

# Science First®

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## 10-205 Tesla Coil

### Instructions & Applications

#### Parts List

26-2010	Generator, high frequency
29-1020	Lampshell socket
50-0208	Aluminum disc electrode 3"
50-0209	Aluminum disc electrode 6"
26-1008	Neon bulb
24-1205	Instructions
50-0201	Aluminum electrode
26-8200	Wire, stranded, #20 gauge
26-9118	#18 gauge uninsulated copper wire
22-2322	Capnuts, Nylon, 8-32
26-1010	Binding post
26-2012	Capacitors
50-1020	Aluminum ball
56-0205	Top plate
56-0206	Bottom plate
56-0207	Corona cap
56-1207	Acetate collar
60-0205	Coil assembly
56-1205	PVC spacer

#### Warranty & Replacement Parts

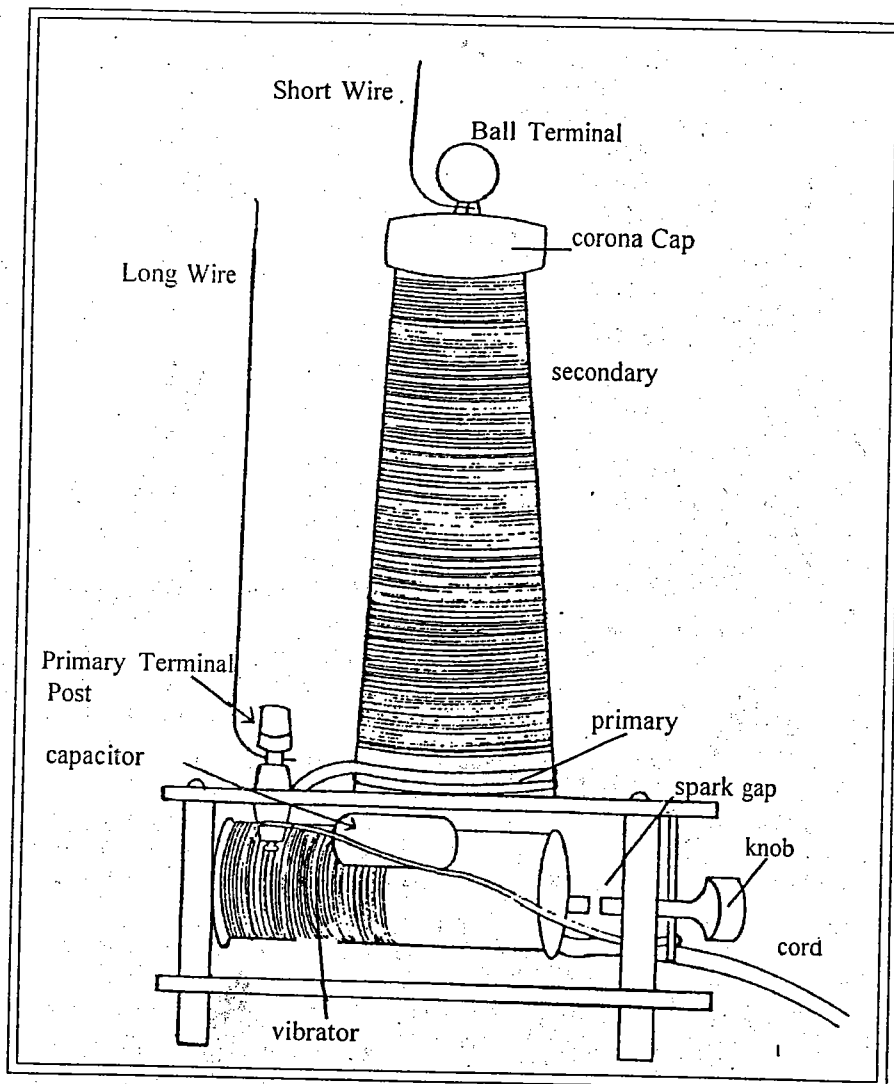
We replace all defective parts free of charge. Additional replacement parts may be ordered toll-free at 1-800-875-3214 by referring to part numbers above. We accept Master Card & Visa, minimum parts order \$5.00 (\$20.00 school P.O.). All products warranted to be free from defect for one year. Does not apply to accident, misuse or normal wear and tear. Made in U.S.A.

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#### Introduction

The Tesla Coil is an air-core transformer with primary and secondary coils tuned to resonate. The primary and secondary function as a step-up transformer which converts relatively low-voltage high current to high-voltage low current at high frequencies.

The Tesla Coil demonstrates the fundamental principles of high frequency electrical phenomena. It illustrates the principles of ionization of gases and

behavior of insulators and conductors when in contact with high frequency electrical fields.

Its inventor, Nikola Tesla, conceived it to be a means to transmit electrical power without wires. An antenna would pull the transmitted electrical energy into the electrical system. You can also consider it a simple radio transmitter, operating within a broad range of high frequencies, which transmits power rather than information.

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Educating the Scientist of Tomorrow®

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## Components

The Tesla Coil consists of a vibrator or transformer, two high voltage capacitors, a primary, and a secondary connected to a ball terminal or antenna.

The vibrator is composed of an air slot core around which coils of copper are wound; and a buzzer which consists of two tungsten points or contacts which open and close by means of a spring as alternating current and electricity passes through the core and discharges in the spark gap.

The capacitors are 2 large cylinders on either side of the spark gap. They are high voltage capacitors of a predetermined size and value. The primary coil is a pair of thick insulated copper wires located next to, but not touching, the secondary and connected in series with the capacitors and spark gap. The secondary is a cone-shaped coil (cone-shaped to keep the coil compact and for manufacturing reasons as less wire is needed) consisting of about 400 turns of thin enameled copper wire. It functions as a transformer by stepping up the voltage to high levels.

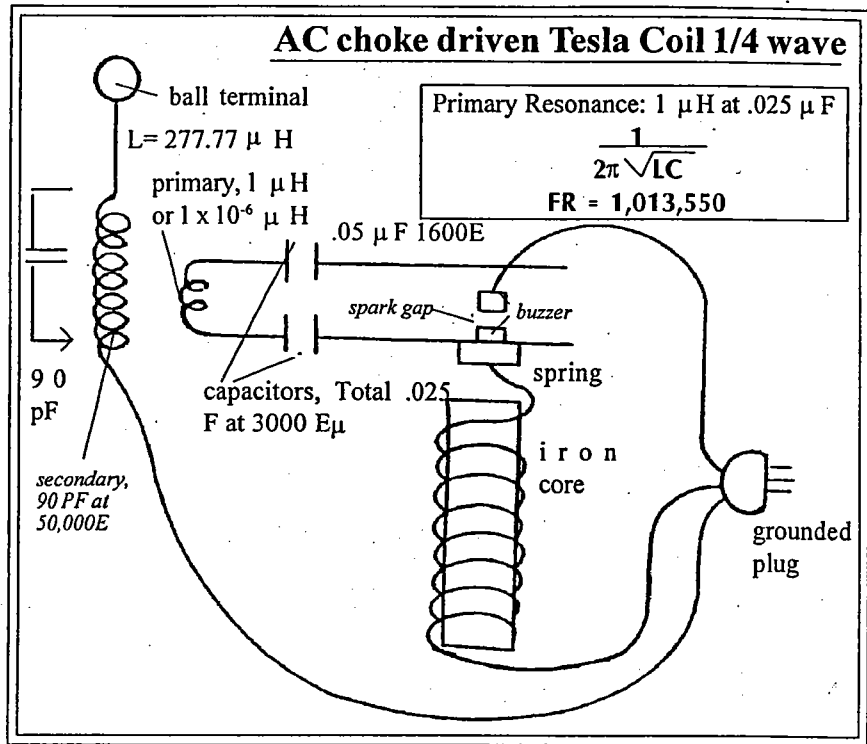
The high voltage produced is given off by the ball terminal.

## How a Tesla Coil Works

Refer to diagram.

When the plug is inserted into 110 AC current (220 volt for model 10-206), electricity flows through the vibrator, an iron core with hollow center around which is wound many coils of copper wire. The iron core becomes an electromagnet. The buzzer, which consists of 2 tungsten contacts located opposite each other, not quite touching, pull apart when the electromagnet is activated and close when the magnetic field decays. This occurs at the rate of 120 times a second to coincide with each time the AC current changes the polarity of the electromagnet.

The capacitors charge up when the buzzer contacts are open, since the current passes into them to complete the electrical circuit. When the contacts are closed, the capacitors are shorted together and current does not pass into them. The open



contacts allow the air in the spark gap - the small space between open contacts - to ionize, which permits a discharge that short circuits the transformer and capacitors. But the capacitors retain their electric charge, since the function of a capacitor is to store an electrical charge and thus provide energy to create an electromagnetic field.

This spark taking place in this spark gap does not consist simply of a single spark passing in one direction, as would appear to the eye, but actually is a number of separate sparks passing back and forth in opposite directions. They take place so rapidly the direction change cannot be seen. The time during which the spark appears to pass may only be a fraction of a second, but during that time the current may have oscillated back and forth several thousand times.

The electromagnetic field is formed by the primary which converts the charge stored in the capacitors to magnetic energy. The electrical charge is transferred to the primary by the capacitors when the magnetic field in the iron core decays. When the magnetic field in the iron core is reactivated, the field generated in the primary is the one to decay,

and the electrical charge is transferred back to the capacitors with every half cycle, a charge of increasingly higher voltage as each activation of the magnetic field adds to the charges previously generated.

The vibrator also acts as an air core transformer, boosting the voltage to medium high levels with every half-cycle pulse of AC current. The high frequencies that are produced are rich in harmonics since each pulse of electricity across the spark gap of the buzzer is composed of many surges of electrical energy.

The capacitors in this Coil have a particular size and value. They serve the dual function of storing electric charge and filtering through the high frequency component of electrical current while blocking low frequency 60 cycle current. This is a safety feature, since by isolating the primary from the 60 cycle component of the current, the electrical circuit will not be complete in regard to the 60 cycle component and you will not receive a shock if you touch the coil directly. Another safety feature is the fact that an air-core transformer by its nature does not pass 60 cycle current well.

The result is that high frequency electrical energy is built up by the generation and decay of the magnetic field in the primary every half cycle, often reaching many million cycles per second.

When the high frequency is great enough and reaches the voltage predetermined by the size and value of the capacitor in this Tesla Coil, the primary induces a magnetic field in the secondary. Inducing means a moving magnetic field causes a magnetic field to form in another wire coil located close to, or inside, the first coil.

The Primary consists of two thick insulated copper wires which are resonated by the capacitors to equal the natural resonant frequency of the secondary. When the resonance equals that of the secondary, a magnetic field is formed in the secondary. Resonance may be compared to a cymbal: when a cymbal selected for a certain size and weight is struck, it rings at a specific frequency. In the Tesla Coil, the right capacitors and secondary "ring" at the chosen high frequency.

Resonance may also be compared to a swing. When inductive impedance and capacitive impedance of a circuit are equal, the electricity oscillates back and forth between inductive component (primary) and capacitive component (capacitors, also be called condensers.) When pushing a swing, a person can cause large forward and backward motions with small pushes administered at the correct frequency. Applying energy at correct frequencies builds up high potentials in a resonant circuit.

A person in a swing weighing 200 pounds may be pushed by a small child about 50 pounds who may push with only one pound of force. If he times his pushes to coincide with the direction of the swing and keeps adding a pound of force each time, he will eventually have to stop to avoid hurling the person in the swing out into space.

An analogy used by inventor Nikola Tesla himself is to picture a wine glass broken by a violinist's note. The glass is shattered because the vibrations happen

to be the same frequency as the vibrations of the glass.

Since at the right resonant frequency, the AC resistance, or reactive impedance, is zero with the right coil and right capacitor, and now the maximum current can flow according to formula:

$$2\pi \sqrt{\frac{1}{LC}} = Fr$$

The secondary, like the vibrator, functions independently as a step-up transformer of about 3,000 volts. Since it has many more coil turns of copper wire in its secondary from the primary voltage of 110 volts of AC input, then electrical energy is supplied.

As the electrical energy from the vibrator is fed to the capacitors of the primary air core transformer and its two-turn coil at its base, it now creates another independent circuit of the vibrator type transformer. The vibrator secondary output of 3,000 volts is applied to this primary circuit, known as the air core tesla resonant transformer or oscillator.

Its energy is then induced to the cone shaped coil with the ball on top. It is the number of turns known as inductance and its self-capacitance. When the primary supply is properly tuned to the secondary, a high voltage, high frequency output is developed of about 50,000 volts.

In this case, this unit's total primary capacitance is .025 microfarads at 3,000 volts and its secondary capacitance is 90 picofarads at 50,000 volts. It is the square root of the primary to the secondary capacitance that determines the approximate output voltage of 50,000 volts, according to the following formula

$$\sqrt{\frac{C_p}{C_s}} \text{ or } \sqrt{\frac{.025 \mu F}{90 \text{ pF}}} \text{ or } \sqrt{\frac{.025 \times 10^{-6}}{90 \times 10^{-12}}}$$

$$= \text{Total } \sqrt{277.77}$$

$$= 16.66 \times 3000 \text{ volt vibrator secondary}$$

With the current at maximum resonance, a high voltage, high frequency of one million impulses are produced at the ball of the secondary.

The Tesla transformer does not function on turn ratio windings. It functions

instead on the ratio of the primary capacitance to the secondary capacitance.

The secondary, like the vibrator, functions as a transformer. Since it has more coils of wire than the primary, it boosts the high voltage even higher.

The secondary is a cone-shaped coil located next to but not inside the primary. Only the first few turns are within the electromagnetic field created by the primary. Only a small difference in voltage exists between each turn of the coil and the one preceding it. This low voltage differential per turn prevents voltage from breaking down copper wire insulation and short circuiting the secondary.

The secondary produces a current called high frequency electricity. High frequency currents reverse their flow, or alternate, from 100,000 to one million times a second.

#### How To Operate:

Use Tesla Coil on bench or table with nonmetallic surface (to rule out danger of electric shock.) Plug into grounded outlet supplying 110 volt 60 cycle current (in case of 10-206 Tesla Coil, 220 volt electricity.) Voltage of household current may vary slightly. Turn black knob on vibrator until a buzzing sound is heard.

#### How To Handle High Frequency High Voltage Electricity Safely

The electricity generated by the Tesla Coil does not pass through your body. It flows harmlessly over your skin.

High-frequency currents possess unusual properties. Since they travel only on the surface of wires and conductors, a hollow tube conducts this type of current as well as a solid rod of same diameter. High frequency currents do not cause a shock. You can take a piece of metal, approach a high frequency coil and throw a spark 2 to 3 feet long without any sensation except that of a slight warmth.

However, while high frequency high voltage electricity will not produce a shock, it can cause a burn if taken into your body at one small point of contact. This is because the output is concentrat-

ed in a small area (the vicinity of the ball terminal) forming an electrical arc that becomes intensely hot.

This concentration of current may be broken down by discharging the coil with a small piece of metal held close to the ball terminal. We suggest a coin, knife, or even piece of bare wire. As you approach holding this item, you increase the area of contact and reduce the current per unit of area to a lower value which will not cause a burn.

You can also move your finger quickly so that it does not remain in the same position with relation to the ball terminal. This results in a safe flow of high frequency high voltage electricity over your skin.

Low frequency currents, either AC or DC, do not possess this ability. They pass through the body directly (specifically through the liquid-filled tissues.) A voltage that can produce serious injury in the form of low frequency AC or DC will flow over the surface of your skin if it is in the form of high frequency electricity.

## Experiments

### How To Adjust for Maximum Output

You'll get the best results in these experiments if you adjust your Coil for proper operation.

**1. While machine is unplugged, fasten wire to ball terminal.**

Take small piece of fine bare wire provided and fasten underneath ball terminal by winding it around the screw tip to which ball terminal is attached. Point free end upward.

**2. Plug in Coil.**

Plug into ordinary 110 volt household outlet (for 10-206, 220 volt.) Light streamers will issue from the tip of the wire, since the wire's sharp end will break down the surrounding air more easily than will the ball terminal.

**3. Adjust buzzer knob until long-**

**est possible streamers emanate from end of wire.**

Longest possible light streamers indicate the circuit of the primary and secondary coils are resonated. In this resonated condition your machine operates at maximum efficiency.

### Using Discharge Wand to Adjust and Demonstrate

The discharge electrode is a large hooked metal rod. Its uncurved end is placed in the hole in the top of the primary terminal post - a black plastic knob protruding from the plastic base. When you plug in your Coil, discharges will pass between the ball terminal and the tip of the discharge electrode. Long, intense discharges mean maximum output.

The discharges can be seen from a distance, making this a good class demonstration.

### Additional Materials Needed

Some of the experiments that follow require one or more additional materials.

◆ **1 100-200 watt clear glass incandescent light bulb, nitrogen filled.**

This is the standard 100-200 watt light bulb. The higher the wattage, the more visible the results. A frosted bulb will also work but results will not be as visible.

◆ **Fluorescent lamp tube**

Any size, 40 watt standard tube recommended.

◆ **1 2 to 3 volt miniature screw-base flashlight bulb**

◆ **1 miniature screw-base lamp socket**

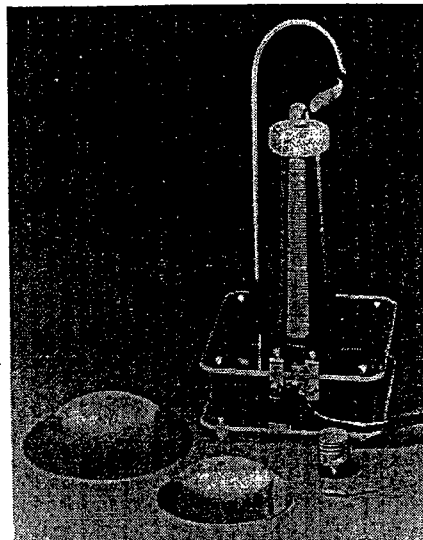
◆ **Aluminum foil**

◆ **4 foot length of 20 gauge, plastic stranded wire.**

This is included in your accessory kit. Cut into 1 foot and 3 foot lengths.

◆ **Uninsulated copper wire**

Also included. Cut wire into lengths required in the following experiments.



#### Experiment 1 Discharging

You Need: Piece of metal (coin, key, bare uninsulated wire etc.)

Hold a small piece of metal in one hand. Plug in Tesla Coil and approach ball terminal with metal. The high frequency high voltage electrical discharge forms an arc between ball terminal and a metal object. See how far out you can draw this arc.

#### Experiment 2 How a Conductor Affects the Flow of High Frequency High Voltage Currents

You Need: Short length of bare wire

With the ball terminal in place, plug in your Coil. Examine ball terminal to see if there are any signs of an electrical discharge issuing from it. The ball terminal, being metal, is a conductor. However, there will normally be no such discharges, since the smooth rounded surface of the ball causes a uniform stress on the surrounding air.

Operate the Coil in a darkened room. Examine the ball terminal. (If the Coil is adjusted properly it may break down the surrounding air despite the smooth, round shape of the ball terminal. Any such discharge will be most noticeable in the dark.)

Unplug the Coil and unscrew the ball terminal from its top. Take a short length of thin, bare wire, preferably point-

ed at one end. Fasten wire to the screw end from which the ball terminal has been removed, with pointed end of wire bent upward. Plug in Coil and note profuse discharge that issues from the sharp bare point. This type of discharge is known as Corona Discharge.

This experiment illustrates the fact that high frequency high voltage electricity issues more readily from a conductor with sharp points than a conductor with smooth round surfaces. (This is the reason that sharp bends, pointed projections and sharp corners are avoided in wiring high frequency equipment.)

A practical example of this principle is the way high voltage metal enclosures of televisions are wired.

### Experiment 3

#### How Insulators Behave at High Frequency

You Need: 1 100-200 watt clear glass light bulb;  
Special lamp socket (included); Piece of metal;  
Other insulators (wood, plastic etc.)

With Coil unplugged, remove ball terminal from top of Coil. Screw special lamp socket on exposed threaded stud. Mount light bulb onto lamp socket by screwing it on.

Plug in Coil, place your finger tip on top of the glass light bulb and move it quickly over surface of bulb. Observe the discharges which take place in the bulb and lightning-like feelers that reach out from the light bulb's electrodes to a point on the inner surface of the bulb directly beneath your finger.

Take piece of metal and touch bulb with it. Observe difference in appearance of discharges.

Although the high frequency currents from the Tesla Coil pass through the glass of the light bulb and into your finger tip, you receive no physical sensation. The reasons are: one, high frequency currents flow over the surface of the skin; two, the total current is distributed over the entire area of your finger tip which is in direct contact with the glass.

Remember to keep your finger mov-

ing quickly. You may get a burn if you concentrate the discharge at a single point on your finger.

This experiment shows that glass, which is considered an excellent insulator for medium and low frequency currents, is readily broken down by high frequency high voltage electricity.

Test the insulating properties of other material. Remove the light bulb and special lamp socket and return ball terminal to the top of the Coil. Hold wood, plastic or paper in direct contact with the ball terminal with one hand while attempting to draw a discharge through the insulating material to a piece of metal held in your other hand.

### Experiment 4:

#### Ionizing Gases by Electrical Stress

You need: Fluorescent lamp tube, any size  
*For best results, we recommend a standard 40 watt tube.*

Neon lamp, included; Short length of bare wire

While Tesla Coil is not in operation, attach neon lamp to ball terminal. The neon lamp is a very small light bulb (NE2) with 2 thin copper wires protruding. Use one of thin wires to attach lamp to ball terminal. Wind wire around screw stud onto which ball terminal is mounted.

Plug in Coil and watch how brightly neon lamp lights up despite the fact that it is connected to the Tesla Coil by only one wire.

With the short length of bare wire (NOT your hand) touch the glass bulb of the neon tube. Watch how the red-orange discharge becomes even brighter and more concentrated. Not only do the electrodes in the neon lamp glow - the entire bulb exhibits a red-orange glow.

Unplug Tesla Coil. Remove neon lamp from ball terminal. Plug in Tesla Coil and approach ball terminal holding fluorescent light bulb in your hand. Note difference in color of the fluorescent light bulb compared to the neon lamp.

The glow appearing in both lamps is caused by ionization. Ionization occurs

when 2 atoms collide, splitting off one or more electrons and giving off energy in the form of light. Every gas will produce its own characteristic color when it becomes ionized.

When the gases in the neon and fluorescent tubes are subjected to high electrical stress at low pressure, their atoms are excited and give off characteristic glows. In the neon tube, neon gas is excited; in the fluorescent tube, mercury vapor and argon gas.

### Experiment 5:

#### How Pressure Affects Ionization of Gases

You Need: 1 100-200 watt clear glass light bulb

Operate your Coil with ball terminal in place. Hold light bulb by glass bulb (not touching metallic base.) Bring base of bulb slowly toward ball terminal. Stop at the point where the gas in the bulb begins to ionize.

Observe the distance between ball terminal and point at which the bulb begins to glow. The gas contained in the bulb ionizes at the same distance from the Tesla Coil even though the electrical stress at this point is much less than it is at the ball terminal's surface.

Observe that although the gas inside is ionized, the gases in the surrounding air are not. In fact, the gases in the atmosphere do not ionize even when they are in contact with the ball terminal, where the electrostatic stress is greatest.

The gas usually used in high wattage incandescent light bulbs is nitrogen, a small amount of which is introduced into what is otherwise a vacuum inside the bulb for the purpose of preventing the filament from growing brittle. The nitrogen is therefore at very low pressure inside the bulb.

This experiment shows that a gas at low or reduced pressure, such as the nitrogen in the evacuated light bulb, will ionize more easily than the same gas at atmospheric pressure.

**Experiment 6:****How Gases Differ in the Ease With Which They Ionize**

You Need: 1 fluorescent tube, any size; 1 100-200 watt clear glass light bulb; Neon lamp (included)

Certain rare gases, such as neon, argon, xenon, krypton and helium, will ionize more readily than others due to their atomic structure.

This is demonstrated using a standard high wattage light bulb (containing nitrogen gas), a fluorescent tube (containing a combination of mercury vapor and argon), and a neon lamp (containing neon.)

Hold each bulb by the glass itself, not touching the metal base. Bring each bulb in turn toward the ball terminal while the Coil is operating. Stop at the point where the gas in each bulb ionizes.

Compare the distances from the ball terminal at which the 3 gases ionize.

The standard high-wattage light bulb must be brought much closer to the ball terminal before its gas ionizes. Therefore nitrogen must be brought into an area of greater electrical stress than either neon or a combination of argon and mercury vapor before it breaks down.

**Experiment 7:****Demonstrating Sparking Potential**

You Need: About 7 inches of stiff bare wire (included - cut to desired size)

While the Coil is unplugged, connect one end of length of stiff bare copper wire to the primary terminal post, a plastic knob protruding from plastic base.

Connect the wire to the terminal post by unscrewing the top knob of the post far enough to expose a hole running horizontal to the base. Bend your length of wire to form a small "L" at one end. Insert small length of the "L" through the hole and then screw the top knob of the terminal post back into place, so that the wire is held securely in position, with its free end projecting vertically into the air. Operate Tesla Coil and move free end of wire toward ball terminal by hand. Stop at point where a spark jumps between free end of wire and ball terminal.

The distance between the free end of wire and the ball terminal represents the distance over which the electrical stress generated by the Coil breaks down, or ionizes, the air. The amount of electrical stress needed to create a spark is called the SPARKING POTENTIAL. For dry air under normal conditions, the sparking potential is 30,000 volts per centimeter.

By measuring the distance between the free end of wire and the surface of the ball terminal, and by assuming that the sparking potential between the two is 30,000 volts per centimeter, you can estimate the sparking potential that exists between the wire and ball terminal.

**Experiment 8****How High Voltage Power is Transmitted**

You Need: 2 lengths of bare copper wire, about 12" and 7" in length (included - cut to length)

Fasten 12 inch length of bare copper wire to ball terminal of Coil by winding it around screw stud onto which the ball terminal is secured.

Fasten 7 inch length of bare copper wire to primary post as in preceding experiment.

Position 2 wires in vertical direction, parallel to each other and about 1 1/2 inches apart. This setup simulates in miniature a high voltage power transmission line, in which 2 wires are spaced far apart.

Operate Coil and observe the ionization that occurs. (Results will be best if performed in a dark room.) Note how ionization is confined to a zone surrounding the 2 lengths of wire, and how it takes the form of a visible corona discharge.

Gradually decrease distance between 2 wires until the point is reached where the air breaks down or sparks. Observe effect that decreasing the spacing of the wires has on the corona discharge.

High voltage transmission lines work in a similar fashion. Two lines spaced far apart run parallel to each other. When the air surrounding the wires of a high voltage transmission line becomes ion-

ized, the ionization is confined to a zone around both wires and produces a discharge in the air called a corona. The important factor is the distance between the two wires: it must be far enough so that sparking between wires does not occur.

**Experiment 9****High Frequency High Voltage Brush Discharges**

You Need: One 100-200 watt clear glass light bulb; 12 inch length of plastic stranded wire (included); special lamp socket (included)

Replace ball terminal with special lamp socket. Insert 100-200 watt clear glass light bulb into lamp socket.

Operate Tesla Coil and adjust for maximum output as follows: turn buzzer knob counterclockwise (as you face Coil with buzzer on your right) until buzzer just stops working. Then slowly turn buzzer knob clockwise and observe changes occurring in light bulb.

(The reason for this procedure is because the Tesla Coil is finely adjusted as it leaves the factory. You will be able to determine the point at which it just begins operation by first turning knob counterclockwise.)

The discharges taking place inside the light bulb have differing characteristics. At one setting they resemble slow-rising, smoke-like streamers. At another setting they take the form of miniature bluish-colored lightning bolts. At a third setting you observe quick, erratically moving little points of bluish flame travelling up and down the wires inside the lamp.

These brush discharges produced by high frequency electricity are more pronounced in a gas at reduced pressure (as in low-pressure nitrogen inside the evacuated light bulb) than in air.

Remove special lamp socket from top of Coil. Strip insulation off both ends of 12 inch piece of plastic stranded wire to a length of about one inch.

Fasten one end of wire to screw stud from which lamp socket has been removed, with other end protruding upward in vertical direction. Fan out indi-

vidual strands of free end of stranded wire so they are arranged like a comb.

Operate Tesla Coil at different settings of buzzer contacts (as described above.) Observe types of brush discharges that result.

### Experiment 10

#### Transmitting High Frequency Electricity Over A Single Conductor

You Need: Special lamp socket (included); one 100-200 watt clear glass light bulb; one 3 foot length of plastic 20 gauge stranded wire (included - cut to size); one 8/32 screw, glass or plastic tumbler.

Cut 3-foot length off 4-foot plastic stranded wire. Strip insulation off both ends to a length of about 1/2 inch.

With ball terminal in place, fasten one end of wire to screw stud onto which ball terminal is mounted. Connect other end of wire to base of lamp socket. Do this by winding wire around threaded spacer at base of lamp socket and fastening on screw to hold wire in place.

Stretch wire out to full length between light bulb and Coil so it has no contact with other objects.

Install high-wattage light bulb in lamp socket. Insert bulb inside glass. The reason for this is that the light bulb must be insulated from table or bench on which Coil is placed.

Operate Tesla Coil. Observe how high frequency electricity is carried by single wire (with no second wire to serve as return path) to light bulb. Once reaching light bulb, the high frequency high voltage electrical currents stream out from the filaments of bulb to ionize gas inside bulb. From there they pass into the air surrounding the bulb and eventually back to the Coil

This experiment illustrates how air is used as the return path between light bulb and Tesla Coil where no second wire exists to serve as return path.

### Experiment 11

#### Demonstrating the Two Components of High-Frequency Electrical Fields

You Need: 12" length of solid plastic stranded wire (included); one 2 to 3 volt miniature screw-base flashlight bulb; one fluorescent tube, any size; radiating antenna plate, either small or large (included)

Unplug Coil, remove ball terminal. Fasten radiating antenna plate to screw stud by placing small hole in bent "L" of plate over stud. The bulk of plate will project upward in vertical direction. Secure plate by screwing ball terminal back onto screw stud.

Plug in Coil. Hold metal base of fluorescent tube in your hand, approach radiating antenna plate. When you reach point where gas in tube ionizes, slowly move tube away from Coil. Observe how gas in tube, once ionized, will remain ionized even when fluorescent tube is moved away to point where the electrostatic stress is much lower than value required to produce ionization in the first place.

The 2 components of high frequency electrical fields are: an **electrostatic radiation field** and an **electromagnetic induction field**. This experiment demonstrates the effect of the electrostatic radiation field. Its electrostatic stress is insufficient to initiate ionization (as shown by bringing the fluorescent tube close to the Coil to cause it to glow) but is sufficient to maintain ionization in a gas at reduced pressure (shown when you moved the tube away from the Coil.) The radiation field can ionize a gas but cannot light the filament in a lamp.

Remove antenna plate. Take 12" length of stranded wire, strip about 1/2" insulation from both ends of wire, and form a single-turn loop about 3 to 3 1/2 inches in diameter.

When Coil is unplugged, arrange loop around plastic base (corona cap) near top, beneath ball terminal. Fasten ends of plastic wire (scraped free of insulation) to each screw terminal of flashlight lamp socket by winding each

wire end around each screw terminal.

Insert 2 to 3 volt screw-base flashlight lamp into lamp socket fastened to top of Coil. Operate Coil.

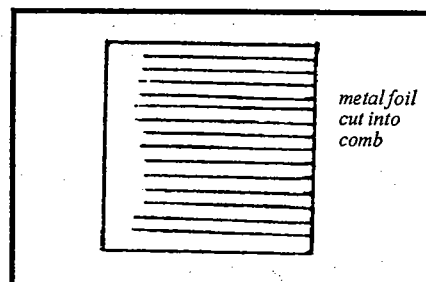
The flashlight lamp is short-circuited by this wire loop. Therefore no electrical energy can come from the electrostatic radiating field. An additional factor is the weakness of the field itself, which can maintain but no initiate ionization. And yet the flashlight lamp glows brightly. The energy for this must come from the electromagnetic induction field generated by the Tesla Coil.

### Experiment 12

#### How Faraday Shields Affect Electrostatic Radiation

You Need: 12" square piece of metal foil; neon lamp (included)

Construct a simple Faraday Shield by cutting slots in piece of aluminum foil to resemble comblike teeth.



A Faraday Shield is a network of parallel wires or conductors connected to a common conductor at one end only, much like a comb. The common conductor of a Faraday Shield is usually grounded. Faraday Shields are used where electrostatic shielding is needed by the electromagnetic component if the electrical field must remain unaffected.

With ball terminal in place, operate Tesla Coil. Hold neon lamp by glass bulb and bring toward ball terminal until neon gas ionizes. Stop at point where neon ionizes. Holding Faraday Shield in your other hand, lower it slowly between ball terminal and neon lamp. (Holding Faraday Shield in your hand provides the ground needed for high frequency currents.)



Observe how neon lamp deionizes or stops glowing when Faraday Shield is between lamp and Tesla Coil.

Bring neon lamp closer to ball terminal and repeat procedure.

This shows how a simple Faraday Shield can cut off the electrostatic radiation field from the Tesla Coil.

### Experiment 13

#### How an Insulated Conductor Affects an Electrostatic Field

You Need: Neon lamp (included); small radiating plate (included); piece of string or rubber band.

Tie piece of string through hole at one end of small radiating plate or loop long rubber band through hole. (Purpose is to insulate radiating plate from direct contact with your hand.)

With ball terminal in place, operate Tesla Coil. Hold neon lamp by glass bulb and bring toward ball terminal. Stop at point at which neon gas in lamp ionizes.

Withdraw lamp to position just beyond that in which neon gas deionizes or ceases to glow.

While continuing to hold lamp in this position, pick up string or rubber band attached to small radiating plate with your other hand. Bring suspended plate toward neon lamp until it touches one of lamp terminals (one of thin wires protruding from base of lamp.)

Observe how neon lamp ionizes when insulated conductor - the plate - touches one terminal.

Break contact with insulated conductor by removing radiating plate from between lamp and ball terminal. Observe that lamp stops glowing.

This experiment demonstrates effect of an insulated electrical conductor on an electrostatic field. Introducing an insulated conductor alters the electrostatic stress distribution by concentrating stress around the conductor. The conductor will then ionize lamp when lamp is located at greater distance from ball terminal than distance required to ionize lamp in the first place.

### Experiment 14

#### Stress Distribution on Insulated Conductor in Electrostatic Field

You Need: Neon lamp (included); small plate; string or rubber band

Suspend radiating plate from string or rubber band as in experiment above.

Holding lamp by glass bulb, bring it toward ball terminal, stop at point at which neon gas ionizes, and withdraw neon lamp to position just beyond that in which neon gas stops glowing.

Hold plate in your other hand by means of attached string or rubber band. Approach neon lamp from opposite side - the lamp is between the plate and ball terminal. Touch one terminal of lamp with radiating plate. Observe that neon lamp starts to glow when insulated conductor - the plate - touches one terminal, despite fact that lamp is too far away from ball terminal to ionize on its own.

Radio and TV antennas on rooftops operate this way. They serve as insulated conductors to intercept high frequency broadcasts from radio & TV transmitters.

### Experiment 15

#### Transmitting Electrical Power Through Space without Wires

You Need: One 2 - 3 volt flashlight bulb; miniature screw-base lamp socket; piece of string or rubber band; small plate; large plate; 2 lengths of plastic insulated wire, 18" each (included)

Cut 3 foot length of wire (used in Experiment 10) in half, yielding two 18" sections. Strip insulation 1/2" from both ends of both pieces. Remove ball terminal and mount either small or large plate vertically on threaded stud. Fasten in place by screwing ball terminal onto stud.

Connect one end of one wire length to "primary terminal post" by inserting bare end of wire through small hole located between two black plastic portions of primary terminal post. Fasten other end of wire to one side of miniature lamp socket. Unscrew nut on one of terminals of socket, wind bare end of other end of this wire around screw stud, and replace nut on stud.

Connect second stripped wire between remaining terminal of lamp socket and

second antenna plate. (Connection with antenna plate can be achieved by looping one bare end of wire through hole at one end of plate.) Mount miniature flashlight bulb into lamp socket. Attach rubber band or piece of string through hole at end of second antenna plate (through which one wire end is already looped) to support this plate vertically. This is plate connected to lamp socket.

Operate Tesla Coil. Holding antenna plate connect to lamp socket (this is receiving antenna plate) by rubber band or string handle, slowly bring toward other plate mounted to top of Coil.

Observe that at a certain point the 10-watt lamp will light despite fact there is only one wire connecting it to Coil.

This experiment illustrates the dream of inventor Nikola Tesla: to send electrical power through the air, without wires, to run factories and homes. Tesla was able to light a bank of 200 lamps at a distance of 20 miles from his Coil by plugging one wire into the ground and connecting the other to an electrical receiving aerial.

To transmit electrical power without wires in an actual situation, the metallic connection between the suspended receiving plate and Tesla Coil in Experiment 15 would be replaced by the ground return through earth.

### Experiment 16

#### How Concentrating Output Produces High Temperatures

You Need: Piece of metal (coin, key); sheet of paper

### **Warning: Perform in Area Where Fire Can be Promptly Extinguished**

Operate Coil with ball terminal in place. Holding piece of metal in your hand, approach ball terminal until discharge occurs. Observe that this initial discharge takes the form of a thin blue spark.

Move piece of metal closer to ball terminal. Observe that discharge grows into arch with yellow flame as distance



between piece of metal and ball terminal is decreased.

Take sheet of paper with your other hand and hold it close to ball terminal, without touching directly. Hold piece of metal behind paper. This will draw discharge through paper.

Move metal closer so discharge becomes an arc. Observe how quickly paper is ignited.

This experiment demonstrates how a high temperature is produced when the entire output of the Coil is concentrated in an arch discharge.

### Experiment 17

#### How Air and Metal Compare as Conductors of High Frequency Currents

You Need: Piece of Metal; Length of stiff bare copper wire, about 7" (included)

Operate Tesla Coil with ball terminal in place. Hold piece of metal in your hand and draw out discharge as far as possible. This is the maximum separation over which a discharge can be obtained.

Unplug Tesla Coil. Fasten 7" length of bare copper wire through small hole in primary terminal post by unscrewing top plastic knob of terminal post, inserting tip of bare wire (bent into small "L") through exposed hole, and screwing knob back into place.

Bend free end of wire upward so it projects vertically and is about 1" or less from ball terminal. This is discharge electrode.

Operate Tesla Coil. Move free end of discharge electrode away from ball terminal to draw out discharge as far as possible. Move wire at its base, close to where it attaches to primary terminal post. Observe length of this second maximum separation. Compare distances of maximum length of discharge which have been created by these two methods.

Observe how length of discharge is greater using discharge electrode than the piece of metal. This discharge electrode provides a metallic return path for the electrical current, whereas the metal

requires that the current pass through the air-filled space between your body and the Coil

It is impossible to obtain the full output of the Coil in this experiment, due to high resistances offered by your body and the air to the flow of high frequency electrical currents.

### Experiment 18

#### Demonstrating Principles of Modulation

You Need: Piece of metal

This experiment illustrates basic concepts of modulation, which is a condition in which a lower frequency can supersede a higher one. Here the several million cycle per second high frequency voltage produced by the Tesla Coil is modulated by the 60 cycle per second power line frequency.

Operate the Coil, holding the piece of metal in your hand. Move metal up and down rapidly in a small arch near the ball terminal. Observe that discharges are not continuous but instead occur in the form of individual sparks.

The individual sparks occur at a rate of 120 sparks per second - one discharge at each peak of the 60-cycle power frequency. The Tesla Coil generates a few million cycles per second. Therefore the individual sparks serve to modulate, or bring down to a lower level, the high frequency generated by the Coil to correspond to a 60-cycle per second modulating frequency.

Experiment with different speeds as you move the piece of metal up and down. You add the dimension time to your observations because at each instant the metal occupies a different position with respect to the ball terminal.

You may actually be able to make individual sparks appear to stand still, a condition known as **synchronizing**. When your speed of movement is in step with the 60-cycle per second power line frequency, each discharge appears to occur at the same position in space between the moving metal and ball terminal.

### Experiment 19

#### Transmitting Power with Radiating Antenna Plates

You Need: One 100-200 watt clear glass light bulb; large radiating antenna plate (included); small antenna plate (included); special lamp socket (included); small length of wire

Mount one radiating antenna plate vertically to top of Coil by removing ball terminal, fastening radiating antenna plate to screw stud by placing small hole in bent "L" of plate over stud, and screwing ball terminal back on stud to hold plate in place. This is transmitting antenna plate.

Attach special lamp socket to second radiating plate (receiving plate) by threading small length of wire through both the hole in the bent "L" of antenna plate and hole in base of special lamp socket, then looping wire over securely.

Place light bulb in special lamp socket. Operate Tesla Coil.

Position both antenna plates so they are parallel to each other. Holding receiving antenna plate by the glass of the light bulb, approach the transmitting plate, keeping both plates parallel.

Observe the point at which the air in the light bulb ionizes. You must approach transmitting plate closely when the plates are parallel to each other.

Turn receiving plate at right angles to transmitting plate and repeat procedure. Compare distance at which ionization occurs.

#### How To Teach With Tesla Coil

**Concepts:** High frequency electricity & generation. Resonance in electromagnetic field. Reversed polarity induction.

**Curriculum Fit:** Physical Science; Electricity & Magnetism. *Unit: Moving Charge & Magnets. Grades 11-12.*

**Subconcepts:** Primary/Secondary Coil. Mutual inductance. Voltage/current relationship during induction. Open & closed circuits, short circuiting. Energy conservation in electromagnetic fields.

Transformation of electricity to magnetism, vice versa. Capacitor. Discharge through sparks.

**Curriculum Fit:** Physical Science/ Electricity & Magnetism. *Unit: Electric Circuits. Unit: Energy Transformation. Physical Science; Electricity & Magnetism. Unit: Static Charge. Grades 6-10.*

## Safety Tips and Safety Features

This product is designed to be safe when used properly. As with any electrical appliance, please follow these safety rules:

1. Plug into grounded (3-prong) 110 volt 60 cycle outlet only (household current.) For 10-206, plug into 220 volt outlet.
2. Do not operate in wet or damp location or outdoors.
3. Check for loose, worn or frayed wires. Have defective parts replaced. (We carry full line of replacement parts. Please call toll-free at 1-800-875-3214 for prices.)
4. While high frequency high voltage electricity will not produce a shock, it can cause a burn if taken into your body at one small point of contact. Do not come too close to a discharge; you may be burned. Use a piece of metal to take away discharge so it will not build to unsafe levels of intense heat.
5. Do not remove plastic cover (ring) around bottom of Coil. This is a safety guard to ensure your fingers will not come into contact with the vibrator or spark gap.

**Removal of safety guard is a shock hazard.**

6. Operate Tesla Coil on bench or table with non-metallic top.
7. Operate Tesla Coil under adult supervision.

## Background of Inventor and Invention

Nikola Tesla, born in 1856 in a small village in Yugoslavia, died an American citizen in 1943 after a spectacular career as inventor, visionary and high-society eccentric. A sensation of his time, he combined photographic memory, ability to visualize complete designs in 3 dimensions, and excellence at languages and math to bequeath to the world his alternating induction motor, high frequency high voltage generator (Tesla Coil), fluid propulsion turbine and innumerable patents.

Eccentric even as a child, Tesla suffered from inexplicable flashes of light when he was in stressful situations and an abnormal sensitivity to noise. He suffered one apparent nervous breakdown at age 5 as a reaction to an older brother's death and two other breakdowns later in life. Yet his original mind was also readily apparent. When introduced to the fascinations of electrical machinery by a teacher, he immediately conceived the idea of dispensing with direct current and commutators in the electric motor. In 1881 he conceived the rotating magnetic field by 2 or more alternating currents out of step with each other; a year later he built his first actual AC induction motor, using 60 cycle AC which has since been the standard.

Arriving in 1884 in America with an introduction to Thomas Edison, he went to work for the Edison Electric Company. But Edison's heavy investment in direct electric current, as well as personality differences, doomed their relationship. "The War of the Currents" began with mounting hostility, as it would take Edison 20 years to admit his blunder in refusing to recognize the importance of alternating current. Tesla then went to work for George Westinghouse, to whom he sold the 40 patents he had been granted during development of the AC motor, an act for which he would suffer financially in later years.

At this point Tesla seemed at the peak of his creativity. The ideas expressed in 4 sensational lectures in 1891-2 are considered forerunners of: theory of cosmic rays; point electron microscope; atom smasher; diathermy; modern electric clock; and "Litz" wire, a stranded cable. It was also the time in which he developed his Tesla Coil, used today in every radio and TV, and in which he conducted research several years before the first experiments of Marconi.

In 1893 occurred 3 triumphs: in St. Louis he made the first public demonstration of radio

communication. (Later a prolonged, bitter war ensued between Marconi and Tesla over radio patents); alternating current was used to illuminate the Chicago World's Fair; and Westinghouse was awarded the contract to build the first 2 generators using AC at Niagara Falls.

Tesla continued to attract media attention. He was an early experimenter with X-rays and robots. In 1898 he innocently set up an "earthquake" by means of vibrations that travelled beneath Manhattan: A bachelor all his life, he attracted the platonic devotion of several women, including J.P. Morgan's daughter, but seemed to have a close relationship only with his mother, whose death he foretold in a "vision", making him of interest to believers in the occult.

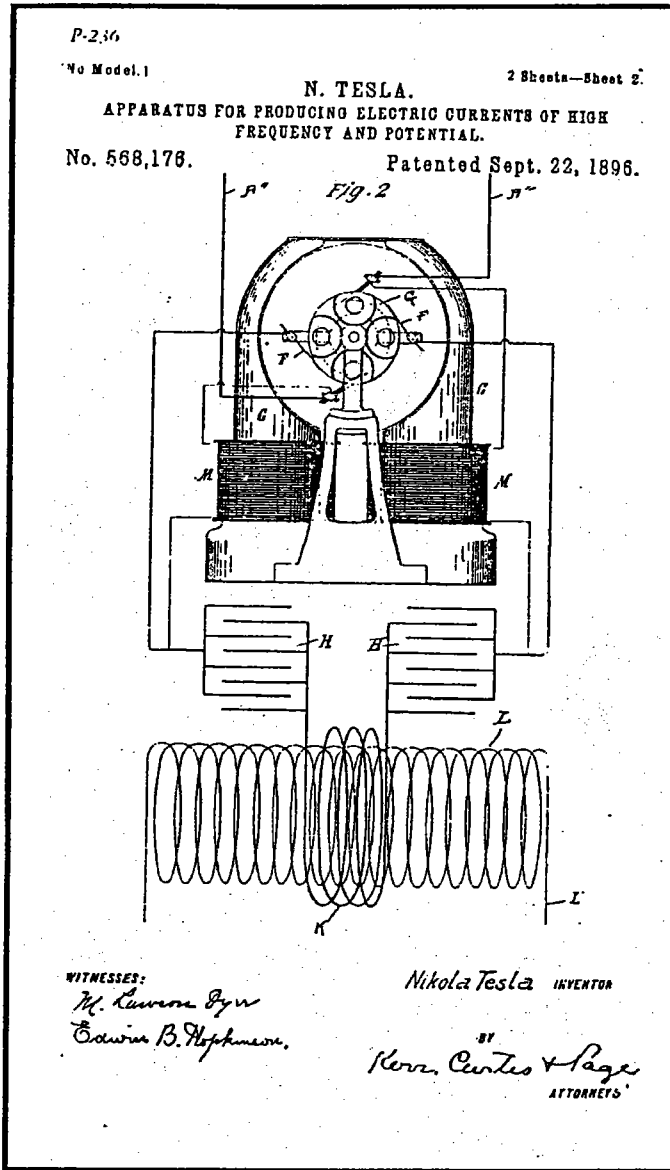
In 1899 he was enticed to Colorado Springs where he set up his famous experimental station with the transmitter he would later claim as his greatest invention. He duplicated electrical fireworks, conducting power-transmission experiments and research into ball lightning. Hearing what was probably radio waves from the stars, he became convinced he had received messages from outer space.

Ridicule and sensationalism now dogged his footsteps. Continually short of funds, his work languished. What appeared a comeback resulted in the doomed relic of the Wardenlyffe Tower erect on Long Island in 1901. This huge transmitter was intended to be the hub of a world system for broadcasting. It was initially financed by J.P. Morgan who withdrew his backing, leaving the tower incomplete.

In later years, although outwardly elegant, Tesla grew bitter, self-serving, defensive and secretive. He continued to produce sensational shows in his laboratory intended to "dazzle" money out of backers. Always neurotic, he became obsessive, gathering up sick and wounded pigeons and carrying them back to his fashionable hotel room to tend lovingly. In his office he worked in the dark, talking to himself.

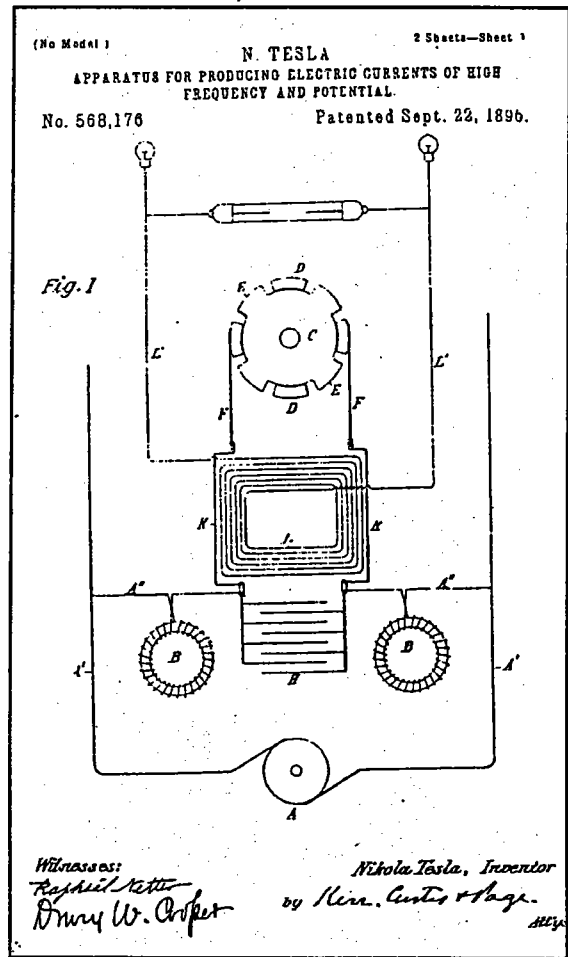
His creativity remained: in 1906, at age 50, he built his first model of his bladeless turbine. At 72 he filed for patents on his brilliantly designed vertical takeoff and landing aircraft. The advent of World War II led to his publishing the basic principles of what would be known as radar.

In old age he began to court the press, clamoring for attention with predictions for the future. Growing feeble in 1942, he worried about his beloved pigeons, sent a note to Mark Twain - dead for 25 years - and finally died on January 8, 1943 at age 86. 8 months later the Supreme Court handed down the decision he had felt sure would come - that he invented the radio.



Nikola Tesla patented his air core transformer between June 1891 and November 1891 but the better designs were improvements patented in September of 1896. Two sketches are shown here.

Information about patents courtesy Robert Lichtenberg



### Tesla Coil Timeline:

- 1891, April 24: Patent: high frequency transformers,
- 1891, May 20: Tesla lectures on Experiments with high frequency currents at Columbia College
- 1892, February 3, 4, and 19: 3 more famous lectures. Tesla speaks on Experiments with currents of extremely high frequency before three professional engineering groups
- 1893 - 1899: Various patents concerning high frequency currents

## Related Products

These products may be ordered from your distributor or directly from manufacturer Science First®.

10-060 (200,000 volt) and 10-085 (400,000 volt) Van de Graaf Generators. Raise hair, experiment with electric wind, create lightning. Safe, easy-to-use, comprehensive instructions.

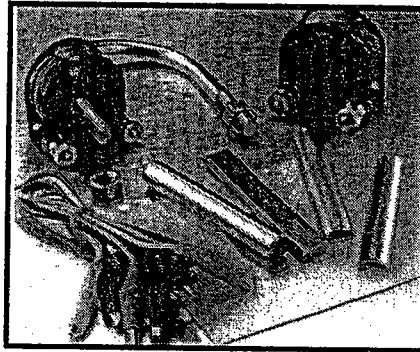
20-030 (lifts 200 pounds) and 20-035 (lifts 500 pounds) Compact Electromagnets. With only one (or two) 1 1/2 volt D batteries, lifts weights of 200 to 500+ pounds while weighing only 2 to 5 pounds themselves. Instructions.

40-200 Gyroscope- Learn about inertial guidance, gyroscope compasses, stabilization and precession with this precision instrument. Bridges the gap between toy and high-tech. Includes gimbal cradle, precision-machined rotor, accessories, instructions

10-091 Electrostatic Demonstration Kit. Complete set of materials for studying electrostatic attraction and repulsion, surface distribution of a charge, Faraday cage, charging electroscopes.

10-125 Leyden Jar - Shows how a dielectric retains a charge even when taken apart. Two aluminum cans, polystyrene dielectric jar, electrode, instructions. Use Van de Graaf Generator as your source of static electricity.

10-110 Electromagnet Kit - Everything you need to build a powerful electromagnet. Study induced currents, reversed polarity and magnetic lines of force. Includes two coils with binding posts; round core; 2 half-round cores; square core; U-shaped double core; card; iron filings; clip leads;



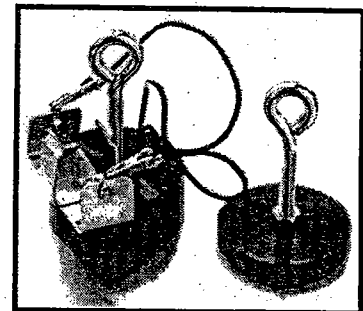
10-110 Electromagnet Kit



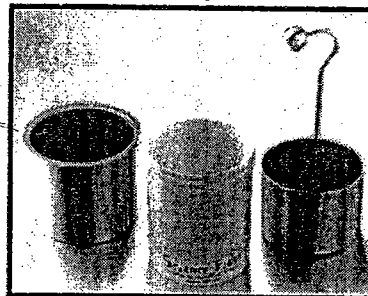
10-085 Van de Graaf (large)



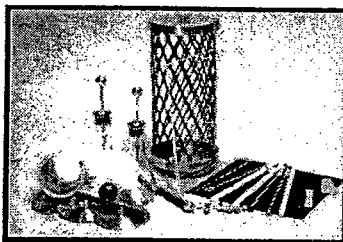
40-200 Gyroscope



20-030 Lifting Magnet (small)



10-125 Leyden Jar



10-091 Electrostatic Demonstration Kit

Do you have an interesting application or photo using our Tesla Coil? Please get in touch. We'll credit your ideas & photos in our next catalogs & instructions.

10-060 Van de Graaf (small)



10-085 Van de Graaf (large)