Vibrations and Frequency

In previous lessons we've learned that energy is the ability to do work, and that work is moving something a distance against a force. The concept of energy is fairly easy to see as far as lifting things or pushing things go. We are exerting energy to lift a box against the force of gravity. We are exerting energy to pedal our bike up a hill. But how does this energy stuff relate to light, electricity, or sound? What's moving against a force there? As usual, you have asked an excellent question! With much energy, what's happening is that outrageously tiny particles are moving back and forth outrageously tiny amounts, at outrageously high speeds. With light you've got little photons moving, with electricity little electrons and with sound you've got molecules moving back and forth. This back and forth motion is called vibration and these vibrations make waves. When one particle moves back and forth, it does work on another particle, which does work on another particle and so on. As these particles do work on one another, they cause a wave to move from one place to another. Energy moves by waves or, in other words, waves are energy-mobiles! Before we get in over our heads talking about waves however, we need to spend some time on this vibration thing. This lesson we will be taking a careful look at vibration and frequency.

Frequency

The concept of frequency is very important to understanding energy. When it comes to electromagnetic waves it is frequency that determines whether the wave is radio, light, heat, microwave or more. It's all the same type of energy, it's the frequency that determines what that energy actually does. With sound energy the frequency determines the pitch of the sound. As we move forward with energy, it is quite important that you know that all waves come from some sort of vibrating particle somewhere. The reason you can pick up a signal on your radio is because somewhere, maybe miles away, there is a particle vibrating at some ridiculous speed, creating a wave that moves across distances to finally vibrate the particles inside your radio's antenna. It's important to realize, however, that the particle does not move over that distance. The particle that started the wave back at the radio station is still there. It did not move to your radio it just vibrated at the antenna and started the wave.

Frequency is a measure of how many times something moves back and forth. A swing, a pendulum, a leg of a walking person all have a frequency. All those things start at one place, move, and come back to the same position that they started. This moving and coming back is one vibration. The faster something vibrates, the more frequency that something has.

Hertz

Frequency is measured in Hertz. One Hertz (or Hz for short) is one vibration in one second. The Hertz is named after Heinrich Rudolf Hertz (1857-1894) a German physicist and professor. Hertz proved that electricity can be transmitted in electromagnetic waves, which travel at the speed of light and which possess many other properties of light. His experiments with these electromagnetic waves led to the development of the wireless telegraph and the radio. A Hertz is a relatively slow vibration so there are also kilohertz (KHz), megahertz (MHz), and gigahertz (GHz). A kilohertz is 1000 Hz, a megahertz is 1,000,000 (a million) Hz, and a gigahertz is 100,000,000 (one thousand million) Hz. Some examples of things that work at these frequencies are AM radio stations which broadcast at KHz, FM stations which broadcast at MHz, and microwaves which cook your food with GHz. If your radio is "crankin" tunes from radio station 750 AM, a part of your radio is vibrating at 750,000 times a second. If you're "pumping wattage into your cottage" with WSCI at 94.2 on your radio dial, a part of your radio is vibrating at 94,200,000 times a second. If your radio happens to be green then light is vibrating off your radio at 6×10^{14} Hz. That's 6 with 14 zeros behind it or 600,000,000,000,000 vibrations in one second. That's some serious vibes! By the way, if you can hear the sound coming out of your radio, your speakers are vibrating anywhere between 20 and 20,000 Hz. See how vibrations are important? They're everywhere!

Let's do a couple of experiments and see if we can get this vibration thing down pat.

Experiment 1
Make it Hertz So Good

You need:

3 Foot Long String
A Weight that can be tied to the end of the string
A Timer or Stopwatch
Masking Tape
A Table or Chair
A Partner is helpful

In this experiment you will be adjusting the length of string of a pendulum until you get a pendulum that has a frequency of .5 Hz, 1 Hz and 2 Hz. Remember, a Hz is one vibration (or in this case swing) per second. So .5 Hz would be half a swing per second (swing one way but not back to the start). 1 Hz would be one full swing per second. Lastly, 2 Hz would be two swings per second. A swing is the same as a vibration so the pendulum must move away from where you dropped it and then swing back to where it began for it to be one full swing/vibration.

1. Tie your weight (the official name of the weight on the end is bob. Personally I've always preferred the name Shirley, but Bob it is.) to the end of the 3 foot string. If you've done the gravity lesson in the Mechanics set of lessons you'll remember that the weight of the bob doesn't matter. Gravity accelerates all things equally, so your pendulum will swing at the same speed no matter what the weight of the bob.

2. Tape the string to a table or chair or door jam. Make sure it can swing freely at about 3 feet of length.

3. I would recommend starting with 1 Hz. It tends to be the easiest to find. Then try .5 Hz and then 2 Hz.

4. The easiest way I've found to do this is to start the pendulum swinging and at the same time start the timer. Count how many swings you get in ten seconds.

5. Now, adjust the string. Make it longer or shorter and try again. When you get 10 swings in 10 seconds you got it! That's one swing per second. You should be able to get quite close to one swing per second which is 1 Hz.

6. Now try to get .5 Hz. In this case you will get 5 swings in ten seconds when you find it. (A little hint, the string is pretty long here.)

7. Now speed things up a bit and see if you can get 2 Hz. Be prepared to count quick. That's 2 swings a second or 20 swings in 10 seconds! (Another little hint, the string is quite short for this one.)

Did you get all three different frequency pendulums? It takes a while but my classes found it rather fun. You've created three different frequencies. 2 Hz being the fastest frequency. That was pretty fast right? Can you imagine something going at 10 Hz? 100 Hz? 1,000,000 Hz? I told you things were moving at outrageous speeds!

Experiment 2
Good Vibrations

This will let you see how a vibration can create a wave.

You need:

At least 10 feet of rope (if you have 25 or 50 feet it's more fun)
A partner

1. Give one end of the rope to your partner.

2. Stretch the rope out so that it is a bit slack.

3. Now move your hand up and down. Feel free to do it several times in a row. Your partner should keep his or her hands as still as possible.

4. Watch the waves move from your hand to the other end of the rope.

5. Now let your partner create waves.

6. If you wish, you can try to time your vibrations and create waves with specific frequencies. A frequency of one Hertz is fairly easy to do (one rope shake per second). Can you create rope waves of higher frequencies? You may find that your arm gets tired pretty quickly!

Your hand is the vibrating particle. As your hand vibrated up and down, you moved the particles of the rope up and down. As those particles of rope vibrated, they vibrated the particles next to them. As they vibrated, they vibrated the particles next to them and so on and so forth. So the wave moved from your hand across the room. Did your hands move across the room. Nope, but the wave you created with your vibrating hand did. This is the way energy travels. Why is the rope wave energy? Because the particles moved a distance against a force. Work was done on the particles. In fact, when you shook the rope, your energy from your body moved across the room with the wave and was transferred (moved to) your partner. Your partner's hands could feel the energy you put into the rope in the first place. The work you did on the rope was transferred by the rope wave and did work on your partners hand. You have moved energy across the room!

In a Nutshell

Energy moves by waves.

All waves begin as vibrating particles.

The particles vibrate back and forth.

They do not move along the wave.

Frequency is the amount of vibrations there are in a given amount of time.

Hertz is a measurement of frequency and is one vibration per second.

Did You Get it?

1. What starts waves?

2. Where is work being done in a wave?

3. With the rope wave, what moved from partner to partner?

4. What is frequency?

5. What is Hertz?

6. If a swing is vibrating at .5 Hz, how many times does it go back and forth in 1 second?

7. If a yo-yo goes up and down 10 times in 10 seconds what is its Hertz?

8. If you create a rope wave by moving your hand up and down twice in one second, what's the Hertz of that wave?

Answers to Did You Get It

1. Vibrating particles of some sort.

2. Work is done by the particles moving a distance against a force.

3. Energy. The particles didn't move from partner to partner, the rope didn't move across the room, the energy from one person moved in the form of a wave across the room.

4. Frequency is how many times something vibrates in a second. Something that is vibrating quickly is said to have a high frequency, something that is vibrating slowly is said to have a low frequency.

5. A Hertz is a measure of frequency. One Hertz is one vibration per second.

6. One half a time. The swing would swing forward or backward in one second. It would not go back and forth.

7. The yo-yo's Hertz would be one. One vibration (up and down) per second would be 10 vibrations in 10 seconds.

8. 2 Hz. 2 vibrations per second.