Chapter 6: Energy and Work

Emphasize Chapter 6 Sections 4, 7, and 10.

What can we say about energy?

- Energy is the ability to cause change.
- Energy is always the property of some system. There is never "pure energy." All energy is just a property of some system or other.
- A system is the object or the collection of objects in which we are interested. Useful systems in physics usually include a specific set of material objects and the fields through which they interact. For example, you and the Earth can be considered a system. This system includes you, the Earth, and the gravitational field through which you and Earth interact.
- Energy can be transferred from one object (or system) to another. There are three common ways in which systems can gain or lose energy in a transfer: 1) working, 2) heating, and 3) radiation. Chapter 6 is about work. Work is the amount of energy a system gains or loses due to a force exerted by some agent over a certain distance.
- Energy is not a vector; it is a scalar. In this respect it is like its 'closest cousin,' mass. This means that we can do normal arithmetic with energy. We just add and subtract values as normal.
- Energy is never created or destroyed. Therefore, we say it is conserved.
- No matter where it is stored, energy is just energy. It doesn't change form or anything in its nature when it goes from the gravitational field to the ball, it just changes where it happens to be stored, and so we give it names that tell us what's storing the energy, whether it's a moving ball, a gravitational field, or a spring.

Where is energy stored, so far as we are concerned in this course?

There are three systems for which we can calculate stored energy, moving objects, gravitational fields, and springs.

- Moving objects have kinetic energy. $KE = \frac{1}{2}mv^2$
- Gravitational fields store energy: $GPE = mgh$

  When a ball falls from the top of a building, it gains energy (KE) from the gravitational field that pulls it downward. Therefore, the gravitational field loses energy to the ball. No matter where it is stored, energy is just energy. How do we calculate GPE? You first have to decide where you want the "zero point" of h to be. Usually we just choose the zero point to be the lowest point in the motion of our object. But you can choose any point to be $h = 0$ that you want. But you have to stick with that zero point for the rest of your solution to the problem.
- Springs store energy when they are stretched or compressed: $SPE = \frac{1}{2}kx^2$. "k" is the spring constant. You can find the spring constant for a given spring from a plot of the spring's force against its stretch (or compression), "x.". There is such a plot farther down in this paper, and you should find that its spring constant (the slope) is 100 N/m. It tells us the number of Newtons required to stretch or compress a spring one meter from its relaxed, equilibrium length.

Energy is measured in a unit called Joules in the SI system of units. That's what we will use. Energy is also measured in calories sometimes.

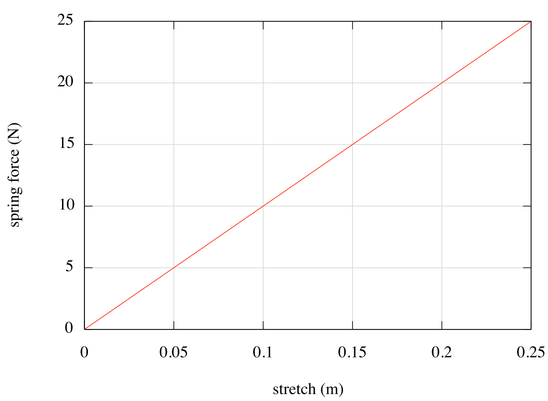
We have two ways to find how much energy is transferred through work done by an agent exerting a force on our object of interest:

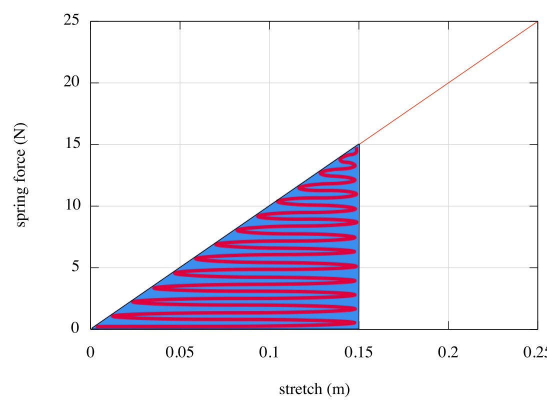
- The first way is by evaluating the expression for the work done by one object or system on another:

  $$W = F\Delta x \cos\theta$$

  This expression tells us how much energy is gained or lost by the object that experiences the force. You need to know what F represents. It represents the force exerted by the agent (or system) acting on the object of interest. Δx is the change in position of the object of interest along its path while experiencing the force F. We deal with straight paths but not curved paths when we use $W = F\Delta x \cos\theta$ in this course. Calculus will enable you to deal with curved paths, but that's for another physics course.

- The second way we have to evaluate the work done on our object or system is by using a graph in which the force exerted by the agent acting on our object of interest is plotted as a function of the position of the object: In the graph shown below we see the force exerted by a spring on an object attached to the end of the spring. The work done as the spring changes its "stretch" turns out to be equal to the "area" under the plot. This area is shaded in the second plot for a 0.15 m stretch. This area is a triangle, so the area is found by $\frac{1}{2}bh$. In this plot the work done by the spring on our object turns out to be about 1.1 Joule. But whether it is +1.1 J or −1.1 J depends on whether the spring is stretched more or stretched less at the end of the process. We cannot determine that from the plot; the problem statement would have to tell you that. Then you would know if the spring gained or lost energy as it interacted with the object of interest.





Tracking energy of your object or system

$$E_1 + W = E_2$$

- **Evaluate the initial energy in your system,** E_1

  We evaluate E_1 by adding up all the known initial energies in our system. These energies can be any or all of KE, GPE, or SPE.

- **Evaluate the change in energy in your system,** W

  We find either $W = F\Delta x \cos\theta$ or the "area" of an $F\ vs\Delta x$ plot.

- **Evaluate the final energy in your system,** E_2

  We evaluate E_2 by adding up all the known final energies in our system. These energies can be any or all of KE, GPE, or SPE.

  As a rule in Physics I, you will be able to find all the energies except for the unknown when you complete the accounting for energy in your system. Then you solve for the unknown in $E_1 + W = E_2$.

Suppose a falling ball has 2 Joules of kinetic energy and, as it falls, the gravitational field does +3 Joules of work on the ball. The ball will then have 5 Joules of kinetic energy.

$$2\text{ J} + 3\text{ J} = 5\text{ J}$$

In symbols we write this as follows:

$$E_1 + W = E_2$$

This just says that the total energy in a system to begin with, E_1, plus any energy added through working, adds up to the final energy of the system, E_2.

Suppose you throw a ball straight upward, giving it 10 Joules of kinetic energy. The gravitational field will do work on the ball, but this work will *reduce* the kinetic energy of the rising ball. Eventually the ball will stop rising and, for at an instant in time it will have no kinetic energy. That will happen when the gravitational field has reduced the ball's kinetic energy by 10 Joules. We say that the gravitational field has done *negative* work on the ball. We can see this from the arithmetic:

$$10\text{ J} + W = 0\text{ J}$$

$$W = -10\text{ J}$$

Conservation of Energy

It turns out that the amount of energy in our universe does not change; it is said to be "conserved." The same thing can be true for small systems, too, just as long as there is no gain or loss of energy from or to the surroundings. For us, that means $W = 0$.

In that case, $E_1 + W = E_2$ becomes $E_1 = E_2$, because $W = 0$. So when energy is conserved as for a roller coaster car that has negligible friction, the KE and GPE always add up to the same total:

$E_1 = E_2$ becomes $KE_1 + GPE_1 = KE_2 + GPE_2$ or just $mgh_1 + \frac{1}{2}mv_1^2 = mgh_2 + \frac{1}{2}mv_2^2$

This is a typical kind of problem in physics instruction, and there is one unknown in that equation as a rule. Study Chapter 6 Section 7 and its examples.

A qualitative illustration of what this is about is shown in the pendulum simulation at https://www.glowscript.org/#/user/pgswack/folder/My_Programs/program/PendulumForces. This simulation shows energy bars that are associated with the energy stored in the only two relevant storehouses for energy, the pendulum bob (red bar) and the gravitational field (green bar). The total amount of energy that these two energy storehouses hold stays the same as it flows back and forth between the bob (kinetic energy) and the gravitational field (gravitational potential energy).

Power

Section 10 of Chapter 6 is about "power." Power is the rate that energy is transferred from one thing to another, so we measure it in Joules/second, which we call "Watts."

$P = \dfrac{W}{\Delta t}$ or, to be more general, $P = \dfrac{\Delta E}{\Delta t}$, or to be more accurate, $P = \dfrac{dE}{dt}$. We will stick to algebra, though. So no calculus. Study Section 10 up to equation **(6-17)**.

Chapter 7: Momentum and Impulse

Emphasize Chapter 7 Sections 1, 2, 3, 4, and 6.

What can we say about linear momentum?

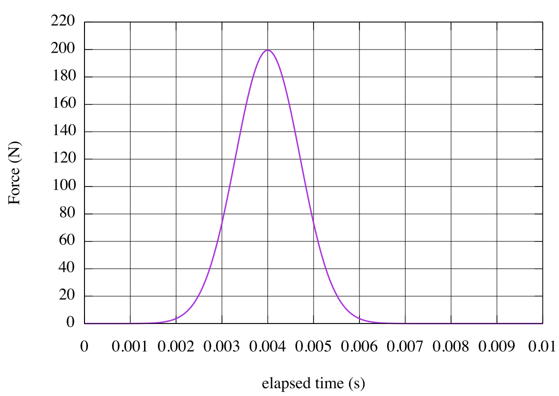
- Newton thought of momentum as the amount of motion associated with some moving object. The greater the speed, the greater the momentum. The greater the mass of the object, the greater the momentum.

  $\mathbf{p} = m\mathbf{v}$

- Momentum is a vector quantity like velocity and force (and unlike mass or energy). The direction of the momentum of an object is the same as the direction of its velocity.

Changes in the momentum of an object

- Momentum of an object changes due to a force acting on that object over a period of time.
- The change in momentum delivered to an object by a force acting on that object over a period of time is called "impulse." Impulse is a vector quantity, naturally, because it is a change in momentum, which is a vector quantity.
- There are two ways to determine the impulse (aka "change in momentum") delivered to an object.
  - One can calculate $\overline{\mathbf{F}}\Delta t$. That's the impulse, but you need to know the average force, $\overline{\mathbf{F}}$ and the amount of time this force acted. $\overline{\mathbf{F}}\Delta t = m\Delta\mathbf{v}$ Impulse is the same thing as the change in momentum, $\Delta\mathbf{p}$
  - A second way to find the impulse is to calculate the "area" under a plot of F as a function of the elapsed time t. In the plot below I would estimate the number of boxes to be between 18 and 20, and each box represents 0.02 Ns of momentum. So the impulse or change in momentum produced by this force on the object it affects is roughly 0.4 Ns, give or take a little bit.



$m\mathbf{v_1} + \text{Impulse} = m\mathbf{v_1'}$ Here $\mathbf{v_1'}$ is the final velocity.

Collisions in one dimension

Momentum is conserved in systems that are not affected by a net external force (i.e. a net force exerted by something outside of the system).

Therefore, if the external net force is zero, the momentum of two objects before they collide with each other is the same as their total momentum after they collide:

$m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$

The primes indicate final values (after the collision).

Classification of collisions

There are three classes of collisions, elastic, inelastic, and perfectly (or "completely") inelastic. You should be able to classify these three linked collisions and you should know what happens to any lost kinetic energy.

https://www.glowscript.org/#/user/pgswack/folder/My_Programs/program/CollisionMIPa

https://www.glowscript.org/#/user/pgswack/folder/My_Programs/program/CollisionMIPb

https://www.glowscript.org/#/user/pgswack/folder/My_Programs/program/CollisionMIPc

Chapter 8: Rotational Motion

Emphasize Chapter 8 Sections 1, 2, 4, 5, and 8.

Examples 8-1, 8-3, 8-4, 8-6, 8-8, 8-11, and 8-16 are good ones to understand thoroughly.

Describing angular motion

The things that rotate can be described by three variables, θ, angular position, ω, angular velocity, and α, angular acceleration.

Explaining angular motion

Be able to sketch a force diagram for a bridge or similar object that is subject to forces, and from that diagram be able to write the net torque equation: $\alpha = \frac{\sum_i \tau_i}{I}$ and then solve for any unknown.

Be able to calculate torques, given enough information to determine F, r. and $\sin\theta$.

Be able to find the net torque on an object such as the compound wheel in the Figure that accompanies Problem 24 on p 220.

Conservation of angular momentum

Skaters, divers, and collapsing stars were the cast of characters for the conservation of angular momentum.

$I_1\omega_1 = I_2\omega_2$