun on the an asteroid holds the asteroid in an orbit around the Sun. The work done by someone applying a force to move the asteroid further away from the Sun is

(A) zero

(B) positive

(C) negative

(D) impossible to determine

Question

The gravitational force exerted by the Sun on the an asteroid holds the asteroid in an orbit around the Sun. The work done by someone applying a force to move the asteroid further away from the Sun is

(A) zero

(B) positive $\leftarrow$

(C) negative

(D) impossible to determine

Question

The gravitational force exerted by the Sun on the an asteroid holds the asteroid in an orbit around the Sun. The work done by the force of gravity on the asteroid as the asteroid moves further away from the Sun is

(A) zero

(B) positive

(C) negative

(D) impossible to determine

Question

The gravitational force exerted by the Sun on the an asteroid holds the asteroid in an orbit around the Sun. The work done by the force of gravity on the asteroid as the asteroid moves further away from the Sun is

(A) zero

(B) positive

(C) negative $\leftarrow$

(D) impossible to determine

Question

The gravitational force exerted by the Sun on the Earth holds the Earth in an orbit around the Sun. Let us assume that the orbit is perfectly circular. The work done by this gravitational force during a short time interval in which the Earth moves through a displacement in its orbital path is

(A) zero

(B) positive

(C) negative

(D) impossible to determine

[1] Serway and Jewett, page 180.

Question

The gravitational force exerted by the Sun on the Earth holds the Earth in an orbit around the Sun. Let us assume that the orbit is perfectly circular. The work done by this gravitational force during a short time interval in which the Earth moves through a displacement in its orbital path is

(A) zero $\leftarrow$

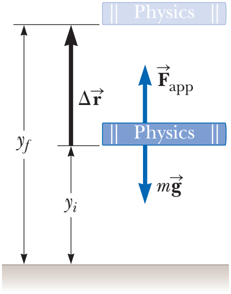
(B) positive

(C) negative

(D) impossible to determine

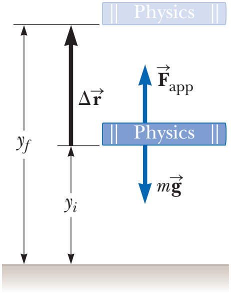
[1]Serway and Jewett, page 180.

Work Example



What is the work done to lift a 1 kg physics book 30 cm?

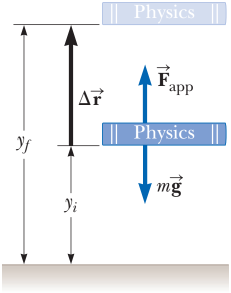
Work Example



What is the work done to lift a 1 kg physics book 30 cm?

$$W = Fd$$

Work Example



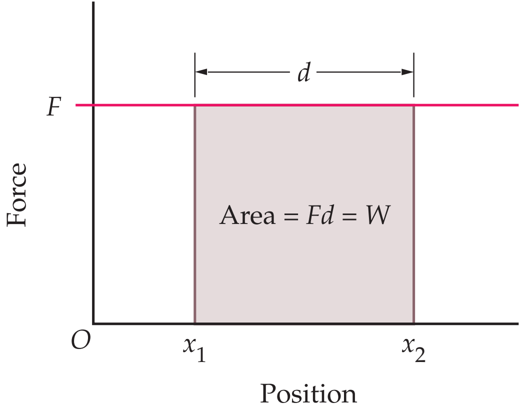
What is the work done to lift a 1 kg physics book 30 cm?

$$
\begin{aligned}
W &= Fd \\
&= mgd \\
&= (1\ \text{kg})(10\ \text{m/s})(0.3\ \text{m}) \\
&= 3.0\ \text{J}
\end{aligned}
$$

Work Done and Force-Displacement Graphs

We can understand that the work done by a force is the area under the **force-displacement** curve.

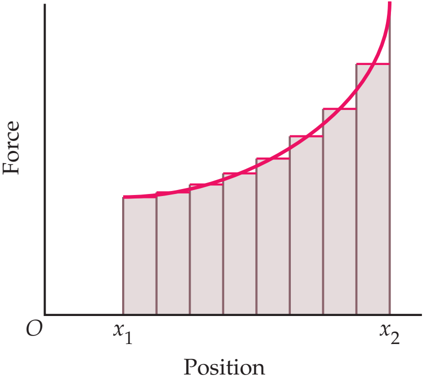
Plotting a constant force F as a function of x ($\Delta x = d$), $F(x)$:



[0] Figure from James S. Walker, "Physics".

Work Done by a Variable Force

When $F(x)$ is not constant, we can approximate the area under the curve by breaking it up into rectangles and adding the area of each rectangle.



[0]Figure from James S. Walker, "Physics".

Power

Power

the rate at which work can be done.

$$\text{Power} = \frac{\text{work done}}{\text{time interval}}$$

Power

Power

the rate at which work can be done.

$$\text{Power} = \frac{\text{work done}}{\text{time interval}}$$

Units: Watts, W.

$1\ \text{W} = 1\ \text{J/s}$

Power Example

A motor can lift a crate 20 m in 10 s.

If the motor is replaced with a new motor with twice as much power, how long does it take to lift the crate now?

If the new motor was used to lift a crate that was twice as heavy, how long would it take to lift the second crate?

Kinetic Energy

kinetic energy

energy that a system has as a result of its motion

To do work, we apply a force, a force can cause an acceleration.

$$F = ma$$

Kinetic Energy

$$\text{Kinetic Energy} = \tfrac{1}{2}\ \text{mass} \times \text{speed}^2$$

or, calling the kinetic energy K,

$$K = \frac{1}{2}mv^2$$

Kinetic Energy

$$\text{Kinetic Energy} = \tfrac{1}{2}\ \text{mass} \times \text{speed}^2$$

or, calling the kinetic energy K,

$$K = \frac{1}{2}mv^2$$

Notice that this means that if the speed of an object is doubled, it's kinetic energy quadruples!

Work and Kinetic Energy

The fact that doing work on an object can increase its kinetic energy leads to an important relation.

Work-Kinetic Energy theorem

The net work done by all external forces is equal to the change in the kinetic energy of the system.

$$W_{\text{net}} = \Delta K$$

Question

A dart is inserted into a spring-loaded dart gun and then released so that work W is done by the spring as the dart is fired. If the gun is reloaded and the spring is compressed further so that it now does work $4W$ on the dart, how much faster does the second dart leave the gun compared with the first?

(A) four times as fast

(B) two times as fast

(C) the same

(D) half as fast

[1] Modified from question in Serway and Jewett, 9th ed.

Question

A dart is inserted into a spring-loaded dart gun and then released so that work W is done by the spring as the dart is fired. If the gun is reloaded and the spring is compressed further so that it now does work $4W$ on the dart, how much faster does the second dart leave the gun compared with the first?

(A) four times as fast

(B) two times as fast $\leftarrow$

(C) the same

(D) half as fast

[1] Modified from question in Serway and Jewett, 9th ed.

Potential Energy

potential energy

energy that a system has as a result of its configuration; stored energy

There are different kinds of potential energy

- gravitational
- elastic
- chemical

Potential Energy

The only form that we will use to solve problems in this course is gravitational potential energy.

An object at some height above the ground can be said to have potential energy.

This is reasonable because if we dropped the object it would accelerate and develop kinetic energy.

$$\text{Potential energy} = \text{weight} \times \text{height}$$

Using the symbol U for potential energy:

$$U = mgh$$

Mechanical Energy

mechanical energy

the useful energy in a system; the sum of kinetic and potential energy

$$E_{\text{mech}} = K + U$$

Mechanical energy is "useful" because it can be used to do work.

Conservation of Energy

Just like momentum, the total amount of energy in an isolated system is constant: it can't change!

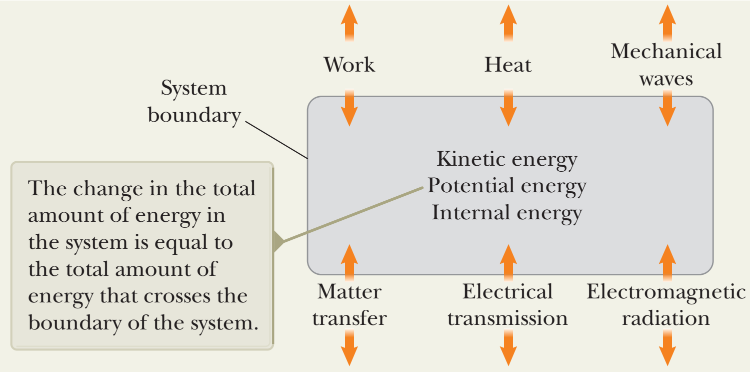
Energy cannot be created or destroyed, though it can be changed from one form into another.

For example, potential energy can be changed to kinetic energy, and back to potential, but you will never find more than you started with.

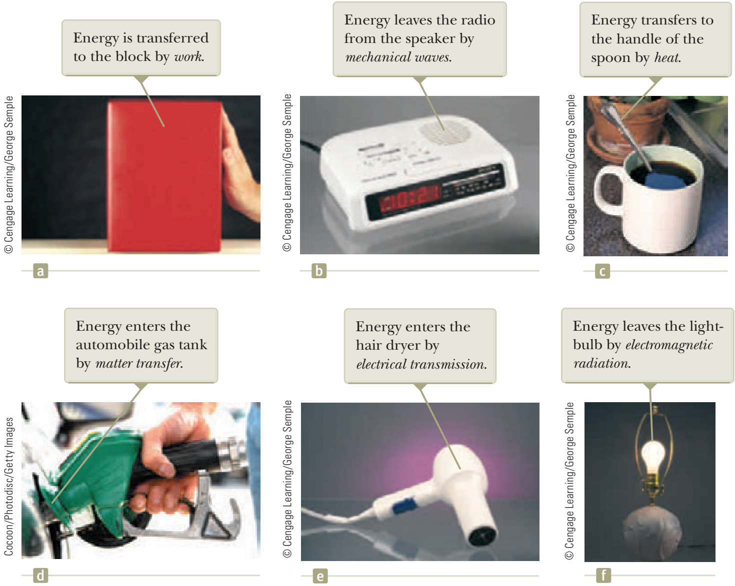
Conservation of Energy and a Nonisolated system

Just like momentum, the total amount of energy in an isolated system is constant: it can't change!

Energy can be transferred into a system if it is not isolated.

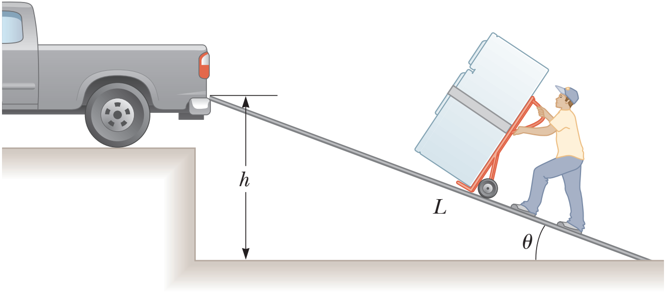


Energy transfer examples



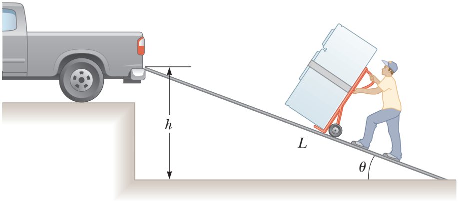
Work and a simple machine

Can we do less work by using a ramp to lift a refrigerator?



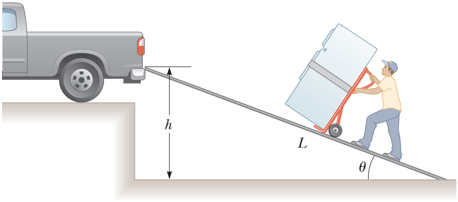
(Assume the axle of the wheels on the cart is frictionless...)

Work and a simple machine



If we just lifted the fridge directly, we would require and upward force $F = mg$ to do work on the fridge against gravity:

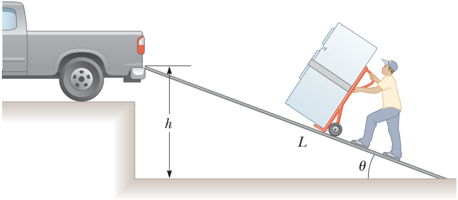
Work and a simple machine



If we just lifted the fridge directly, we would require and upward force $F = mg$ to do work on the fridge against gravity:

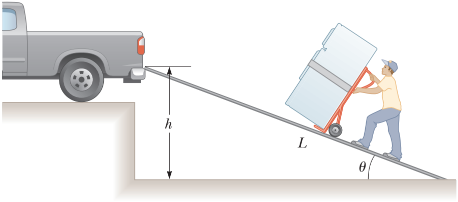
$$
\begin{aligned}
W &= Fd \\
&= mgh
\end{aligned}
$$

Work and a simple machine



If we pushed the fridge up a ramp, we would require $F = mg\sin\theta$:

Work and a simple machine



If we pushed the fridge up a ramp, we would require $F = mg\sin\theta$:

$$
\begin{aligned}
W &= Fd \\
&= (mg\sin\theta)L \\
&= mg(L\sin\theta) \\
&= mgh
\end{aligned}
$$

Work and a simple machine

Implication: the ramp allows us to use less force, but we still must do the same amount of work.

This also shows that it doesn't matter *how* the fridge gets into the truck, it has the same potential energy once it gets there: the potential energy it gains from the external agent (the man) doing work.

This is an example of a **simple machine**.

Simple Machines

A simple machine is any tool or set of tools designed to change the magnitude or direction of the force we need to apply to do some work.

The ramp (an *incline*) did both: we exerted less force in a different direction.

Simple Machines

A simple machine is any tool or set of tools designed to change the magnitude or direction of the force we need to apply to do some work.

The ramp (an *incline*) did both: we exerted less force in a different direction.

However:

$$\text{Work input} = \text{Work output}$$

We had to move the refrigerator a further distance, so either way, we did the same work.

Simple Machines

A simple machine is any tool or set of tools designed to change the magnitude or direction of the force we need to apply to do some work.

The **Mechanical Advantage** of a simple machine is the ratio:

$$\text{Mechanical Advantage} = \frac{\text{Force out}}{\text{Force input}}$$

Simple Machines

Other examples of simple machines:

- levers
- pulleys
- screws
- wedges
- wheels

This helps us when there is a limit to how much force we can supply.

Efficiency

In principle, simple machines are 100% efficient. That means:

$$\text{Work input} = \text{Work output}$$

But life is seldom that kind to us.

Almost always there are losses due to friction, etc.

Efficiency

In principle, simple machines are 100% efficient. That means:

$$\text{Work input} = \text{Work output}$$

But life is seldom that kind to us.

Almost always there are losses due to friction, etc.

We can define the **efficiency** of a machine as:

$$\text{efficiency} = \frac{\text{Work output}}{\text{Work input}}$$

It is usually stated as a percentage.

Efficiency

$$\text{efficiency} = \frac{\text{Work output}}{\text{Work input}}$$

For example, a typical efficiency of a car is around 20%, but can be higher particularly for diesels and hybrids/electrics.
(This is actually thermal efficiency - it's a little more complicated.)

Sources of Energy

Sources of energy:

- oil
- coal
- natural gas
- wood / charcoal / peat
- solar - photovoltaics and heating
- wind
- waves
- hydroelectric
- geothermal
- nuclear - thermonuclear, fission, and fusion(?)

Summary

- Energy!
- types of energy and work
- conservation of energy

Essay Homework due July 19th.

Homework Hewitt,

- Read about "Sources of Energy"
- Ch 7, onward from page 118. Plug & Chug: 3, 7, 11; Ranking: 3; Exerc: 1, 7, 13, 21, 25, (35); Probs: 3

Other: Think about energy sources that provide electricity and heat for our homes and offices. Pick one particular source of energy and study it. Come to tomorrows's class prepared to tell the class about it: what are its benefits and drawbacks? Is it renewable? Is it cheap? And so on.