Name ______________________________

The Second Law of Thermodynamics

The second law of thermodynamics: "Heat always flows from hot areas to cold areas" (simplified).

What does the *first* law of thermodynamics state?

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Demonstration: Air and Water in Balloon

Watch demonstration by teacher.

Discuss what happened when the flame was applied to the balloon WITHOUT water. Why do you think this happened?

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Based on the second law of thermodynamics and **heat flowing from hot areas to cold areas**, complete the following hypothesis:

IF a flame is placed on the balloon which is filled with cold water

THEN the balloon ____

BECAUSE ____

Experiment: Build a Heat Engine

With the teacher's help, and using the second law of thermodynamics, try and explain why your machine is rotating in the water.

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Review:

- ✓ Heat flows in what direction? ___________________________
- ✓ A heat engine works because

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- ✓ The "work" done by the engine is an example of what other thermodynamics law? __________________________________

The Second Law of Thermodynamics

Teacher Notes

The second law of thermodynamics: "Heat always flows from hot areas to cold areas" (simplified).

What does the *first* law of thermodynamics state?

"That energy is neither created or destroyed, but can only be converted from one form to another."

Teach

The second law of thermodynamics is also called the law of entropy. Unfortunately, the laws of thermodynamics are not intuitive and can be quite difficult to grasp. For the sake of simplicity, this lab will not discuss entropy *per se*, but will instead provide a qualitative description. Neither will it discuss the laws of probability that go into a thorough description of entropy.

Instead, this lab is designed for young people to get their head around the basic principles.

The definition this lab provides gets to one of the most basic second law principles (yes, there are others!), but more importantly as we shall see a little later, it allows the students to apply the law to real life and the workings of engines.

In one of its simplest forms, the second law of thermodynamics describes the movement of heat energy. Heat energy always moves in a single direction, from hot to cold. Put an ice cube in a cup of boiling water and the heat from the cup will quickly move into the ice and melt it. This scenario will never go the other way. Heat cannot flow from a cold object to a hot object. If it did, the ice cube would not melt even though the water is boiling!

(Statistical thermodynamics can be very confusing because it posits it is, although highly unlikely, *possible* for this to happen. But in real life, and even given all the time in the universe this would never occur. In other words, it is for all intents and purposes impossible.)

Not only does heat energy always flow from hot to cold, it also diffuses out into space. Think of a fire producing smoke. The smoke always diffuses out and eventually disappears. You will never see this occurring in reverse! Or think of the air in the room right now. You are breathing in nitrogen and oxygen that is evenly dispersed throughout the room. These evenly distributed molecules will never push themselves into a corner of the room. If they did, you would end up with a vacuum and would not be able to breathe!

So, what do gas molecules have to do with energy? Well, heat energy is transferred in the atoms that make up the gas. The gas molecules in your room contain heat that is constantly seeking to find cooler states. If it is cold outside and you leave the window open, the warm air in your room will naturally want to move outside. This is the key to this aspect of the second law of thermodynamics.

As we shall see, this is all very practical and is fundamental to life as we know it!

Demonstration: Air and Water in Balloon

Fill a balloon with air and place it over a flame. The balloon will burst. Now fill a balloon with water over the flame. The balloon will not burst, at least not straight away!

Watch demonstration by teacher.

Discuss what happened when the flame was applied to the balloon WITHOUT water. Why do you think this happened?

The heat from the flame moved into the water because according to the Second Law of Thermodynamics, heat flows from hot areas to cold areas. There was simply too much heat for the air to absorb.

Based on the second law of thermodynamics and heat flowing from hot areas to cold areas, complete the following hypothesis:

IF a flame is placed on the balloon which is filled with cold water

THEN the balloon will not burst

BECAUSE according to Newton's second law, heat flows from hot areas to cold areas, and so all the heat from the flame moved into the water.

Teach

The heat from the flame did move into the "cold" air just around heated rubber, but there was just way too much heat for the air to absorb. The water, however, is able to absorb lots and lots of heat. So, all of the heat applied to the rubber moved into the water, keeping the rubber cool. Just for fun, keep the flame on the balloon until it bursts. You may have to move the flame to a location nearer to the air in the balloon. Prepare to get wet but the students will love it!

Experiment: Build a Heat Engine

Use tealight candles, 3.0 mm copper tubing (aluminum or even steel tubing is ok too, but not as efficient), cork, a hacksaw, and a tub of water. I got my copper tubing from a hobby store for just a few dollars.

Roll the copper tubing around a solid object so that you end up with a circle about 2.5 – 4.0 cm (1.0 to 1.5 inches) in diameter (see video). Cut the corking (as in video). Bend the ends of the tubing so as to act as a propulsion system (see video). Fill the tubing with water, put engine in place on the cork, light the candle, and place entire engine in the water (see video).

The principle of this homemade engine is, although simple, the basis for all heat engines including those that are at work in your car! That is why the second law is so practical!

The flame heats the water in the tubing. This causes the water to turn into steam (a gas). The energy in the flame has been transferred into the gas molecules (the first law of thermodynamics). And here is where the second law of thermodynamics kicks in. The hot gas can only move in a single direction. No, and it's not because the copper pipe is enclosed with only two ends! If the piping immediately to the right and the left of where the flame is burning were supercooled, the heat from the gas inside the piping would find its way into the copper at those supercooled locations. This would stop the gas from travelling down the pipe!

So, because the hot gas must find a cold sink, it travels down the piping to the even colder ends which are submerged in water. And this is where humans can utilize the second law of thermodynamics! The molecules of gas that exit the pipe can be used to do work. And that is exactly what they are doing in our engine. The molecules are being pushed out of the piping which propels the engine in a circular motion.

More precisely, the air molecules bang against the copper tubing at all locations within the tube. But, just before the water exists into the water, many more molecules will smash into the outside corner of the two bends. This produces a net force in that direction which causes the whole device to rotate.

The gas molecules can also be used in a turbine. Imagine a tiny little fan blade sitting inside the copper tubing. As the molecules hit the blade, it would turn. This mini turbine could be connected to an axel which in turn can be used to drive wheels (as in a steam engine).

Review:

- ✓ Heat energy flows in what direction? Hot to cold
- ✓ Heat energy always spreads out into space
- ✓ A heat engine works because
  Energy trapped in gas molecules must move from hot to colder areas. Since gas molecules are small objects, they are able to push on other objects and do work