PLASMA SCIENCES EXPO 2011

November 17 and 18
Suggested Student Questions
(WITH ANSWERS)

Brigham Young University

Ross Spencer (ross_spencer@byu.edu)

By literally "waving your hands" explain the difference between transverse and longitudinal waves. What kind of a wave is involved in the "singing rod?" What kind of wave is involved in the Chladni plate?

Answer: If your hands make a side-to-side snaky motion, the wave is transverse. If your hands move together and apart, the wave is longitudinal. Singing rod: longitudinal. Chladni plate: transverse.

How are the waves in the singing rod and Chladni plate excited?

Answer: These are "stick-slip" oscillations where alternate sticking and slipping of fingers or the bow combine with wave motion in the rod or the plate.

What kind of wave interference is a standing wave and why do soldiers break their marching cadence when they cross a bridge?

Answer: Standing waves are the interference of two waves traveling in opposite directions. Soldiers break step on a bridge so they don't excite standing waves that could collapse the bridge.

Contemporary Physics Education Project (CPEP)

Sam Lightner (lightner@westminster.edu)
Cherie Harper (gsphysics@live.com)

Of the three types of energy-releasing reactions (chemical, fission, fusion) which one releases the most energy per kg of fuel?

Answer: fusion

List three naturally occurring plasmas that exist in space beyond the Earth's atmosphere.

Answer: solar corona, solar core, solar wind, nebula, interstellar space

In the fusion simulation done at the booth, what specific nuclei do the large and small bottle tops represent?

Answer: Large = Tritium (T, Triton), Small = deuterium (D, Deuteron)

General Atomics

Rick Lee (leer@fusion.gat.com)

What is gaseous plasma and why is it referred to as the 4th state of matter?

Answer: Gaseous plasma, or just plasma, is ionized gas. An ionized gas is produced when one or more electrons are removed from an atom or molecule of gas. This removal of electrons results in separating the positively charged ions and negatively charged electrons. The path of travel of each of these charged particles can be influenced using electric and magnetic fields. Examples of plasma include: lightning, sparks, the discharge inside of a fluorescent tube, the aurora borealis (or australis), the sun and other stars, and discharges inside high-temperature magnetically confining tokamaks. While plasma was present in the universe before solids, liquids, and gases, it wasn't characterized as the 4th state of matter until well after the establishment of solids, liquids, and gases as the (first) three states of matter.

General Atomics – Continued

What is the most abundant element in the universe? Through what process is this element incorporated into heavier elements?

Answer: Hydrogen (single proton in nucleus, single electron outside of nucleus) is the most abundant element in the universe. Most of the hydrogen present today was formed more than 13 billion years ago, just after the Big Bang. Hydrogen is incorporated into heavier elements through fusion. Fusion is the process of bringing nuclei together to form another nucleus; the fusion process will lead to energy release if the reacting nuclei are less massive than (or about equal in mass to) iron, cobalt or nickel; the fusion process requires energy if the reacting nuclei are more massive than iron, cobalt, or nickel.

How is electricity generated that comes into your home?

Answer: Depending on the region, electricity production may start with coal, oil, natural gas (methane), fission, solar power, or hydroelectric. In general, a turbine (a set of closely spaced fan blades) is spun which, in turn, spins an electrical generator. One can spin the turbine using steam produced from heated water or by wall falling, thereby producing electricity from the connected generator. There is a large distribution system made of wires, cables, poles, transformers, and more that students may be familiar with.

Suppose oil production peaked (maxed out) in 15 years. How old will you be? How will you rely on oil in 15 years? How will you rely on oil in 30 yrs? How will your children rely on oil?

Answer: A 15-year-old student will be 30 years old. Gasoline availability (more $$) will probably be less than seen today, electricity will still be produced using oil. Cosmetics, plastics, pharmaceuticals, and all other organic chemistry-based products will become more expensive as the raw material, oil, becomes increasingly scarce. Your children will probably rely on oil for (a guess) about 20% of the electricity production. Hopefully, more energy dependence on truly long-term methods, such as fusion, will be realized.

The Laboratory for Laser Energetics (University of Rochester)

Reuben Epstein (reps@lle.rochester.edu)

What do the letters in the name LASER stand for?

Answer: Light Amplification by the Stimulated Emission of Radiation.

What amount of seawater contains an amount of fusion energy equivalent to the energy in the world's oil reserve? In other words, what volume of seawater, in cubic kilometers, would this be?

Answer: One cubic kilometer.

What kind of rocket is used to compress fusion fuel to high density?

Answer: The rocket is a spherical rocket, compressing the spherical fuel volume to a greatly reduced volume. The rocket is also a laser-driven rocket, where the laser heats the outer surface of the fuel capsule. This causes the outer surface to vaporize and expand rapidly, creating the rocket thrust.

Lawrence Livermore National Laboratory

Steve Allen (allens@fusion.gat.com)
Josh King (kingjd@fusion.gat.com)

How do radio waves, visible light, and X-rays differ as components of the electromagnetic spectrum?

Answer: Each has its own unique wavelength and frequency.

Why do astronomers use radio, visible light and X-ray telescopes to collect data about the sun and other stars?

Answer: The universe contains numerous types of stars that emit energy at different parts of the electromagnetic spectrum.

Lawrence Livermore National Laboratory –continued

What COLOR is common to the plasmas that we see on earth (like the tokamak) and in the sky (like the Orion Nebula)?

Answer: Red

MIT Plasma Science and Fusion Center

Paul Rivenberg (rivenberg@psfc.mit.edu)

Name at least four examples of plasmas.

Answer: Sun, stars, aurora borealis; lightning and electric arcs; fluorescent light bulbs; fusion experiments; neon signs.

Why are magnets used to confine plasmas in some fusion experiments?

Answer: Fusion plasmas are so hot that they will melt anything they touch. Obviously it would be difficult to contain such a hot plasma in any device. But because plasmas are made of electrically charged particles they respond to magnetic fields. In a fusion experiment, magnets are used to push the plasma away from the inner walls of the fusion experiment (i.e., the vacuum vessel). This only works because the plasma is made of ions and electrons, which are electrically charged. You can't push on a gas with magnets since a gas is made of neutral atoms.

Name two ways plasmas could be used to help people.

Answers: A) Plasmas from fluorescent lights allow people in buildings to see what they're doing when it is dark outside. Fluorescent lights also use less than half as much power to produce the same amount of visible light as incandescent light bulbs, so they save people money.
(More answers on following page)

B) Plasmas can be used to process solid wastes or chemical spills in soil, destroying toxic compounds or converting them into safer forms. At the Hanford site in Washington State, which the Department of Energy describes as "the world's largest environmental cleanup project," plasma was used to target and destroy carbon tetrachloride pumped from the soil.

C) Although fusion energy is not yet a reality, scientists expect that energy produced from fusion plasmas will one day create less radioactive waste than nuclear fission and less carbon dioxide than fossil-based fuels.

D) The sun is a burning plasma that supplies the earth with almost all of its energy. It makes it possible for plants to grow through photosynthesis.

MIT's UV Protection Test

Phil Michael (michael@psfc.mit.edu)

What is UV? What does the UV index signify in the daily weather report?

Answer: The sun emits electromagnetic radiation over a wide range of wavelengths. In addition to visible light, the sun emits higher energy, shorter wavelength ultraviolet (UV) radiation that is divided into categories based on wavelength: the UV-C portion of the spectrum ranges from 100 nm to 290 nm; UV-B ranges from 290 to 320 nm; and UV-A from 320 to 400 nm. Shorter wavelength radiation has greater energy and can do more damage to your skin. Fortunately, the high energy UV-C is almost completely blocked by the earth's atmosphere.

The UV index is a measure of the risk level of skin damage due to UV exposure at the sun's highest point during the day. Its purpose is to help people to effectively protect themselves from over exposure to UV.

MIT's UV Protection Test – continued

What are possible long-term effects of UV exposure on skin?

Answer: UV-A penetrates deeply into skin and can cause toughening, premature aging and wrinkling. U-VB affects the outer layer of skin and is primarily responsible for sunburns. Long-term exposure to high levels of U-VA and U-VB can cause eye damage (including cataracts) and skin cancers.

What does the "SPF" mean on a tube of sun block? What does the SPF rating indicate?

Answer: SPF stands for Sun Protection Factor. The SPF number is a measure of the effectiveness of a sunscreen to prevent burning by UV-B. Higher SPF numbers mean better protection.

How effective are YOUR sunglasses or favorite sunscreen at protecting you from the sun's UV? (Bring sunglasses).

Answer: The sunscreen and sunglass tester in our booth uses ultraviolet lamps to simulate the ultraviolet portion of sunlight, and sensitive spectrometers to demonstrate how effective your sunscreen or sunglasses are at blocking UV.

Nevada Terawatt Facility (University of Nevada)

Phyllis Schmidt (phylliss@unr.edu)

How does the sun produce light and energy?

Answer: Through fusion reactions. That is, two Hydrogen atoms fuse into a Helium atom plus energy. This occurs at the center of the sun. Large amounts of heat and light are released.

What does an electric current traveling through a wire produce?

Answer: Concentric lines of magnetic field.

Does the sun emit anything that strikes the earth other than light?

Answer: Yes, the solar wind. This is a moving gas of charged particles (plasma) that impinges on the earth. The solar wind, consisting mostly of electrons and protons, can cause auroras and geomagnetic storms.

Princeton Plasma Physics Laboratory

Deedee Ortiz (mortiz@pppl.gov)

What is the difference between a gas and a plasma?

Answer: A plasma is a hot gas that can conduct electricity and is effected by magnetic fields.

Name a naturally occurring plasma and a human-produced plasma.

Answer: The sun, stars, lightning, The Northern Lights, a flame, a neon light, a fluorescent light...

The plasma inside a fluorescent light is approximately 10,000 degrees Kelvin. Why is the glass of the bulb warm but not hot?

Answer: The pressure inside the bulb is much less than atmospheric pressure. The plasma does not have a sufficient heat capacity to increase the temperature of the glass to such a large amount.

U.S. ITER Office, Oak Ridge National Laboratory

Jamie Payne (paynejp@ornl.gov)

What is the ITER project?

Answer: ITER is an international collaboration between partners China, European Union, India, Japan, Korea, Russia and the United States to build a burning plasma experiment.

ITER – continued

What kind of reaction, which occurs naturally on the Sun, does the ITER project hope to achieve on Earth?

Answer: A self-burning (or self-sustaining) fusion reaction.

What are the advantages of fusion energy?

Answer: It is a safe, abundant, carbon-free form of energy.

Institute for Research in Electronics and Applied Physics
University of Maryland

William Young (wcyoung@umd.edu)

What is resonance? Name an example?

Answer: Resonance is the accumulation of energy from adding small amounts of energy at the correct frequency to an oscillating system. By pushing and pulling (or turning on and off) an input to a system at the right times, a large response builds up over time, resulting in much larger movements, electrical currents, or other reactions than a single push or pull can produce alone.
Examples: Playground swing, pendulum, musical instruments, a Tesla coil.

How do sparks and lightning make sound?

Answer: Sparks and lightning heat the air to very high temperatures. Gas expands when heated, so the sparks cause the air to expand quickly, pushing a wave of air outward away from the spark. This wave of air is the thunder we hear from lightning, or if repeated many times a second, the tone or hum from a spark.

How does a fluorescent light bulb work, and how can they light up without anything connected?

Answer: In fluorescent lights, electrons are accelerated by external power until they hit atoms, transferring energy, which the atoms then release as light. In order to work, fluorescent lights require a strong electric field to push the electrons, but not a large number of flowing electron. So a large enough electric field from outside the tube will still light it up.

University of Utah

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Where does a capacitor store its charge?

Answer: Some of the charge in a charged capacitor is stored in the insulator that separates the two conductors.

What happens when you charge a human to 50,000 volts?

Answer: If the person is raised to 50,000 volts slowly, he will suffer no adverse effects, although if the surroundings are not raised to the same voltage, the person's hair may stand on end. However, if a person changes voltage suddenly, it may be a shocking experience.

What will happen if a stack of pie tins is placed on top of a Van de Graaff generator, which is then turned on?

Answer: The pie tins will become charged and then repel each other and fly off one by one.

Eric Held (eric.held@usu.edu)

How does the vandegraff build up charge and how is this different than what is in the wall circuit?

Simple answer: This is similar to rubbing ones feet across the carpet or rubbing a balloon on your head. The rollers are where this rubbing occurs. As the belt goes round and round imagine rubbing your feet a lot really quickly. The charge then is built up on the ball and once it reaches a large enough voltage it will jump across the air and discharge through the available route, generally you:).

The difference between this and current from the wall is the type of current provided. The Van de graaff generator generates direct current where as the wall puts out alternating current. With the wall the positive voltage alternates between the two main prongs. The Van de graaff generator always has one positive pole (either the ball or the ground) and one negative pole. By switching the rollers on the belt you can change whether the ball creates a positive or negative voltage, however while it is running you are always only going to get either positive or negative voltage discharges.

Long Answer: A simple Van de Graaff-generator consists of a belt of silk, or a similar flexible dielectric material, running over two metal pulleys, one of which is surrounded by a hollow metal sphere. Two electrodes, in the form of comb-shaped rows of sharp metal points, are positioned respectively near to the bottom of the lower pulley and inside the sphere, over the upper pulley. The top comb is connected to the sphere, and the bottom comb to the ground. A high DC potential (with respect to earth) is applied to the roller.

As the belt passes in front of the lower comb, it receives negative charge that escapes from its points due to the influence of the electric field around the lower pulley, which ionizes the air at the points. As the belt touches the upper roller, it transfers some electrons, leaving the roller with a negative charge (if it is insulated from the terminal), which added to the negative charge in the belt generates enough electric field to ionize the air at the points of the upper comb. Electrons then leak from the belt to the upper comb and to the terminal, leaving the belt positively charged as it returns down and the terminal negatively charged. The sphere shields the upper roller and comb from the electric field generated by charges that accumulate at the outer surface of it, causing the discharge and change of polarity of the belt at the upper roller to occur practically as if the terminal were grounded. As the belt continues to move, a constant charging current travels via the belt, and the sphere continues to accumulate negative charge until the rate that charge is being lost (through leakage and corona discharges) equals the charging current. The larger the sphere and the farther it is from ground, the higher will be its final potential. Long answer from wikipedia Van de Graaff-Generator.

What are the four states of matter? How does liquid nitrogen help to show these?

Answer: Plasma, liquid, solid, and gas are the four states of matter. What state of matter a material exhibits depends on temperature, pressure, and entropy as governed by the Gibbs free energy. Whichever state of matter has the lowest Gibbs free energy (each one a function of the above variables) will be the state of matter seen under those conditions. Because liquid nitrogen is extremely cold ~64K and -220°C this allows us to use it to change one of those variables and create an environment where the lowest energy state is one of a different state of matter. Some examples are oxygen in liquid form, nitrogen in liquid and gaseous form, and obviously water in several forms. Using a vacuum pump we are able to vary the other variable, namely pressure, and see solid nitrogen.

How does the microwave interact with the grape to create plasma?

> *Answer: We don't know. This is an example of science that still hasn't been worked out. One of the great things with science is that we can discover new things and work on discovering what is going on by careful experimentation. There is a predominant idea involving some basic principles of electricity and magnetism; dipoles, wavelength of the radiation, and focusing of E&M waves by a dielectric. However the main point of this experiment is to show plasma and discuss the importance of continuing to find out new things.*

What's the difference between an incandescent and a fluorescent light bulb, and how does each bulb create light?

> *Answer: Incandescent and Fluorescent light bulbs differ in how they excite the atoms that give off the light. Light comes from an atom having an electron in an excited state in the atom fall back to a lower level. In doing so conservation of energy requires that energy be emitted. This energy is given off in a packet called a photon. Only certain levels are allowed in the atoms so any particular photon must correspond to a set of discrete energies. We use this fact in spectroscopy to figure out which element is giving off light. This process is used in all sources of light. The difference is how they excite the atoms. In incandescent light bulbs running a current through the filament causes vibrational heating. This forces many electrons into a higher energy level which then radiate that energy. Most of this is infrared wavelengths. We detect this as heat. That is why they are so inefficient. In fluorescent lamps the same mechanism causes the initial excitation. Electrons traveling through the gas excites mercury which gives off a lot of radiation. This radiation is mainly peaked in the ultra violet because of mercury's atomic structure. The bulb is then lined with phosphorus which takes that uv radiation absorbs it and after some loss of energy due to heat radiates it as visible light. This results in a much more efficient system. This comes from HowStuffWorks.com.*

The Wonders of Physics (University of Wisconsin)

Mike Randall (randall@physics.wisc.edu))

How does a plasma globe work?

> *Answer: There's a LOT of physics going on in a plasma globe! A plasma globe is a clear glass or plastic globe filled with a mixture of various gases at low pressure. The most commonly used gases are helium and neon; xenon and krypton may also be included. High voltage electricity is introduced through an electrode (the small ball at the center). The electricity alternates (changes direction) thousands of times every second.*
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> *When voltage is applied to the electrode, an electric field is created between the electrode and the outer globe. Under these conditions, electrons jump from the electrode and accelerate toward the globe. The electrons collide with the gas atoms in the globe, knocking some of the electrons off the gas atoms. The atoms that are missing electrons are called IONS. A gas containing charged particles such as electrons and ions is called a PLASMA. Electrons have a negative CHARGE, and ions have a positive charge.*
>
> *Moving electrons create their own magnetic field. By rapidly alternating the electric field, we cause the electrons to "jiggle" back and forth, creating an alternating magnetic field. This alternating ELECTROMAGNETIC field helps to contain the plasma when it forms.*

Wonder of Physics – continued

As more gas is ionized, an ion trail created, making it easier for more electrons to follow along in the same path. Pressure from the surrounding "unionized" gas, combined with the containing effect of the alternating electromagnetic field, keep the plasma moving along this path, forming a "streamer".

The streamers move around because the plasma is very hot. As it warms, the plasma expands and becomes less dense than the surrounding gas. This causes the plasma streamers to drift upwards in the globe, like rising hot air.

The streamers are also glowing. Atoms and ions have electrons "orbiting" around them at particular energy levels. Collisions between all these "jiggling" electrons, ions and atoms tend to knock electrons from their normal (ground state) levels to higher (excited) levels. Excited electrons quickly jump back to their ground levels. The difference in energy between the excited level and the ground level is dumped off as burst of light energy called a PHOTON.

The color of the light depends on the amount of energy dumped into each photon. The allowed "jumps" between energy levels are different for different gasses, so the color(s) you see will depend on what gas(es) are in the globe. (For example, neon gas gives off different colors than krypton).

The streamers connect between the electrode and the globe because of the voltage difference between the two. The globe, being made of glass or plastic, is an electrical INSULATOR. If the electrons only moved one way, they would quickly move from the electrode to the globe and cancel out any voltage difference.

Rapidly alternating the voltage keeps the electrons moving back and forth, allowing the glass to charge and discharge. This maintains a voltage difference between the electrode and globe – and keeps the streamers going.

Normally there are many small streamers distributed fairly evenly through the globe. But when you touch the globe, many of the streamers combine into one big streamer between the electrode and where you're touching.

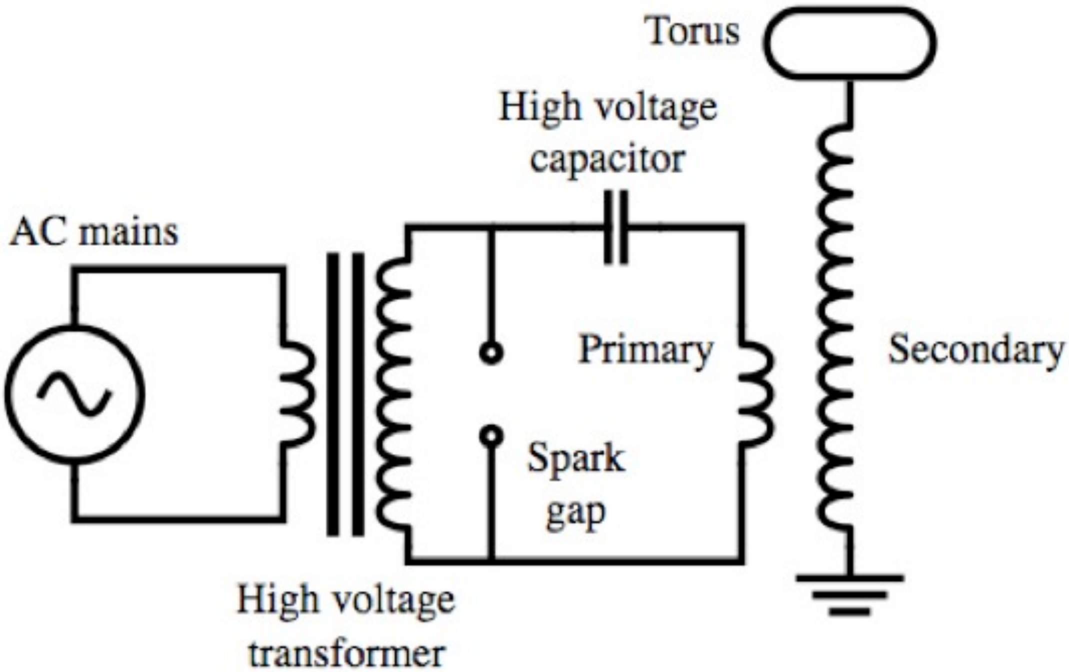
The reason why has to do with CAPACITIVE COUPLING. As charge builds up on the inside of the globe, an equal but opposite charge builds up on the outside. When you touch the globe, mobile charges in your body (mostly made of saltwater) flow to cancel the charges that build up on the outside of the globe.

With the opposing charge cancelled, more charge inside the globe moves to the spot nearest your hand. And, as the charges move toward your hand, a large streamer is formed.

What is a Tesla Coil?

Answer: Stripped down to it's most essential parts, a Tesla coil is a wire sticking out of the ground. To get sparks to fly out of the top the rest of the machine "sloshes" electrons up and down the wire.

The picture you should have in your head is a long bathtub, open to the ocean on one end. The machinery of the Tesla coil is like some dude in the bathtub sliding back and forth, splashing water (electrons) out of the closed end, while the tub is refilled from the ocean (ground).



One possible circuit configuration for a Tesla coil.

The electricity in the primary coil is what's doing the pushing, and the electricity in the secondary coil is what's being pushed. To understand how the driving mechanism works requires a new metaphor and some answer gravy.

Answer gravy: To get sparks to really fly you need very high voltage (up to several million volts) at a fairly exact frequency. The current that flows up and down the secondary coil, and sloshes out the top, has a high resonant frequency (~MHz, unless the coil is ridiculously huge) that you really can't do much about. But the current coming out of the wall has a frequency of only 60 Hz (50 Hz for our Old World readers).

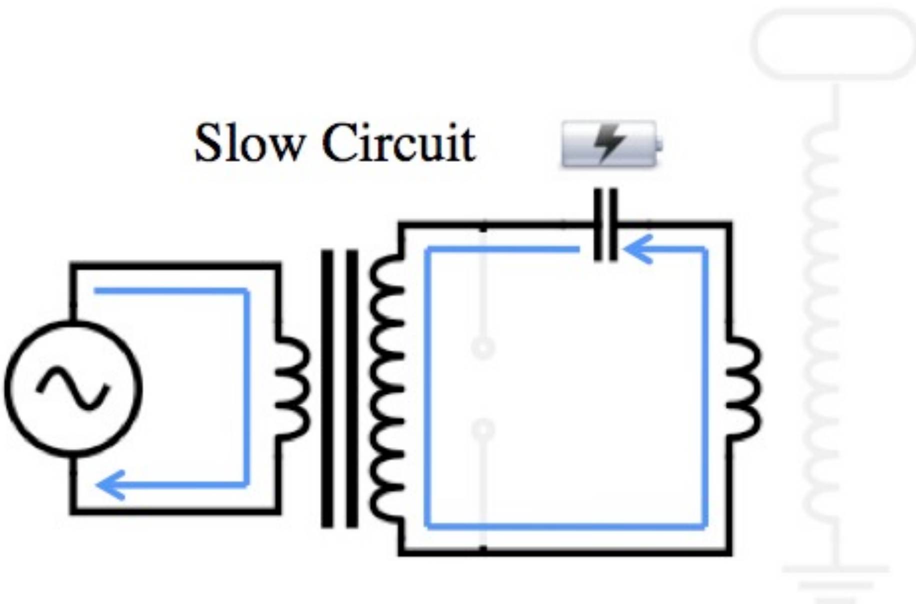
So how do you change frequencies? The answer is you "pluck" the primary coil. For example: If you pick a guitar string once a second you have a frequency of 1 Hz, but the string vibrates on its own at whatever frequency it's made for (~10 kHz).

The AC mains have a low frequency (60 Hz) while the secondary coil needs to be driven at a high frequency (~1,000,000 Hz). That means that the secondary will slosh back and forth thousands of times every time the current from the wall turns over just once. Since the fast part of the circuit is so much faster than the slow part, you can just pretend that the current from the transformer is DC (direct current = 0 Hz).

The secret to plucking is to change the circuit's "shape" using a spark gap. Spark gaps have some pretty slick properties. They have an essentially infinite resistance until a high enough voltage is applied across them, at which point they spark (hence the name). The spark you see is the air being pulled apart and ionized. Now ionized gas is a really good conductor, so a spark is like instantly closing a switch.

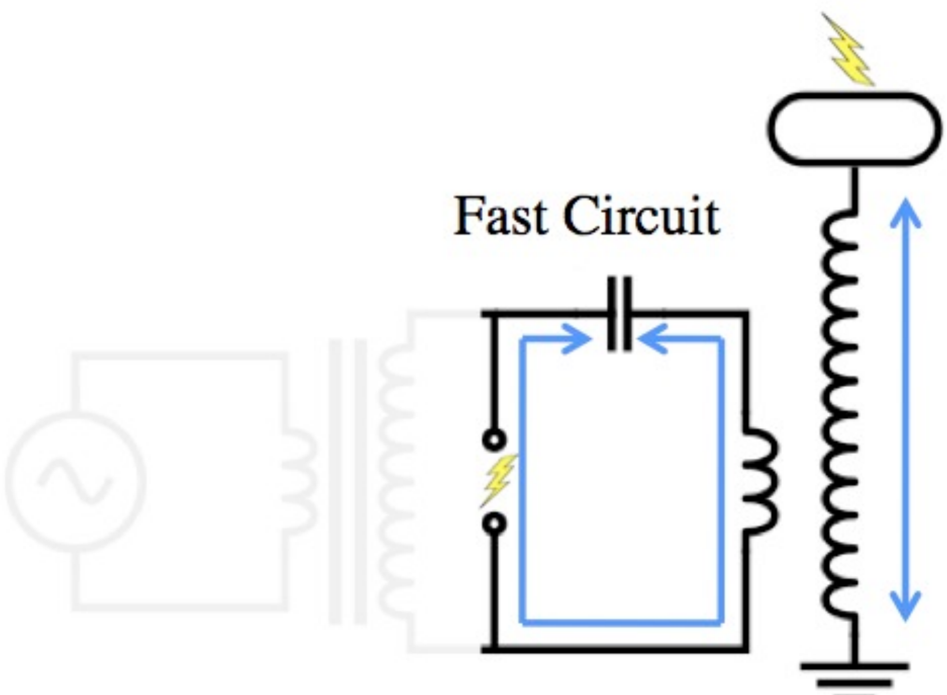
Also, spark gaps are the cheapest circuit element ever. Can you cut a wire? Now you got a gap!

Also, adding spark gaps to a device is one of the quickest ways to bridge the divide between regular and mad science.



The transformer on the left forces charge to build up in the capacitor on the top. But the voltage across a capacitor is proportional to the amount of charge it's holding, so eventually the voltage is high enough to trip the spark gap.

The only job that the slow part of the circuit has is to charge the capacitor (pull back the string). When the spark gap sparks (pluck!) the fast part of the circuit takes over, and the slow part is essentially ignored until all the energy is exhausted by exciting the secondary coil (string vibrates and slows).



With the spark gap active the charge can flow out of the capacitor and swing back and forth many times, very fast (thousands to millions of times per second). The current through the primary coil then drives current up and down the secondary, causing electrons to "overflow" from the top of the Tesla coil. The "overflow" is a delight to children of all ages.

Wonder of Physics – continued

As current flows through the primary it creates a voltage across the secondary that's so high that electricity actually flies out of the top of the coil, despite having nowhere in particular to go. It generally takes at least several hundred thousand volts to make that happen.

The loop in the picture above forms and RLC circuit with a high resonant frequency (that matches the frequency dictated by the secondary). As the energy in this system runs out the voltage needed to maintain the spark gap (which is much less than the voltage needed to start it) is lost, and the whole thing returns to the slow, charging phase.

Since the power supply oscillates at 60 Hz, the whole system briefly turns off 120 times every second (the voltage is +, 0, -, 0, +, 0, ...). For this reason Tesla coils have a very loud 120 Hz hum that sounds "staticy" and ominous, as opposed to Jacob's ladders that are continuous, and tend to sound more like "tearing". Connoisseurs, I'm sure, will agree.

From "Q: How does a Tesla coil work?"
October 9, 2010, by The Physicist
http://www.askamathematician.com

How does the Ring Launcher work?

Answer: A magnetic ring launcher is a coil, wound around an iron core that extends beyond the coil. A non-magnetic metal ring (e.g. aluminum) is placed around the core. When the coil is energized with an alternating current (AC), the ring leaps into the air!

The alternating current in the coil creates a changing magnetic field. The changing magnetic field moves electrons in the metal ring, creating a current. The current in the ring generates its own magnetic field, opposite that of the coil.

What happens when you put two North poles of a magnet together? They PUSH APART – and