Energy & the Environment

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Dr. John M. Pratte is a Professor of Physics and the Dean of the College of Sciences and Mathematics at Arkansas State University. He received his B.S. in Physics from the University of Texas and his Ph.D. in Physics from the University of Colorado. His dissertation was an experimental and numerical study of fluid flows in rotating basins with periodic forcing. After completing his doctorate, he worked for Shell Oil in New Orleans as an exploration geophysicist, which started his studies in energy use and the environment. Since leaving Shell in 1993, Dr. Pratte has been a faculty member at Clayton State University (Morrow, GA) and Kennesaw State University (Kennesaw, GA) before joining ASU in 2006 as the Chair of the Department of Chemistry and Physics. Before becoming the Dean, he was the Associate Dean for Research and External Engagement in the College of Sciences and Mathematics.

Credits

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Dedication

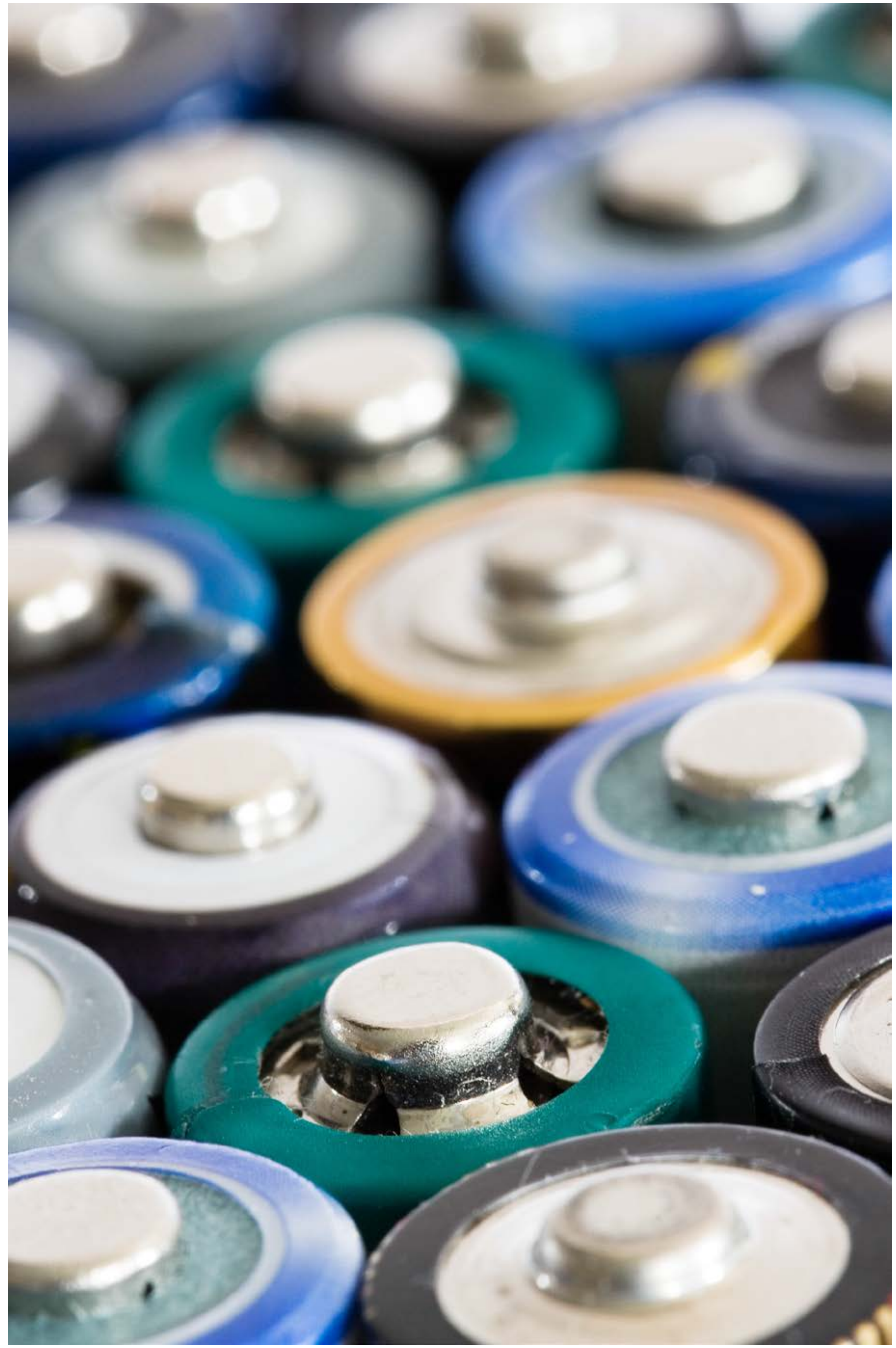
To B.D., for putting up with me

Chapter 1

Energy Basics

Chapter Objectives:

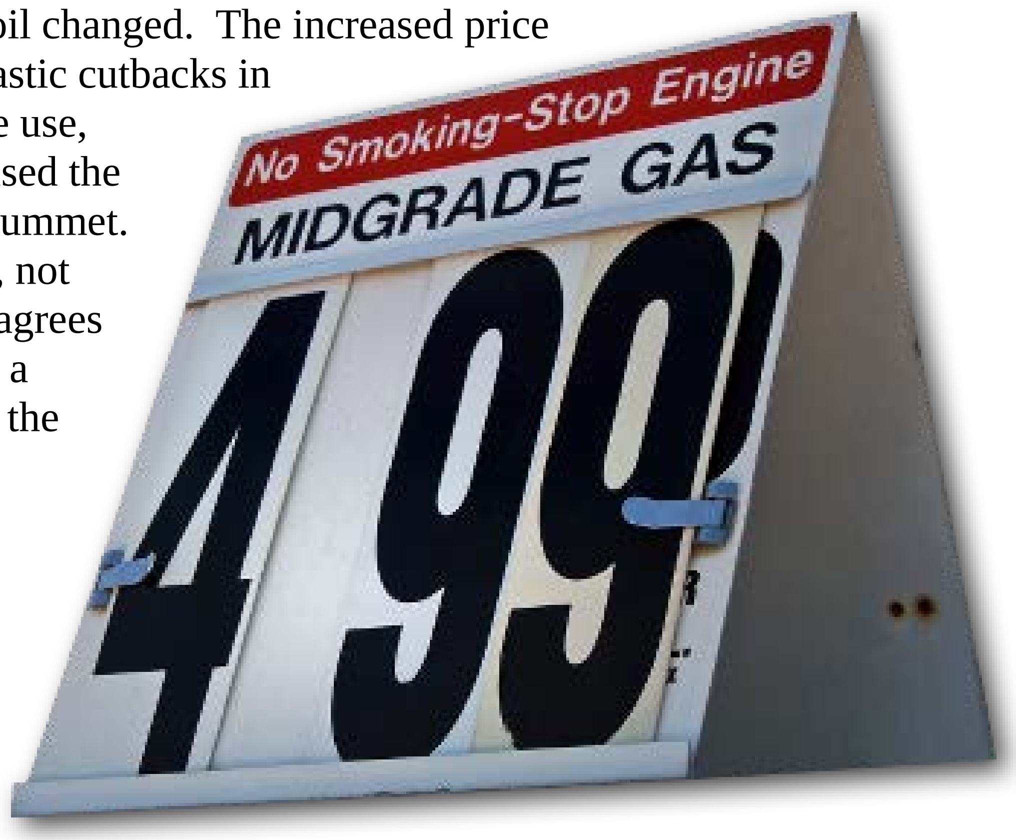
1. Discuss the use of energy both in the U.S. and worldwide.
2. Define and be able to use the equation for key terms: displacement, velocity, acceleration, force, work, energy, and power.
3. State Newton’s first, second, and third laws of motion.
4. Define work and discuss the connection between work, energy, and power.
5. Differentiate between kinetic and potential energy.



The Price

The year 2008 was an interesting one by most standards. In February of that year, Fidel Castro stepped down as the leader of Cuba after 59 years. A magnitude 7.9 earthquake in the Sichuan Province of China killed over 69,000 people. In the U.S., Barack Obama became the first African-American President in history.

From an energy perspective, 2008 will be remembered by Americans of driving age as the year that gasoline prices spiked over $4 per gallon. In October of 2007, the price of gasoline was at a national average of $2.79 per gallon. Just nine months later in July of 2008, it had risen to $4.09 per gallon. By December of 2008 the price had plummeted down to $1.69 per gallon. The causes of this spike are simple: growing international demand for oil, coupled with decreasing production in several key areas, caused the price to shoot up as speculation over the future of oil changed. The increased price caused drastic cutbacks in worldwide use, which caused the price to plummet. Of course, not everyone agrees on this, as a perusal of the Internet shows. There are some who would claim that it was a conspiracy or that it was all due to speculation. Most of the people who make these claims, however, have little understanding about how oil is explored, produced, and refined into gasoline, nor do they understand what the worldwide demand for oil products is, nor what the worldwide demand for energy is.

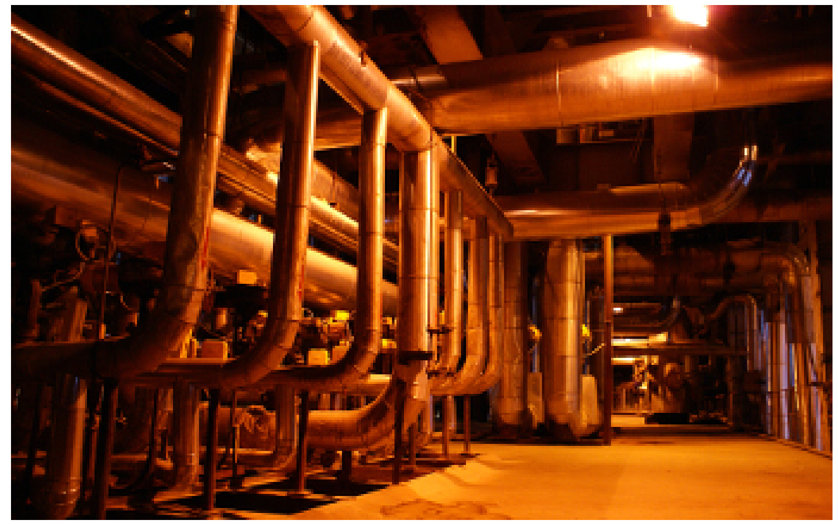


In fact, one would probably be right on the mark if they said that the people making these accusations did not understand anything about energy. Why? Because, with the rare exceptions of when a price spike or dip occurs, we do not talk about it. The study of energy currently has no place in the P-16 curriculum in the U.S. other than the occasional definition of energy in a physical science class. We in the sciences bore you to death with discussions of Newton's Laws of Motion, Kirchhoff's Laws, the Stefan-Boltzmann Equation, etc., because they really are important to your everyday life. What we never do discuss, though, is how all of these things are important to your life.

It is a shame that we do this, as the gasoline price spike of 2008 is not an aberration. Things of this nature have occurred in the past, and they will continue to happen in the future as long as we rely on fossil fuels for so much of our energy. In fact, as I write this, the price of gasoline is hovering at around $2.40 per gallon in most states, even though it was over $3.50 per gallon just two years ago. Access to cheap sources of energy is incredibly vital to any country on Earth. The economy and military of every country relies heavily on energy, and the lack of cheap sources can drive a country's economy into a tailspin and put the country in a vulnerable position militarily. Our educational systems need to discuss these issues so that people will be prepared for these situations in the future and find ways to head them off.

If you think that this is being a little overly dramatic, consider this one example: World War II was driven mostly by oil[1]. Our entry into the war and our ability beat back the enemy and defeat them was a consequence of access to oil. While the bombing of Pearl Harbor on December 7, 1941 was what officially got us into the war, our naval blockade of Japan's access to the oil fields of Indonesia is what really precipitated it. Japan, which has no native sources of cheap energy and is one of the most energy desperate countries in the world, needed that oil to fuel its ships and planes in its war against China. Its response to the blockade was not to attack the U.S., but to attack the U.S. Navy, which was responsible for keeping the blockade active. They hoped to break the blockade long enough to strengthen their supply lines to the oil to repel the U.S. forces after they recovered from the attack. However, the U.S. Navy recovered from the attack much quicker than expected, which ultimately led to Japan being repulsed in the Pacific.

The battle in the Pacific was not the only action being driven by oil. The German military was fighting two major fronts in the war by the early 1940's: North Africa and Russia. On the surface, neither of these campaigns makes much sense, as North Africa had little in the way of resources needed by the Germans and trying to take Russia by force had been shown historically to be very troublesome (see Napoleon). However, Germany, whose sole source of native energy at the time was coal, needed oil very badly to supply its military if it was going to continue to keep the land that it had conquered by the late 1930's (running tanks and planes takes a lot of oil). The best locations for Germany to get this oil were the Middle East and the oil fields of Russia. Getting the oil from Russia meant going through Stalingrad; getting the oil from the Middle East meant either going through the Balkans (a bad idea, given the topography and local population) or going through North Africa. The success of the Allies in stopping both of these drives was a primary reason for the eventual victory over Germany, as tanks and planes went abandoned by the end of the war due to a lack of petrol.



We do not have to go so far back for other examples of the importance of cheap energy to our economy or politics. The rampant inflation of the 1970's was driven mostly by the doubling of gas prices by a factor of two in 1973 due to the OPEC oil embargo followed by the tripling of gas prices in 1978 over the situation in Iran and the hostage crisis. The first Gulf War (1990) was driven by Saddam Hussein's takeover of Kuwait, which held over 5% of the remaining oil reserves in the world at the time. Today, we are still at war in the region, mostly due to the continued instability in the world's oil market and our desire to control it.

Educating yourself about energy is one of the more important activities that you can do. If you understand the different sources of energy, how they are used, and how they affect the environment, you will be much more likely to make good economic and environmental choices in the future. Luckily for you, we have developed this course to help you to do just that. Better yet, we have put this course in the general education curriculum to allow you to prepare yourself for the world rather than re-taking your 9th grade physical science course again. However, before we do that, we need to go back and remind you of some of the 9th grade material so that you will understand why we do what we do in terms of energy. First, we will define energy and relate it to forces. After this, we will discuss the laws of thermodynamics that govern how energy can be transferred. Next, we will look at one particular form of energy: electricity. Lastly, we will discuss some basics about Earth itself so that we understand where our energy comes from and how we impact our planet by extracting it.

Energy: Definition

Energy is all around us. It is in the food we eat, the gasoline we put in our cars, and sunlight that strikes our face. But what exactly is energy? We use the term often, as in "I just don't have any energy today." Since we are all so familiar with the word energy, one would think that we would all be experts on the subject. However, our use of the word "energy" in our everyday lives is somewhat different from what the word means in a scientific sense. For the purposes of this class, we are going to define energy as "the ability to do work."

Of course, this definition is not as useful as it would appear, since the word "work" in this definition also has little to do with our everyday usage. We do not mean “job, task” for work. Instead, we mean "the transfer of energy to an object by applying a force on it through a distance." Once again, we find a definition that is lacking, as we must now define what we mean by a force. Therefore, before we go forth with our definition of energy, we will need to backtrack a bit and review some terminology from physics.

A Physics Primer: Position, Velocity, and Acceleration

The study of physics is concerned, to a large degree, with finding the **position** of an object at a particular time. In both physics and our everyday language, “position” means the same thing: location. If we say that the position of an object is 4 meters to the east of a lamppost, then we are specifying a unique location that should be able to be found by anyone who can see the lamppost and has a compass that tells direction. Figure 1 shows a diagram of a point that is 4 meters to the east and 5 meters to the north of the origin. This would be a valid way of stating the position of the point, although there are others. For instance, you could say that it is 6.4 meters from the origin, at an angle of 51 degrees above east.

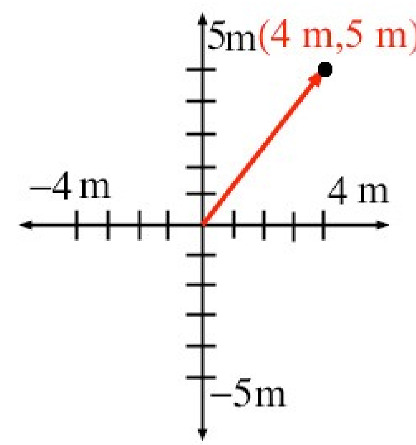


Fig. 1: position diagram

Knowing the position of an object at a particular time allows it to be found by anyone with a clock and knowledge of the origin point. If the object is not moving, then the position allows this object to be found for all time. If the object is moving, then finding it becomes a bit harder, as we will need to know something about how it is moving in order to locate it at times in the future. One thing that we might wish to know is the rate at which the object is changing its position. This quantity is known as the **velocity** of an object, and mathematically, it is written as:

(Equn. 1.1)

velocity = $\Delta r/\Delta t$ = (change in position)/(change in time)

where **r** is the vector that defines the position of the object and **t** is the time. The unit of velocity in the SI system is meters/second or m/s. The Greek letter Δ means "the change in."

If the velocity of an object is constant, then knowledge of it and the position at a given time allow the object to be found for all time. For example, if we notice that a bird passing over our head at exactly 12 noon is moving at 20 m/s due south and that this velocity does not change, then we will be able locate the bird's position 10 seconds after this by multiplying the amount of elapsed time by the velocity. (Video EXAMPLE)

Thus, the bird will have moved 200 m in the southerly directions from its original position, which was directly overhead.

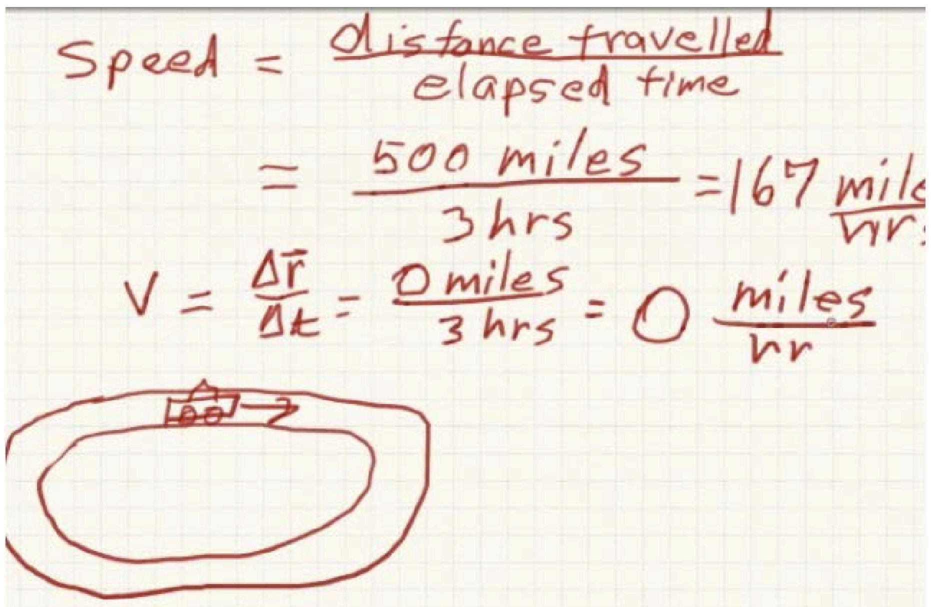
While not exactly Earth shattering, the previous example does illustrate a point. If you know the position of an object at a particular time and the velocity of that object at that time, you can begin to make statements about the object's position at a future time. Of course, if the object's velocity is changing, then using the model above will not tell what is going to happen in the future with much accuracy. However, there are other models available that will allow this. In our everyday lives, we can sometimes do this without pencil and paper, such as when we are able to catch an object that is thrown to us. We are able to do this because, with practice, our brain and eyes learn to account for changes in position and velocity instinctively. For word problems, we will need to do a lot of that same practice, but with pencil and paper, in order to be able to solve things so effortlessly (Hint, hint: work the problems at the end of the chapter).

Before we leave the subject of velocity, let us make a small aside to explain another common term: speed. Since the position is a vector quantity (vectors are designated either with a small arrow over the quantity or by using bold print), the velocity is also a vector quantity. Many times, people will say that velocity is the speed of an object with direction. This is, in fact, only true in a very special circumstance when we are talking about the instantaneous velocity and the instantaneous speed. Strictly speaking, speed is defined as the distance travelled divided by the amount of time to travel.

(Equn. 1.2)

speed = (distance travelled)/ Δt

The reason why this is not the same as the magnitude of the vector quantity velocity is that that the distance travelled can be greater than the change in position. To illustrate, consider the Daytona 500, an automobile race in which cars travel 500 miles. The average speed of a car in this race is 500 miles divided by the amount of time that it takes to complete the race. If it were to take 3 hours to complete the race, then the average speed would be 167 miles/hour. (Video EXAMPLE)



Since the cars finish the race where they start it, the change in position over that same 3 hours is 0 miles. Thus, the average velocity of a car in this race is 0 miles/hour, which just goes to show how senseless the Daytona 500 is. The only time that one is assured that the speed is the magnitude of the velocity is when instantaneous speeds and velocities are under consideration, i.e. when Δt is an infinitesimally small amount of time.

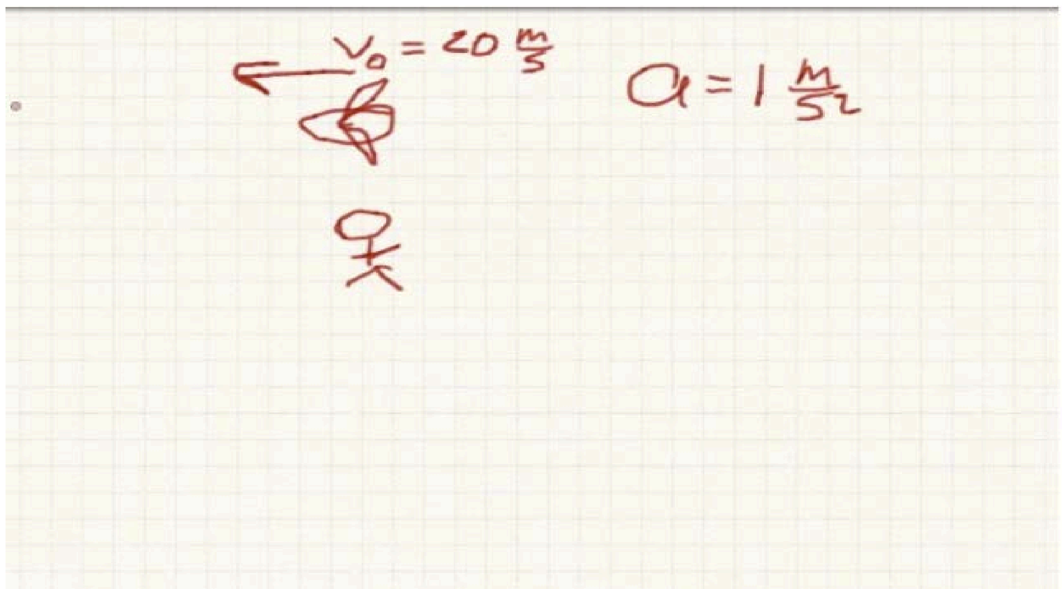
Now let us return to our discussion of locating objects. As with position, knowing the velocity is vital for locating an object; if the object has a constant velocity, then the position at a given time and the velocity are all that one needs to know to calculate its position at all times. If the object's velocity is not constant, then one would need to know the rate at which the velocity is changing. This needs to be known in order to determine its velocity at some point in the future, which will be used to determine position. This rate at which velocity changes is known as the **acceleration**, and is given by the equation:

(Equn. 1.3)

acceleration = **a** = Δ**v**/Δt

The unit of acceleration in the SI system is meters/second/second, or m/s^2. Again, since the velocity is a vector quantity, the acceleration is also one. Some people call negative accelerations "decelerations" although it is still an acceleration.

As an example of how to use the acceleration, if the bird in the previous example had a velocity that was known to change by 1 m/s^2 in the southerly direction, then we would be able to determine the velocity of the bird 5 seconds after it passed overhead by multiplying the acceleration by the elapsed time and adding it to the initial velocity. (Video EXAMPLE)



Since the bird was initially flying at 20 m/s, this means that its velocity after 5 seconds is 25 m/s.

Forces

As you might guess, the acceleration of an object can change, which would cause one concerned with its motion to be motivated to compute the rate of change of the acceleration (there is such a thing; it is called the jerk). The fact is that you could continue defining the rates of change in an endless stream if you are really concerned about the motion of an object. However, we stop at acceleration since it is related to a much more useful term: **force**. As discovered by Isaac Newton, the acceleration of an object is related directly to the net force on an object. More precisely, he found that

(Equn. 1.4)

$$\mathbf{F}_{\mathbf{net}} = m\mathbf{a}$$

where **m** is the mass of an object. The unit of mass in the SI system is kilograms, which leads to forces being measured in kilogram m/s^2, or kg m/ s^2. This is known as a Newton, which is represented by a capital N. In the English system of units, forces are measured in pounds (lbs.), whereas the unit of mass is known as the slug. Unfortunately, many books confuse this matter by stating conversions between pounds and kilograms, which is technically incorrect since pounds are force and kilograms are mass. What is assumed in this conversion is that the object is at the Earth's surface, where **gravity** is providing a force that causes objects to accelerate at 9.8 m/ s^2.

This equation is just one part of a set of laws that have come to be known as **Newton's Laws of Motion**, even though Newton only discovered the last two of them (Galileo is credited with discovering the first one). These laws are normally stated as:

1. **An object at rest, or in a state of constant motion, will continue in that state unless acted upon by an unbalanced force.**

2. **F_{net} = ma**

3. **For every force, there is an equal and opposite reaction.**

These laws are very useful tools, as they allow us to relate measurable quantities (acceleration) to dynamical variables, which can be used for all manner of calculation and observation. They tell us that anytime we see an object accelerating, we know that there is a net force acting on it, whether we see the any other evidence of that force or not. For instance, if we detect a faraway star moving in a circle, then we know that something is acting upon the star to make it do so. By calculating its acceleration, we can determine the magnitude and direction of the force, which will allow us to search for the source force.

Because of our everyday experiences, though, we often misunderstand forces that occur here on Earth. For instance, if you push a large box across the floor at a constant speed, Newton's Laws state that there is no net force on the box. However, you know that you are applying a force, as you can feel it in your muscles and bones. What is happening is that, as you are applying a force to the box, friction is applying an equal and opposite force to keep the box from accelerating. When you initially began to push the box, you were able to push harder than friction, and thereby accelerate the box to some velocity. At some point, either the force of friction increased to match your force, or you began to push with less force so that the two became equal.

The situation becomes even more misunderstood when we consider a box so large that you cannot move it. In this case, you are applying a force to the box that is equal to the force that friction is applying to the box, and there is no net movement. Often, folks will cite Newton's Third Law (Action-Reaction) as the reason for the lack of movement. However, this is wrong. The reaction force to you pushing on the box is the box pushing on you, not the force of friction of the floor on the box. Even when the box is moving across the floor at a constant velocity, the reaction force of the box on you is still there.

A better way to visualize the Action-Reaction Force Law is to consider two people without skates in the middle of a very slippery ice rink. If either of the two attempts to walk off the ice, they will find that there is nothing to push on, meaning that they will not experience the reaction force that will propel them off of the ice. Each will find that they can get off of the ice if they push off of the other. However, in doing so, they will notice that the other person is also propelled off of the ice. This is because in pushing on the other person, the other person was actually pushing back on them.

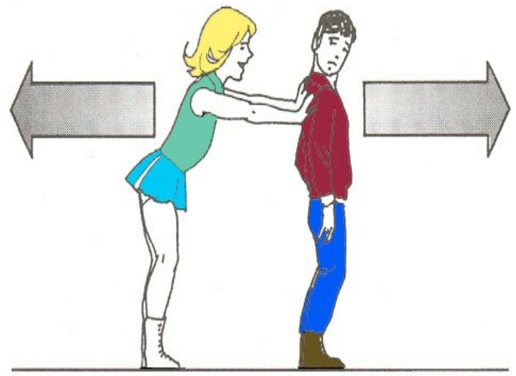


Fig. 2: two people on ice

Forces and Work

Now that we know what a force is, we are ready to get back to our definition of **work**. We said at the beginning of this chapter that work is the transfer of energy by applying a force through a distance. If the force is unchanging, then we can write the work as:

(Equn. 1.5)

$$\mathbf{W} = Fd$$

where **F** is the applied force and **d** is the distance through which the force is applied. The units of work in the SI system are newton-meter, or **joule**, named after James Joule, the scientist that discovered the First Law of Thermodynamics. The end of the chapter discusses other units of energy.

If the force is constant, calculating the work that is done is quite simple: multiply the constant force times the total distance traveled. If the force is changing in some manner, we can still use the above equation, but we must break it up into small chunks. For this situation, we divide the total distance traveled into small segments over which the force does not change that much. If we can take the force to be nearly constant, then the work over that little segment is just the force times the small distance segment. Doing this for all of the small distance segments and then adding all of the small works will give the total work over the total distance traveled.

Before proceeding any further, we need to point out that the force used in Equation 1.5 is only that portion of the force that is parallel to the path of travel. Figure 3 shows a diagram of two different boxes that are being pushed across a floor with the same force F. In the first case (box with the fish on it), the force is parallel to the surface of the floor, whereas the second box (box with tree) is being pushed at an angle θ with respect to the surface of the floor. If both boxes move the same distance d, then the work done on the first box is F d, while the work done on the second box is less. This is because it is only that portion of the force that is parallel to the surface of the floor (F times the cosine of θ or F cos θ) that is doing work in moving it across the floor. Some portion of the force (F sin θ) is going towards pushing the box into the ground, and is doing nothing more than increasing the force of friction on the box. In the extreme case, the angle θ would

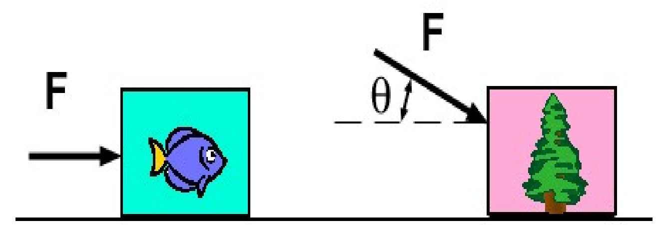


Fig. 3: Boxes being pushed on floor

be 90° (pointing straight down), in which no work would be done, as the box would not move parallel to the surface of the floor.

This can also be applied when you lift up the box and carry it across the room. While you are lifting the box, you are applying the force in the direction that the box is moving, and are thus doing work on the box. However, as you carry the box across the room, the force that you are applying to hold the box up is not doing any work on the box, even though the box is moving and a force is being applied to it. Since the force that holds the box up is perpendicular to the direction of motion, it does no work on the box. The only work you are doing on the box is the small amount of force that you are applying to keep it moving across the room times the distance you move it.

Relationship Between Work and Energy

So far, we have been looking at the world from the standpoint of doing work on objects in order to transfer energy to them. This standpoint is perfectly valid. However, you might remember that we defined energy as "the ability to do work". Thus, it would seem that there is an alternative view that looks at the world from the standpoint of expending energy in an effort to perform work on other objects. To get a better understanding of this view, it might help if we discuss a concrete example of energy. To do this, we must first define two different types of energy: **kinetic energy** and **potential energy**.

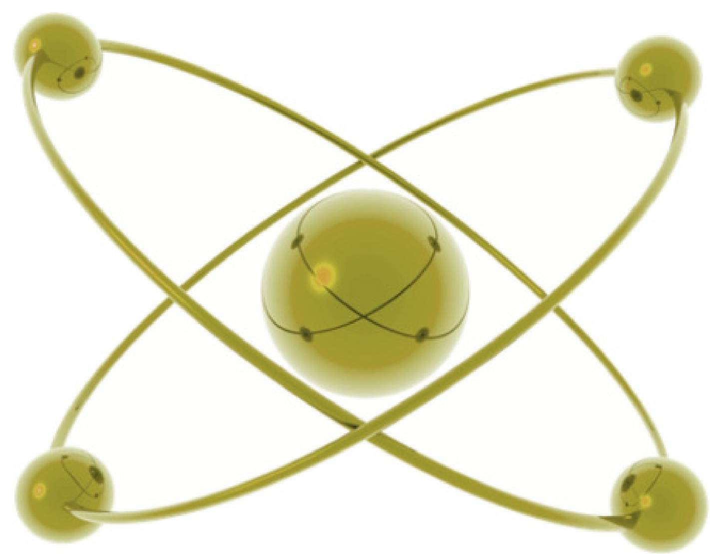
Kinetic energy is the energy that an object has because it is moving. A car traveling down the highway at 50 miles per hour has kinetic energy, as does a baseball that is thrown at 100 miles per hour. By slamming into other objects, they will be able to do work, since their momentum will cause them to apply a force through a distance as they collide. How much kinetic energy they have is determined by the formula:

(Equn. 1.6)

$$\text{Kinetic energy} = \text{K.E.} = (1/2)\, m\, v^2$$

Since the car has so much more mass than the baseball, it will have much more kinetic energy, even though it is moving at half of the velocity. Anyone who has been hit by both a car and a baseball, and survived, can attest to this.

Potential energy is the energy that an object has because there is a force operating on it in a direction in which it is able to move. A book perched on the top of a shelf has gravitational potential energy since gravity is pulling it toward the ground, and there is a distance between the shelf and the floor through which it can move. Likewise, a uranium-238 nucleus has nuclear potential energy since the protons and neutrons can move under the



influence of the forces acting on them (strong and weak nuclear forces) to be more tightly bound. Since the forces involved in the potential energy will change depending upon the object and situation, there is no way to write one formula that will cover all types of potential energy. However, we can readily derive the formula for a given object by simply considering the amount of work that is required to move the object from one place to another.

As an example, let us consider moving an object near the surface of the Earth. In 1684, Isaac Newton wrote that the force of gravity between two objects of mass m1 and m2 that are separated by a distance r is given by:

(Equn. 1.7)

$$F = G\, m_1\, m_2 / r^2$$

In this equation, G is a universal constant. If we consider an object with mass m that is being attracted to Earth (mass = mE), then we can re-write the equation as

$$F = G\, m\, m_E / r^2$$

Since the Earth is so large (radius = 6,300 km), the difference in force between an object that is at the surface, and one that is a kilometer above the surface is less than .04%. This means that, for all intents and purposes, the force of gravity near the surface of the Earth on an object is a constant. By plugging in the appropriate values for G, m_E, and r, we get that the force is

(Equn. 1.8)

$$F = mg$$

where the constant g is called the acceleration due to gravity and is given by

$$g = 9.8 \text{ m/s}^2$$

This value is good for objects within 20 kilometers of the surface of Earth. If you are considering some mass much further out than that, or that is near the surface of another planet or moon, you will have to go back to Newton's Universal Law of Gravity (Equn. 1.7) and calculate what the acceleration due to gravity is for that situation.

Now, let us consider an object of mass m that is a height h above the ground (fig. 4). In order to get the object to the height h, we had to pick the object up from the ground and lift it to h. This would require that we offset the force of gravity, i.e. we have to lift it with a minimum force of F = mg. From Equation 1.5, this means that we had to do an amount of work equal to

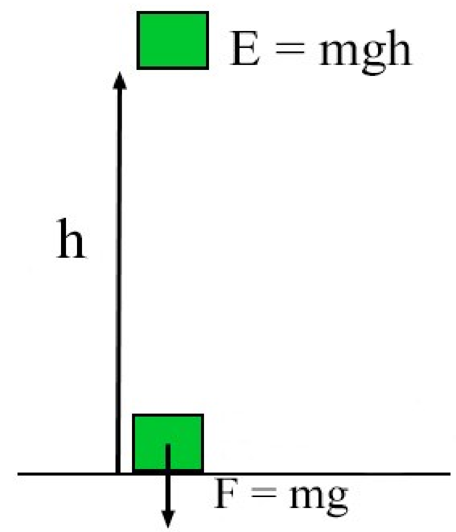


Fig. 4: Lifted box

(Equn. 1.9)

$$W = F\, d = (mg)(h) = mgh$$

Since this is the amount of work that was required to lift it to h, then the amount of potential energy that the object acquired is this. Thus, the gravitational potential energy of the object is mgh.

Since we have not designated any object mass or height, this equation (P.E. = mgh) is true for any object near the surface of the Earth. (Video EXAMPLE)

This type of procedure can be done for any system that stores potential energy. For forces that vary with distance, calculus must be used to sum up all of the little work segments, as we discussed previously. A spring operates with a force given by F = -kx, where k is a constant and x is the distance the spring is compressed or extended from equilibrium. This results in a potential energy of P.E. = (1/2) kx^2. The force between two charged particles q_1 and q_2 is F = K q_1 q_2/r^2, where K is a constant, q_1 and q_2 are the charges magnitude, and r is the distance between them. This system has a potential energy given by P.E. = K q_1q_2/r.

Transferring Energy

Both kinetic and potential energy are types of mechanical energy. All forms of energy can be classified into these two categories. Electricity is a form of kinetic energy, since it is the movement of the electrons that is used for all of the work.

TABLE 1	
ENERGY	**TYPE**
electricity	kinetic
solar	kinetic
fossil fuels	potential
nuclear	potential

Chemical energy, such as that found in food or gasoline, is a form potential energy. The energy that is released when chemical energy is used comes from the forces between atoms and molecules that are allowed to operate. Table 1 has examples of energy with designations as to type.

Because energy can be used to do work on another object, it can be transferred from one form to another. Let us, once again, look at the example of the object that is at a height h above the floor. When it is at a height h, we say that it has potential energy of mgh. If we release the object, gravity is allowed to act upon it, and it accelerates. Its acceleration means that it is acquiring kinetic energy (1/2 mv2). However, as it accelerates downward, it is losing height, and thus, potential energy. Right before the object hits the ground, it has lost all of its potential energy. This amount of energy has been converted to kinetic energy, which the object will give to the Earth when it strikes it.

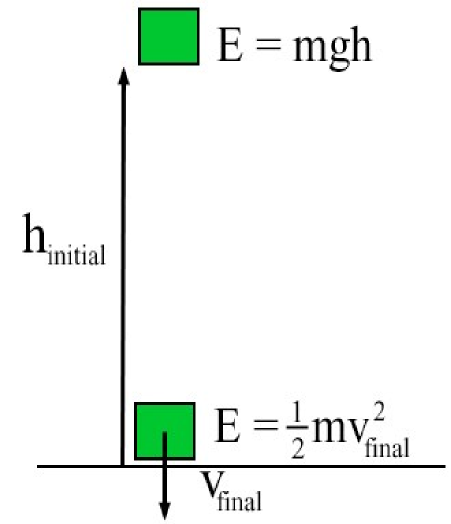


Fig. 5: Diagram of falling box

Since there is no other energy input or output (assuming negligible wind resistance) into the situation, we know that all of the kinetic energy at the moment of impact is equal to all of the potential energy initially. Thus,

$$mgh_{initial} = 1/2\ m\ v_{final}^2$$

Since both sides of this equation are linear in the mass of the object, we can cancel them, and solve for the velocity. Doing so yields

$$v_{final} = (2gh)^{1/2}$$

This equation shows that the final velocity of the object only depends upon the initial height of the object, something that Galileo discovered back in the 1600's by dropping cannon balls of different size. (Video EXAMPLE)

Simple Machines

This type of situation in which there is no net energy input or output is an example of the conservation of energy principle. Energy will be transferred from one form to another, but it will not degrade or increase. This is the basis for a classification of simple devices known as simple machines. These devices allow one to move large objects with small forces by taking advantage of the fact that energy is not lost. In essence, they are force multipliers. The most common simple machines are the lever, the fulcrum, the wheel and axle, the block and tackle, and the inclined plane.

Figure 6 shows a diagram of an inclined plane. This device is used to lift object above the ground. As we have already seen above, one can lift an object straight up to a height h. Doing so will require that the person supply a force equal to gravity (F=mg) and do an amount of work equal to mgh. By using the inclined plane to lift the object, this person will only have to supply a force equal to that component of gravity that is along the path of the plane. Using simple geometry, we can see that this component is given by mg sin θ. Since sin θ = h/L, this means that the force that must be supplied to push the object up the plane is F = mgh/L, which is less than mg. However, the amount of work that must by done is the same as above because the force must be applied over a longer distance L,

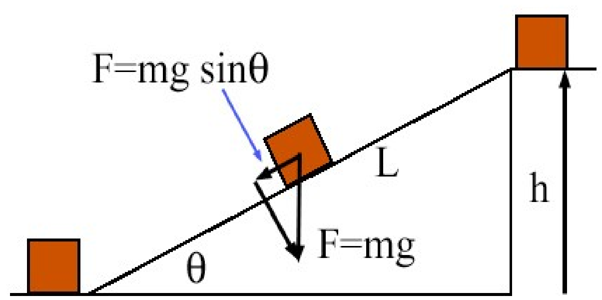


Fig. 6: Box on an incline plane

$$W = F\,L = (mgh/L)\,L = mgh$$

Thus, the incline plane allows for a smaller force to be applied over a longer distance, resulting in the same amount of work done, but a larger object being moved. The same thing holds true for all other simple machines.

Power

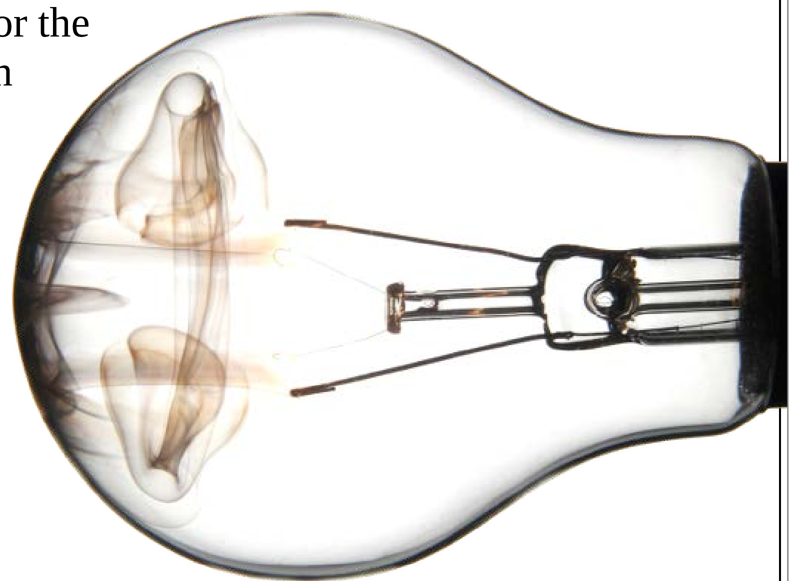
Simple machines are sometimes used to make people think that they are getting something for nothing (you get a greater force, but it requires that you apply the force longer). In a similar fashion, power is sometimes used to do the same thing. Power is the rate at which work is done or energy is expended, depending upon the situation. In other words,

(Equn. 1.10)

$$P = \Delta E/\Delta t$$

The SI unit for power is the watt, which is equal to a joule per second. As an example, a 100 W lightbulb is using 100 joules of energy every second in order to emit light. The confusion comes into play because power and energy are sometimes used interchangeably. For instance, an advertiser can claim that a product will save consumers money because it uses very low power.

While our appliances are rated by power, we are charged for the energy we use, usually in units of kilowatt-hours. It makes sense to charge this way, since it is the energy that determines how much total work gets done. This is not to say that one can neglect power. In particular, the electric company has to be very concerned with power. When many people use appliances at the same time (ex. air conditioners during a hot summer), a tremendous amount of energy must be supplied in a very short amount of time. Even though the electric company might have a lot of energy on hand (ex. large stacks of coal), unless they can supply the energy fast enough, a brownout or blackout will ensue. For this reason, most electric plants are rated by the maximum power that they can output.



Knowing this relationship between power and energy can be very useful to you. It allows you to determine how much energy you use when you turn on appliances.

$$\Delta E = P\,\Delta t$$

For example, if you leave a 5,000 W stove on for 2 hours, then you have used

$$\Delta E = (5{,}000\text{ W})(2\text{ hr}) = 10{,}000\text{ Whr} = 10\text{ kWhr}$$

Multiplying this usage by the rate that your electric company charges you will tell how much money it cost for this operation. Most companies charge somewhere between \$.05-\$.20/kWhr. This would mean that the stove operation above costs between \$.50-\$2.00.

Energy Use: History

From the earliest days, humankind has recognized the need to use energy to condition the environment around it. Wood was needed to heat homes and to cook food. Beasts of burden were needed to plow fields and to provide transportation. When either of these commodities became scarce, hardship prevailed, and solutions were sought. In ancient Rome, for example, the lack of available firewood led to the passing of laws that made it illegal to build a house or structure that would block another person's home from getting sunlight, as this was the primary method of heating homes without fire.

In the 20th Century, fossil fuels (oil in particular) reigned supreme as the energy of choice. The ubiquitous nature of this type of fuel created historically low prices for energy. This led to a substantial increase in the number of mechanized tools used by the average citizen, which has continued into the 21st Century. In 2014, the U.S. had a population of about 319 million people that were driving over 250 million passenger vehicles[2]. Most every home in America has a television, some type of range or stove, and a refrigerator. Almost 90% of all households have their own air conditioner[3], a huge jump over what it was just 20 years ago (68%). Of course, this cheap price for energy does not come without some political and economic consequences, as mentioned above.

Energy Use in the U.S.

This modern dependence on many appliances of convenience requires a lot of energy. Our current energy per capita use is about 303 million Btu's of energy[4]. Put another way, this means that the average U.S. citizen would be responsible for using about 56 barrels of crude oil each year, if all of the energy used in America came from oil. While this is not the worst worldwide in terms of usage, it is far from the best. Several tourist islands (ex. U.S. Virgin Islands) and oil-rich countries in the Middle East use significantly more (more than twice). A few Western countries, like Canada and Iceland, use slightly more. Most of the Western world, such as Germany and France, uses 200 million Btu's of energy or less. In comparison, many Third World countries such as Ethiopia use less than 10 million Btu's per person.

While China uses significantly less per capita (about 85.1 million Btu’s in 2012), the larger population puts its energy usage almost equal to our own. For the last decade, we have been fairly consistent in our energy usage per year, averaging about 100 quadrillion Btu’s per year. We have done this in light of the fact that our population is slowly increasing. In contrast, China has more than doubled their usage during that time, as it attempts to become the world’s superpower. This has increased demand for all types of energy worldwide, which caused the price to go up. One good reason the price of oil was so high in 2008 was that China went from using 4 million barrels per day in 1999 to almost 8 million per day in 2008.

The majority of the energy used in the U.S. (81%) is supplied by fossil fuels. Petroleum accounts for the largest share of this (36%), followed quickly by natural gas (29%) and coal (16%). The remaining energy comes mostly from nuclear (9%) and renewable sources like hydroelectric, solar, and wind (10%)[5]. Contrary to common belief, most of this energy is produced domestically. The only energy source which we are forced to import is crude oil, of which we can currently supply only about 66% of our need.

Of the energy used in the U.S., about 22% of it is used for industrial processes (mining, milling, etc.), 40% of it is used to create electricity to power our homes and offices, and 28% of it is used for transportation. While most of us cannot directly affect the amount of energy used for industrial processes, we can do something about our residential and transportation energy use. The figures above mean that about 100 million Btu's are used each year just to run our households (this does not include the energy that was lost in producing and transporting this energy, which accounts for an additional 70 million Btu's). The larges portion of this energy use is to heat and cool our homes (42%)[6].

Other Units of Energy

As we will point out very clearly in the next chapter with our discussion of temperature, the metric or SI system is not always the best system to use, contrary to what your high school science teacher said. There are some very clear examples where other systems of units are superior when we discuss certain applications. There are two units of energy that clearly better to use than the joule when we discuss HVAC systems and the human body.

If you have ever purchased a new air conditioner or heater, the salesperson, more than likely, discussed how many Btu’s the device either removed from the air or emitted. A **Btu, or British thermal unit**, is the amount of energy required to raise the temperature of one pound of water one degree Fahrenheit. Conversely, it is also the amount of energy that is given off from one pound of water in reducing its temperature by one degree Fahrenheit. This is important in the HVAC industry, as most industrial HVAC systems use water as the medium for moving energy from the centralized boiler/chiller to all parts of the building.

The unit of energy that is important in biological systems presents a clear case of how to confuse people by using a term that is familiar to them to define something different. This unit is the **calorie**, which is the amount of energy needed to raise the temperature of one gram of water one degree Celsius. However, this is not the unit that most of the public uses to determine how much energy is in their food. What you see listed on the label of any item in a grocery store is more accurately called a food calorie. One food calorie is equal to 1,000 calories, or one kilocalorie. This means that a food calorie is the amount of energy needed to raise the temperature of one kilogram of water one degree Celsius. Thus, a candy bar that says that it has “350 calories” which is really 350 food calories, has enough energy raise the temperature of 350 kilograms (770 pounds) one degree Celsius. As you will find in the next chapter, this is a large amount of energy.

Problems

1. How much work do you do by lifting a 15 kg box two meters into the air?
2. What happens to the kinetic energy of a car as it rolls up an incline and stops?
3. If a constant net force of 300 N is applied to a 25 kg box, what is its acceleration?
4. If a 20 kg ball is dropped from a height of 3.8 m.
   a) What is its potential energy right before it is dropped?
   b) If we neglect air resistance, what will be its kinetic energy right before it hits the ground?
   c) What is its speed right before it hits the ground?
5. What will happen to world energy prices if China continues to increase its usage at the rate that it did over the last decade? Is there any way that we in the U.S. can guard against such a price increase?
6. What would happen to the force of gravity between two objects if they were moved to twice the distance apart? What would happen if the distance were halved?
7. If you carry a large box across a level floor at a constant velocity, are you doing any work on the box?
8. If a 100 W lightbulb is left on for 10 hours, how much energy does it use? If that energy costs $.10 per kilowatt-hour, how much does this usage cost?
9. A car is moving at 25 miles per hour along a straight stretch of road. It accelerates to a velocity of 50 miles per hour. By how much does its kinetic energy increase?
10. Newton's Third Law states that, for every force, there is a reaction force. If this is true, how can there ever be a net force?

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