

TEACHER BACKGROUND KNOWLEDGE

ENERGY

WHAT IS ENERGY?

Energy can be defined as ***the ability to cause change***. Growth in plants and animals is an example of a change that requires energy. Think of other types of changes and identify the type of energy involved in these changes. This definition gives us an idea about energy, but it is incomplete.

A more precise definition of energy is ***the ability to do work***. In order to fully understand this definition, we must first understand what work is.

WORK AND POWER

It may seem like you are doing a lot of work today! But unless you are applying a force to something and moving it a certain distance, you are not doing any work, according to scientists!!! In science, if the net force (*the sum of all the forces acting on an object*) is constant (*does not change*) and the object in question is moving along a straight line due to the net force being applied, then **work is defined as the product of the magnitude of the net force and the distance moved in the direction of the force.**

$$\text{Work} = (\text{Magnitude of Net Force}) \times (\text{Distance})$$

The S.I. Unit for work is Joules (J). Work is measured numerically and 1 Joule = 1 Newton x 1 Meter.

Work is associated with both force and motion and is only done on an object when the object moves in the direction in which the force is exerted. When you push a shopping cart and it moves, you are performing work on it. But there are many cases where you may exert a force on something and, yet, do no work. For example, you may push hard against a wall, but if the wall does not move in the direction of your push, you have done no work on the wall on the macroscopic level (even if you are sweating!!!). The distance is zero, therefore the product of the force x distance is zero, so no work has been done! When you lift a grocery bag off the floor, you do work against the earth's gravity, but when you stand in one place holding the bag at a set height you are doing NO work against gravity.

VERY IMPORTANT: Physical exertion is not a measure of how much work is being done. The maximum amount of work done on an object occurs when the net force is in the same direction as the direction of motion. Any deviation from this situation will result in less work being done on the object. Finally, no work is done on the object if the direction of motion of the object is perpendicular to the net force. This makes sense if you think about “efficiently pushing something”. You get the most done (maximum amount of work) when you push in the direction you want to

move something. Someone pushing perpendicular to the direction of motion is no help at all.

The total work done on an object is often less important than the *rate* at which the work is done. **Power is the rate of doing work**, which basically is a measure of how fast work gets done.

$$\mathbf{Power = \frac{Work (Joules)}{Time (Seconds)}}$$

The S.I. unit for power is Watts (W). One watt of power is used when one joule of work is done in one second.

Differences in power can be illustrated by comparing shoveling sand with a shovel and a bulldozer. The bulldozer has more power than a human with a shovel since it does the work of moving sand in less time.

SIMPLE MACHINES

Many books will tell you that simple machines make work easier, but that is not really correct. In physics there is no free lunch. A better way to describe simple machines is that they make work more convenient. The amount of work that you need to do to move an object a certain distance does not change when you use a simple machine. Instead, simple machines allow you to make a trade-off. You can use less force to move the same mass of object, but apply that force over a farther distance. You can use

more force, but apply it over a shorter distance. Also simple machines can allow you to apply the same amount of force over the same distance but in a different direction.

From the previous section you know that $\text{work} = \text{force} \times \text{distance}$.

Because force and distance are both factors, you can increase one, decrease the other, and end up doing the same amount of work. For example:

It takes 10 newtons of force to lift a box to a 1 meter countertop, so:

$$\mathbf{W = 10N \times 1m = 10 \text{ joules}}$$

If you were to move the box to the countertop using a 2m long ramp (a type of simple machine) to push it up to the countertop instead of lifting it directly, and it took 5N of force to push it up the ramp, then:

$$\mathbf{W = 5N \times 2m = 10 \text{ joules}}$$

The same amount of work (10 joules) was done in both cases. With the ramp you wouldn't have to push as hard, you wouldn't have to exert as much force (5 newtons instead of 10 newtons), but you would have to exert the force over a farther distance (2 meters instead of 1 meter).

In the real world, measuring work will not always come out so cleanly due to the fact that there may be other forces acting on your object and depleting energy. For example, friction likely would make you use more force when pushing something up a ramp unless you had a cart (wheels

help – another simple machine), greased the surface of the ramp and box, or did something similar to reduce friction.

The basic types of simple machines are the **inclined plane, wedge, screw, lever, wheel and axle, and pulley**. Each machine allows you to use a different amount, direction, and distance of force to do work. None of them reduce the amount of energy it takes to do something. They just alter the way that energy is transferred so that the work is done under a different set of parameters.

WORK, POWER, AND ENERGY

When an object does work on another object, some of its energy is transferred to that object. You can think of work, then, as the transfer of energy. When energy is transferred, the object upon which the work is done gains energy. If the transfer of energy is work, then power is the rate at which energy is transferred, or the amount of energy transferred in a unit of time. When wind moves a leaf, it causes the leaf to change position (motion) and has done work on the leaf. So the wind has energy. Power is involved when energy is being transferred. For example, a calm breeze has power when it transfers energy to lift a leaf a certain distance. A tornado transfers the same amount of energy when it lifts the leaf the same distance. However, the tornado has more power than the breeze because it transfers the energy to the leaf in less time.

KINETIC ENERGY AND POTENTIAL ENERGY

The two basic kinds of energy are kinetic and potential energy. The energy associated with motion (*kinetic energy*) and position (*potential energy*) of everyday objects.

- **Kinetic Energy**

An object that is moving can do work on another object by colliding with that object and moving it through a distance. For example, a ball does work when it breaks the glass of a window. Because an object in motion has the ability to do work, it has energy. The energy of motion is called kinetic energy (KE). When work is done on an object at rest, such as a ball, the object is accelerated to some velocity and gains kinetic energy. If the object is already moving, the work goes into increasing the kinetic energy. Kinetic energy of an object depends on both the mass and the magnitude of velocity:

$$\text{Kinetic Energy} = \frac{\text{Mass} \times (\text{Magnitude of Velocity})^2}{2}$$

The S.I. Unit is Joules (J).

Do all objects with the same mass have the same kinetic energy? No. Think about someone gently tossing a ball at you, it has a little bit of energy. Now have the person throw the same ball much faster and you will notice

the difference in energy! *The faster an object moves, the more kinetic energy it has (assuming mass remains constant).*

Do all objects with the same velocity have the same kinetic energy? No. Think about a tennis ball rolling over your foot at 5 miles per hour, it probably would not hurt. Now think of a bowling ball (larger mass) rolling at 5 miles per hour into your foot, this time it would probably cause a bruise! *The more mass an object has, the more kinetic energy it has (assuming velocity is constant).*

Suppose you are moving a heavy shopping cart, you must exert a force on the cart to move it (work). Before the cart moved, it did not have kinetic energy because it did not have velocity (plug in zero for the magnitude of velocity into K.E. formula). As you give it kinetic energy, the cart picks up velocity. The more work you do, the faster the cart will move. When you increase the velocity of an object, you increase its kinetic energy. The change in kinetic energy of the cart is equal to the work you have done on it. This is known as the Kinetic-Energy Theorem.

The most common type of kinetic energy is the motion of macroscopic objects. However, there are other forms of energy that involve motion. Thermal energy, or heat, is a measure of the motion of particles in matter. Electromagnetic energy involves the motion of electromagnetic waves (such as light).

NOTE: Even particles in matter have kinetic energy because the particles in matter are in constant motion, even in a solid (more details in Thermal Energy - Heat section).

- **Potential Energy**

An object does not have to be moving to have energy. Some objects have stored energy due to their positions. The *potential energy of an object is the capacity of that object to do work due its position*. An object can be given potential energy by moving it against an opposing force, like lifting it up against the force of gravity (***gravitational potential energy***) or pushing it into a compressing spring (***elastic potential energy***). Drop the object or release the spring and work is done as the potential energy converts to kinetic energy.

Potential energy is related to work in a different way than kinetic energy is. Remember that a moving object has kinetic energy because it can do work as it moves. But an object with potential energy is not moving or doing work. Instead, it is storing the energy that was given to it when work was done on it (e.g. lifting against gravity or pushing a spring). It has the ability, or potential, to give that energy back by doing work.

Gravitational Potential Energy (G.P.E.) is dependent on height:

$$\mathbf{G.P.E. = Weight \times Height}$$

The S.I. Unit is Joules (J).

We can see from this formula that the greater the weight of an object, the greater the gravitational potential energy. The higher the position above the surface, the greater the gravitational potential energy of that object.

Chemical Energy can also be thought of as potential energy. Energy is required to bring atoms together to form bonds (work is done). These bonds have potential energy. When these bonds are broken the energy is released and can be used to do work.

FORMS OF ENERGY

- **Mechanical Energy**: is a form of energy associated with position and motion of an object. An object's mechanical energy is a combination of both its potential and kinetic energy, for example, a swinging pendulum. When moving, the pendulum sphere has kinetic energy. At some point in its path, the sphere is suspended in mid-air and now has potential energy. Sometimes an object's mechanical energy exists only in the form of kinetic or potential energy. A car moving along a flat straight road possesses kinetic energy only. A vase resting on a table has gravitational potential energy only. But both have mechanical energy. Examples of objects with mechanical energy include: speeding train, bouncing ball, swinging pendulum, falling water, and moving sound waves.

- **Thermal Energy:** All matter is made up of tiny particles that are in constant motion. Because these particles are constantly in motion, they have kinetic energy. The faster the particles move, the more kinetic energy they have. The motion of these particles is called thermal energy (heat), so really the faster the particles move, the more heat or thermal energy is produced. The particles in flowing lava have a large amount of kinetic energy, so the lava has a large amount of thermal energy or heat. Rub your hands together for several seconds. Did you feel the heat? Using the friction between your hands, you converted mechanical energy into thermal energy (heat)! Heat can result from friction (a force that acts in the opposite direction of motion of two surfaces that are touching each other).
- **Chemical Energy:** is the (potential) energy stored in chemical bonds. Chemical compounds are made up of atoms and molecules held together by bonds. Energy was required to create these bonds. When these bonds are broken, that energy is released. Examples include: energy stored in wood, fossil fuels, food, and gasoline.
- **Electromagnetic Energy:** Moving electric charges have the ability to do work because they have electromagnetic energy. **Electrical energy** is the energy of electric charges. Depending on whether the charges are

moving or stored (not moving/static), electrical energy can be a form of kinetic or potential energy. You can feel electrical energy when you receive a shock from a metal doorknob. Electrical energy can be found in lightening, batteries, and power lines. **Light**, even non-visible light such as x-rays, radio waves and laser light, is a form of electromagnetic energy. Electromagnetic energy travels in waves. These waves have some electrical properties, magnetic properties, and can travel through space as well as through matter.

- **Nuclear Energy:** The nucleus of an atom is the source of nuclear energy. When the nucleus splits, nuclear energy is released in the form of heat and light. Nuclear energy is also released when lightweight nuclei (plural for nucleus) collide at high speeds and fuse (join). The sun's energy is produced from a nuclear fusion reaction in which hydrogen nuclei fuse to form helium nuclei. Nuclear energy is the most concentrated form of energy.

ENERGY CONVERSIONS

Most forms of energy can be converted into other forms. A change from one form of energy into other forms is called **energy conversion** (Fig.1, Fig.2). Obtaining useful energy may require multiple conversions, for example: striking a match changes mechanical energy into chemical energy,

which is then converted into thermal energy, and finally into electromagnetic energy (light).

One of the most common energy conversions involves the changing of potential energy into kinetic energy or kinetic energy to potential energy. A stone held high in the air has potential energy. As it falls, it loses potential energy because its height decreases. At the same time its kinetic energy increases because its velocity increases. Thus, potential energy is converted into kinetic energy.

Although conversions between kinetic energy and potential energy are common, they are not the only changes in energy that take place. Here's an example of a whole series of energy conversions: the operation of a toaster. Let's start with the chemical energy of a fuel source, such as gas, which is released by burning it. The fuel provides thermal energy, which in turn is converted into mechanical energy. This mechanical energy is used to make a generator do the work of providing the toaster with electromagnetic energy in the form of electricity. When you start the toaster, the electricity is changed back into thermal energy.

The first law of thermodynamics (law of conservation of energy), states: **Energy cannot be created or destroyed but may be converted from one form to another.** The total amount of energy in the universe is constant, that is, it is conserved. Walk through some of the pictures in

your textbook and identify the various forms of energy and their conversions (using figure 1 and 2 as a reference).

How Can Different Types of Energy Convert Between Each Other?

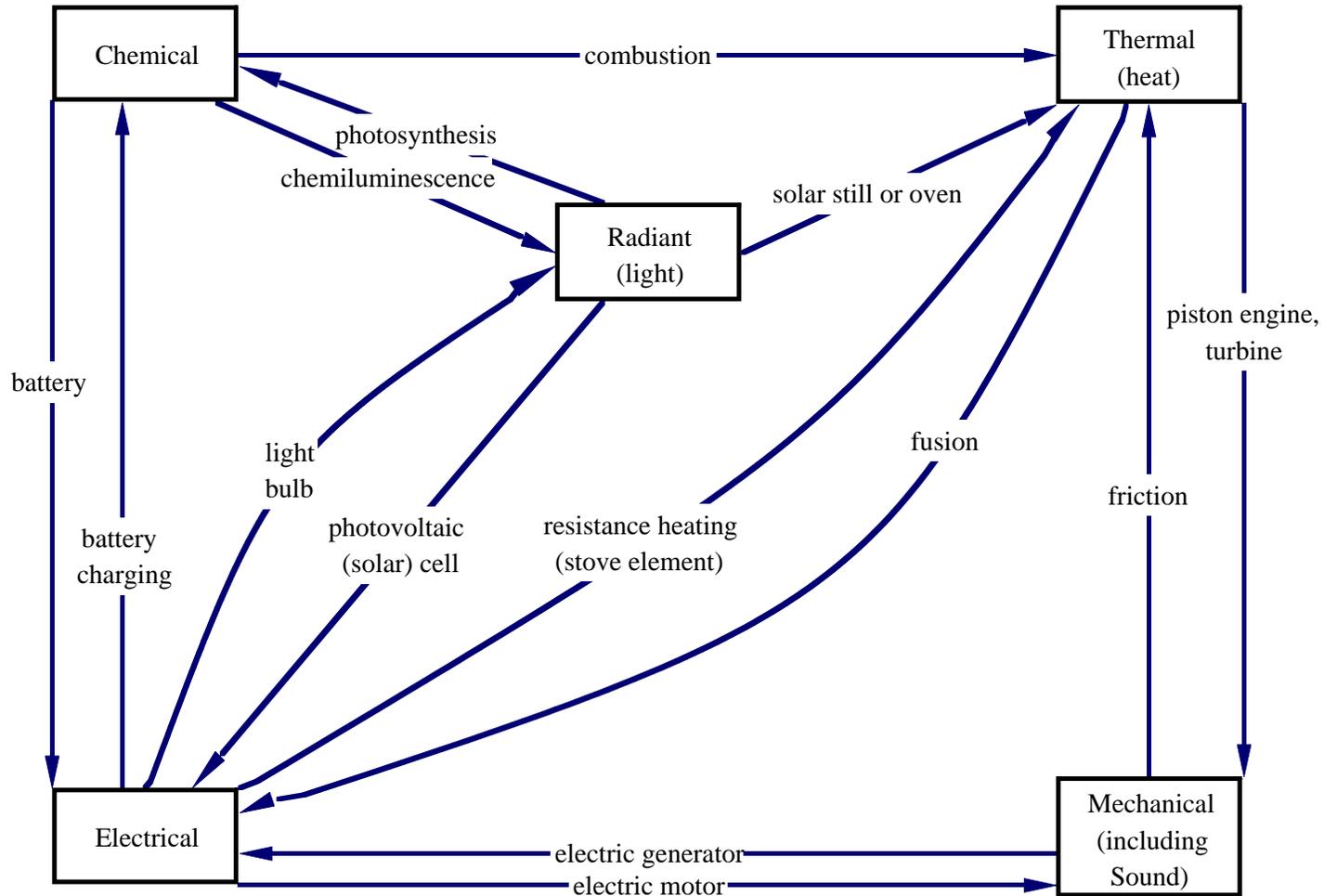


Figure 1 - Some forms of energy and their conversion pathways

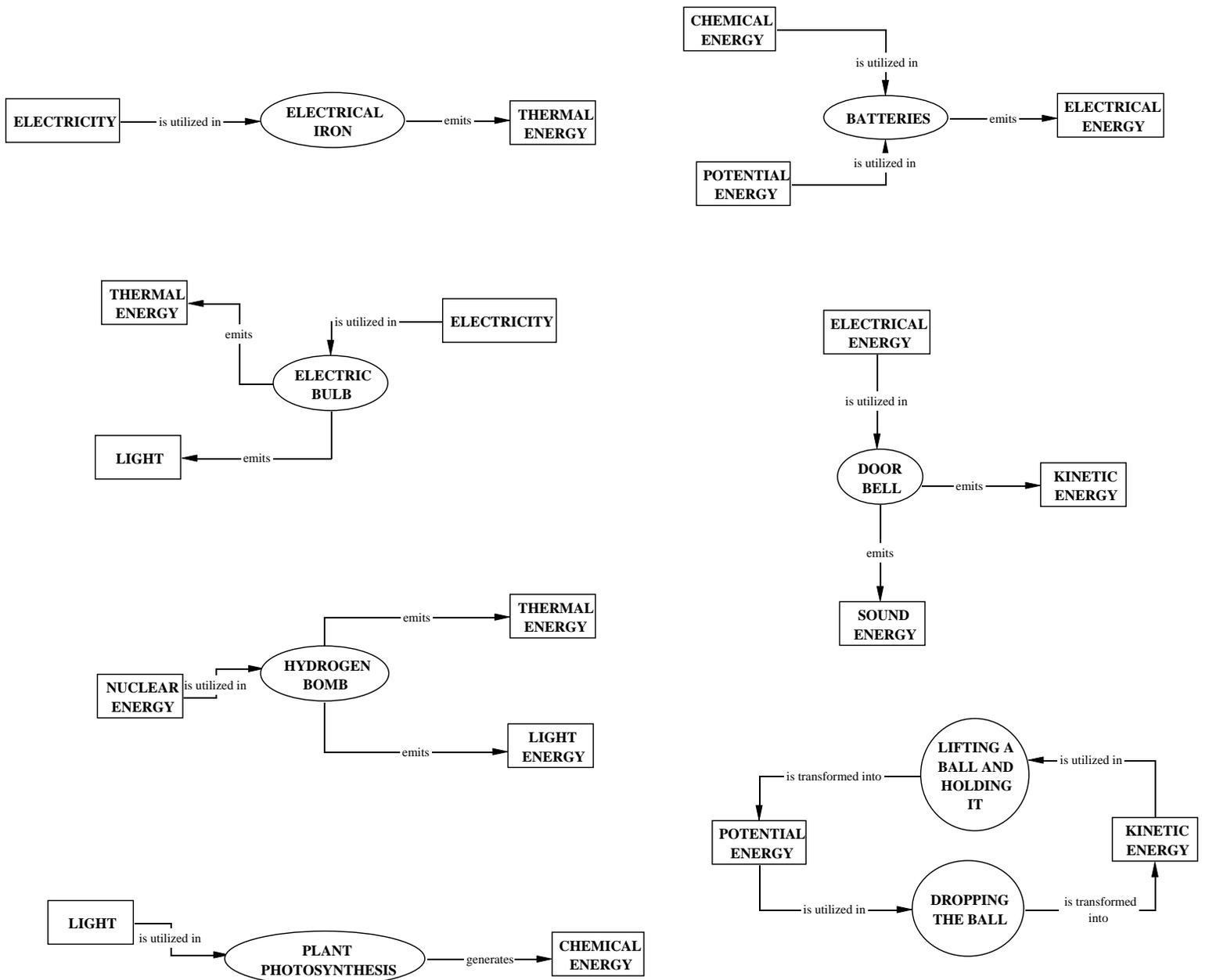


Figure 2 - Examples of energy conversions.