

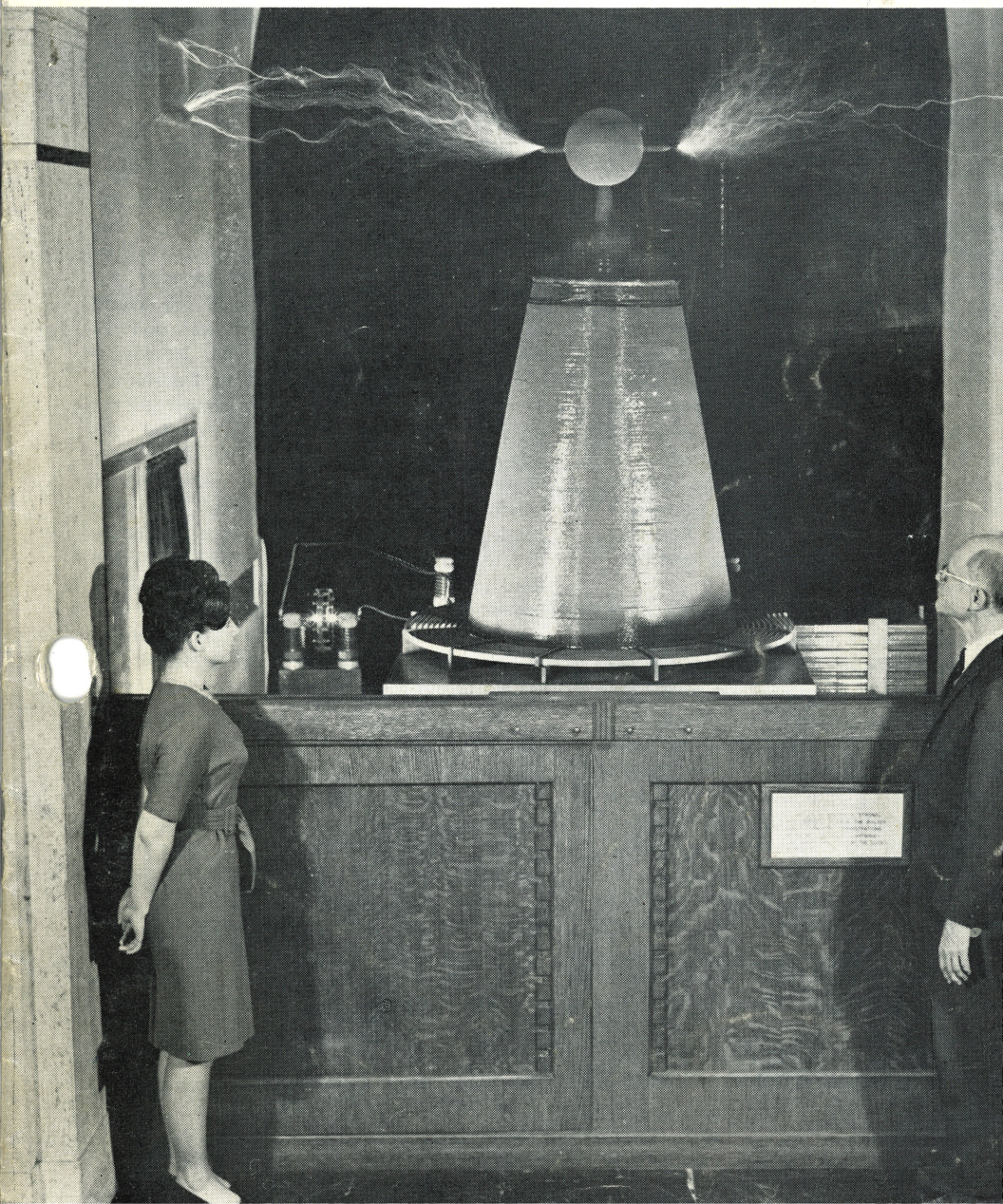
THE

GRIFFITH OBSERVE

Vol. XXIX, No. 8

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THE TESLA COIL

Anyone who has watched the Tesla coil in operation at the Griffith Observatory will have noted its spectacular spark resembling, on a small scale, the natural lightning during a thunderstorm. The air acts like an insulator until a certain voltage per foot or potential gradient is exceeded. This corona type of discharge into the air can be seen on a dark night on high voltage transmission lines. As the voltage is increased the coronal streamers become longer, and if this increase continues, the streamers reach the other side of the circuit, or ground, if the circuit is grounded. When this occurs, an arc is established and the current rapidly increases until the source or supply is exhausted or reduced in voltage to a point such that it cannot support the arc.

Millions of visitors have watched the operation of the Tesla coil and some may have wished to know more of its exact functioning. We receive many requests for information about the Tesla coil. We hope this description will answer these questions and anticipate a few that may have been unasked. A description of the Tesla coil was published in the Griffith Observer 17 years ago, but this issue is now out of print. This article will describe the operation as it is today, as some changes have been made in over 28 years of operation.

The name "Tesla coil" is usually applied to all tuned transformers of this type used to produce a very high voltage. Actually the correct name is "Oudin coil" when one end of the coil is connected to the ground. A Tesla coil has the grounded point in the middle and the spark jumps from one end to the other. We have the other half of the coil but did not have room in the museum to install it. The spark is about twice as long with the complete coil, as tested in our shops.

The following description of the apparatus is necessary to guide anyone wishing to build

a Tesla coil. One word of caution is appropriate at this point. When using a Tesla coil similar to ours, the voltage and current available from the primary and secondary of the coil is enough to have lethal results, if you come in contact with any of the wires. Extreme caution must be used by you and anyone else who may be around the equipment. Many interesting exhibits have been made of the Tesla coil with less power in the driving transformer. These are not as dangerous.

The 120-volt current is fed to the transformer as shown in Fig. 1 through a line filter, which prevents any feedback of the radio frequencies produced by the apparatus into the electrical lines in the building. Each of the four capacitors has 2 microfarads of capacity and 1000-volt insulation. The two coils are wound on a form $3\frac{1}{2}$ inches in diameter and 12 inches long with 57 turns of No. 12 copper wire. The transformer is a power transformer in a case filled with oil. It is similar to the ones you see on power poles to step the voltage down for your home use. This transformer steps the voltage up and has a special type of winding, which limits the current when the spark gap shorts the high-voltage secondary coil. Neon sign transformers, which are often used for Tesla coils, also have a current-limiting winding, so that it is safe to short the secondary winding. This part of the apparatus is below the floor of the museum and is not visible to our visitors.

The rotary gap has two stationary electrodes and the wheel has 14 copper bars in an insulating disk which turns 1800 revolutions per minute. As each copper bar comes between the stationary electrodes, a spark jumps and this shock excites the primary circuit. The spark is between tungsten disks fastened to the ends of the copper bars. The spacing is about one-sixteenth of an inch, but this is not too im-

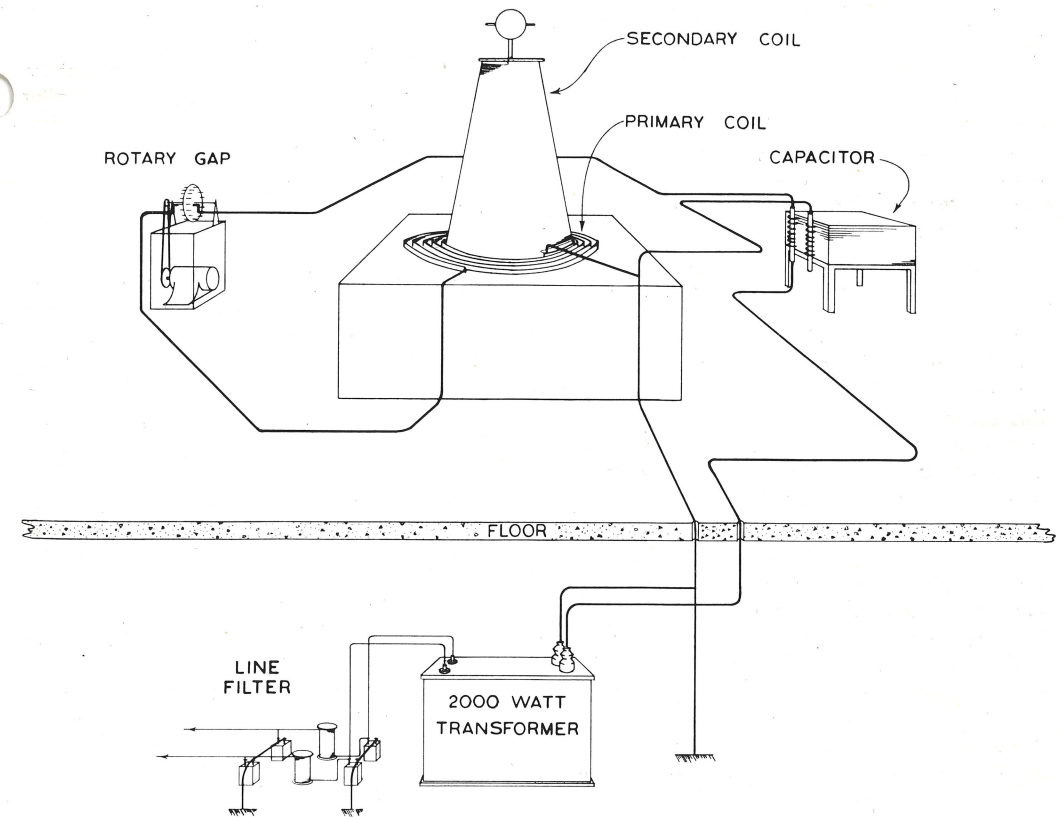


Fig. 1. Diagram of the Tesla coil. The parts shown below the floor are not visible in the museum.

portant except that it must be small enough for the voltage from the power transformer to jump.

The capacitor is made of 30 glass plates 24 inches by 30 inches by $\frac{3}{8}$ of an inch thick. The 29 copper plates between the glass are 15 inches by 14 inches by 0.02 inch thick. The glass plates were made $\frac{3}{8}$ of an inch thick because the original capacitor had 3/16-inch glass and it was often punctured by the voltage. The primary coil has $5\frac{3}{4}$ turns of $\frac{3}{4}$ -inch by 3/16-inch rectangular copper bar. It is necessary to make the primary circuit consisting of the rotary gap, the capacitor and primary coil of heavy conductors, as many amperes flow in this resonant circuit and the efficiency would be decreased if the resistance

was not very low. We use No. 1 wire to connect these units.

The secondary form is 47 inches high and has a bottom diameter of 36 inches and a top diameter of 18 inches. It is wound with 400 turns of No. 14 copper wire. It is not necessary to make a tapered coil, but it is easier to prevent corona from the top turns of the coil if the diameter is smaller. The 12-inch ball on top is a hollow copper sphere. It prevents excessive corona from the top end of the coil and wires. This would constitute a loss of power. The points on each side concentrate the discharge for our visitors to observe more easily.

The operation of the circuit is quite complex and the use of 60-cycle alternating current for

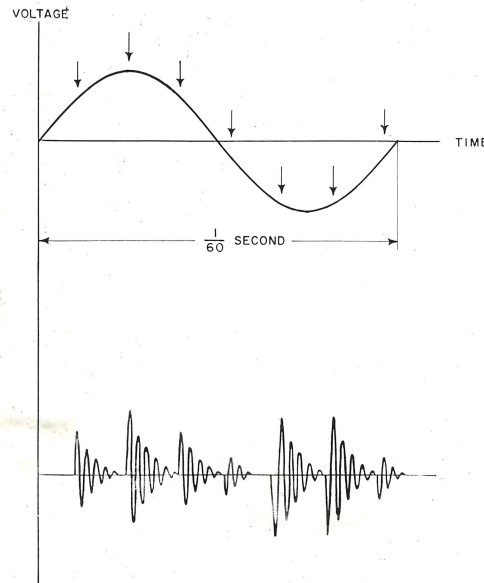


Fig. 2. Upper. 60-cycle sine wave with arrows showing time of breakdown of the spark gap. Lower. Damped wave trains produced in the coil by the spark.

charging the capacitor increases this complexity. The capacitor is charged with a voltage varying as shown in the upper part of Fig. 2. The arrows show a typical set of points at which the spark gap causes a discharge of the capacitor through the primary coil. It will be seen that the voltage is not constant, but may vary from zero to 18,300 volts, the peak voltage from the transformer. The spark gap is not synchronous with the 60-cycle current; so the points of sparking on the sine wave vary.

At each spark of the rotary gap a damped wave train is generated in the primary circuit of the Tesla coil, as shown in the lower part of Fig. 2. The primary circuit is shock excited by the passage of the spark. This is analogous to the striking of a piano string by a hammer. Like the piano string, which then vibrates at the frequency to which it is tuned, so does the resonant circuit consisting of the capacitor and primary coil oscillate at its electrical resonant frequency. In this Tesla coil, the primary and secondary are tuned to 70,000 cycles per

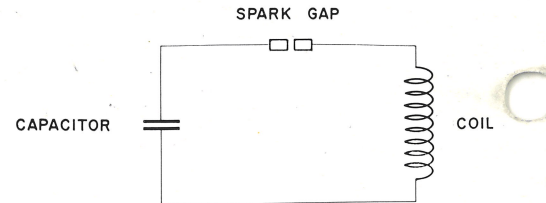
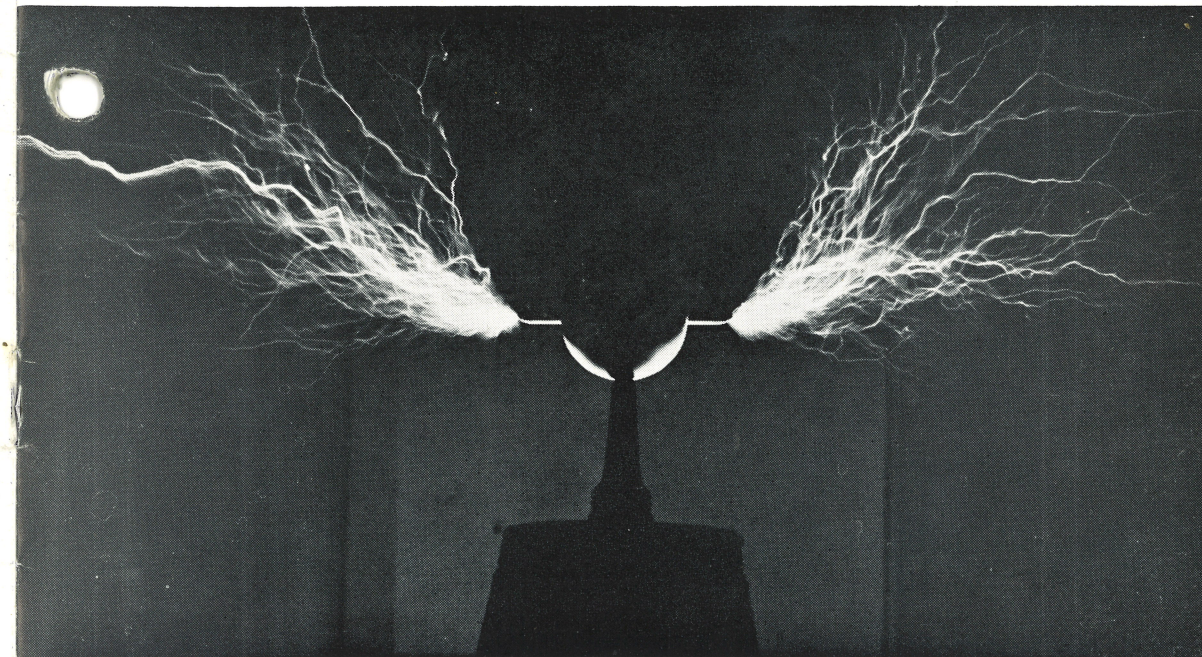


Fig. 3. Primary resonant circuit.

second. Like the vibrations of the piano string, the oscillations die out until the spark passes again. We call this dying out of the wave the damping or decrement of the wave. Its rate depends on the losses in the circuit and the loss of the energy used in producing the corona or spark from the secondary. It will be noticed that the maximum amplitude of the individual wave trains will vary, depending on the potential or voltage to which the capacitor is charged at that instant. In some cases it may be zero and we skip a wave train completely. We now have a series of damped wave trains about 420 per second, their amplitudes varying with the 60-cycle supply current. We do not have the 60-cycle current as such in the primary or secondary of the coil. The wave trains are amplitude-modulated by the 60-cycle current.

The secondary which is tuned to 70,000 cycles receives energy from the primary as in any transformer and is set into oscillation. It is easy to see in the primary that the capacitor is across the primary coil through the spark gap, which is a short circuit when the arc is established between the electrodes. Fig. 3 shows this parallel resonant circuit. In the case of the secondary, we say it is tuned by its distributed capacity. Fig. 4 shows how the capacity between the turns of wire constitute a parallel circuit similar to the primary. The capacitors shown represent the capacity between adjacent turns of wire. The voltage is stepped up by the ratio of the number of turns on the secondary to the number of turns on the primary less the losses in the transformer. When we calculate the various factors involved and estimate the losses, we find that the energy of 2,000 watts at 120 volts and 17 amperes which we put into the primary of the 60-cycle transformer comes out over 1,000,000 volts and between



The lower voltage peaks produce the intense corona seen near the discharge points on the ball. The long spark on the left has crossed the air gap to ground and is produced by high voltage peaks in combination with a fortuitious set of initial conditions.

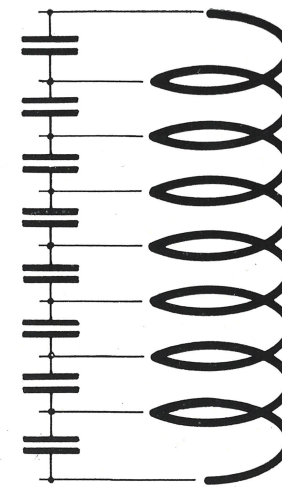


Fig. 4. Secondary resonant circuit.

.001 and .002 amperes. This is the energy which produces the corona and sparks at the top of the secondary coil.

The breakdown of a gas by an electrical voltage depends on many factors, such as shape and material of the electrodes, voltage and available current, nature and pressure of the gas, available ions and electrons in the gas, etc. One important factor is the number obtained by multiplying the pressure of the gas by the distance between the electrodes. This number, if it is small, gives the type of discharges shown in a cabinet close to the Tesla coil. These are at less than atmospheric pressure or have very close spacing of the electrodes. If the number is large, we have the type shown by the Tesla coil. We will only discuss this type at atmospheric pressure. There are a few words we must define, as they will be used often in this description. An electron is a very light particle with one negative charge of electricity on it. A positive ion is an atom that has lost

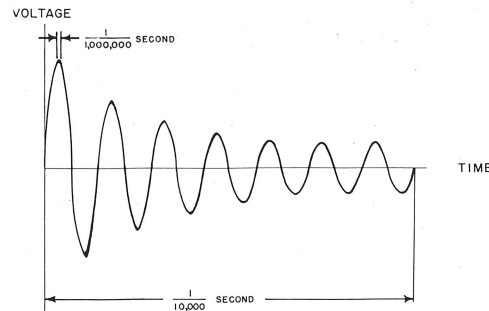


Fig. 5. One damped wave train showing the time of formation of the 1,000,000-volt spark.

one or more electrons, and a negative ion is an atom that has acquired an extra electron. We will call it an atom, but it may well be a molecule, a group of atoms. Ions formed in the air weigh several thousand times as much as an electron. Air is an excellent insulator if it does not contain ions or electrons. A gap between two electrodes spaced $1/32$ of an inch apart will break down with less than 5,000 volts, if there are charged particles available. If the charged particles are removed, it may take 50,000 volts.

In the early part of this century it was thought that the intense ionization of the air necessary for a spark was created by the ions, both negative and positive. Then the time of formation of a spark was measured and it was found that a heavy ion could not cross the gap in time. So it was thought the electrons must cause the ionization, but exact measurements showed that even a light electron would not have time to cross the gap. The time of formation of the spark was very small, of the order of a millionth of a second. Loeb, Meek and others in 1940 evolved the streamer theory, which with some modifications is accepted today.

Ionization of the atoms of a gas can be caused by various means. An ion or electron which has been accelerated by an electric field can, by collision with atoms, break them up into ions and electrons. We have a suitable field between the two electrodes in the Tesla coil. The photons of electromagnetic radiation can cause ionization of atoms. Photons are the

POSITIVE POINT

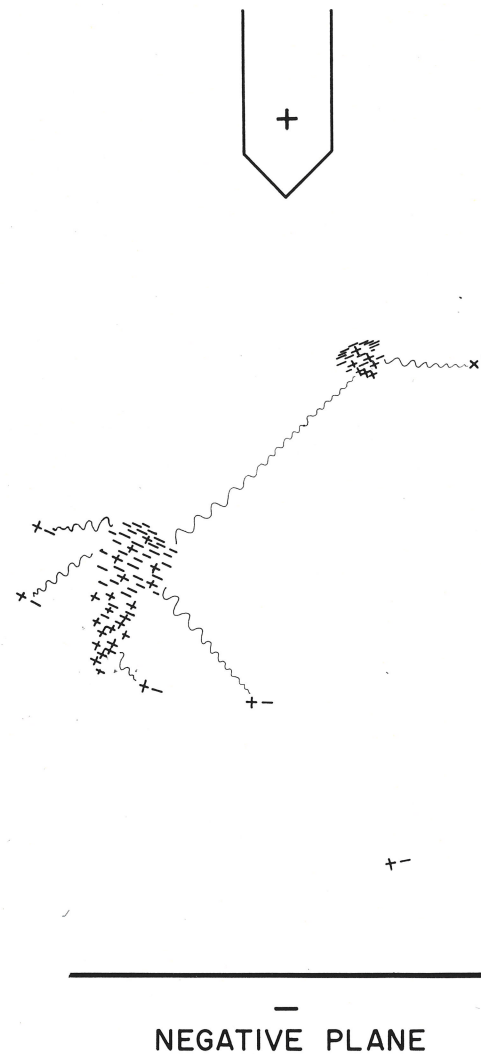


Fig. 6. The charged particles have started an avalanche, and a photon, its path shown by the wavy line, has started another one. In the lower right another ion and free electron have been formed, perhaps by a cosmic ray.

discrete units of electromagnetic radiation. When the photons have different amounts of energy, we call them by different names, such as radio waves, light, X-rays, etc. Photons all

POSITIVE POINT

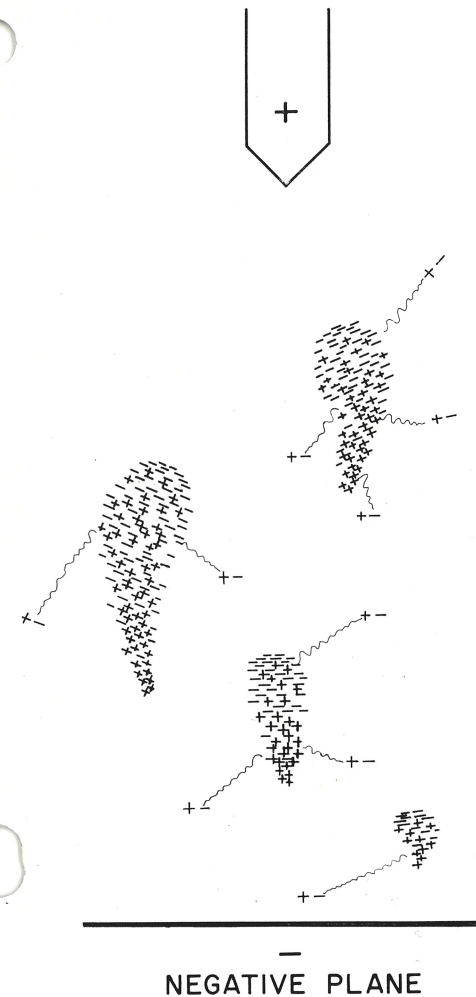


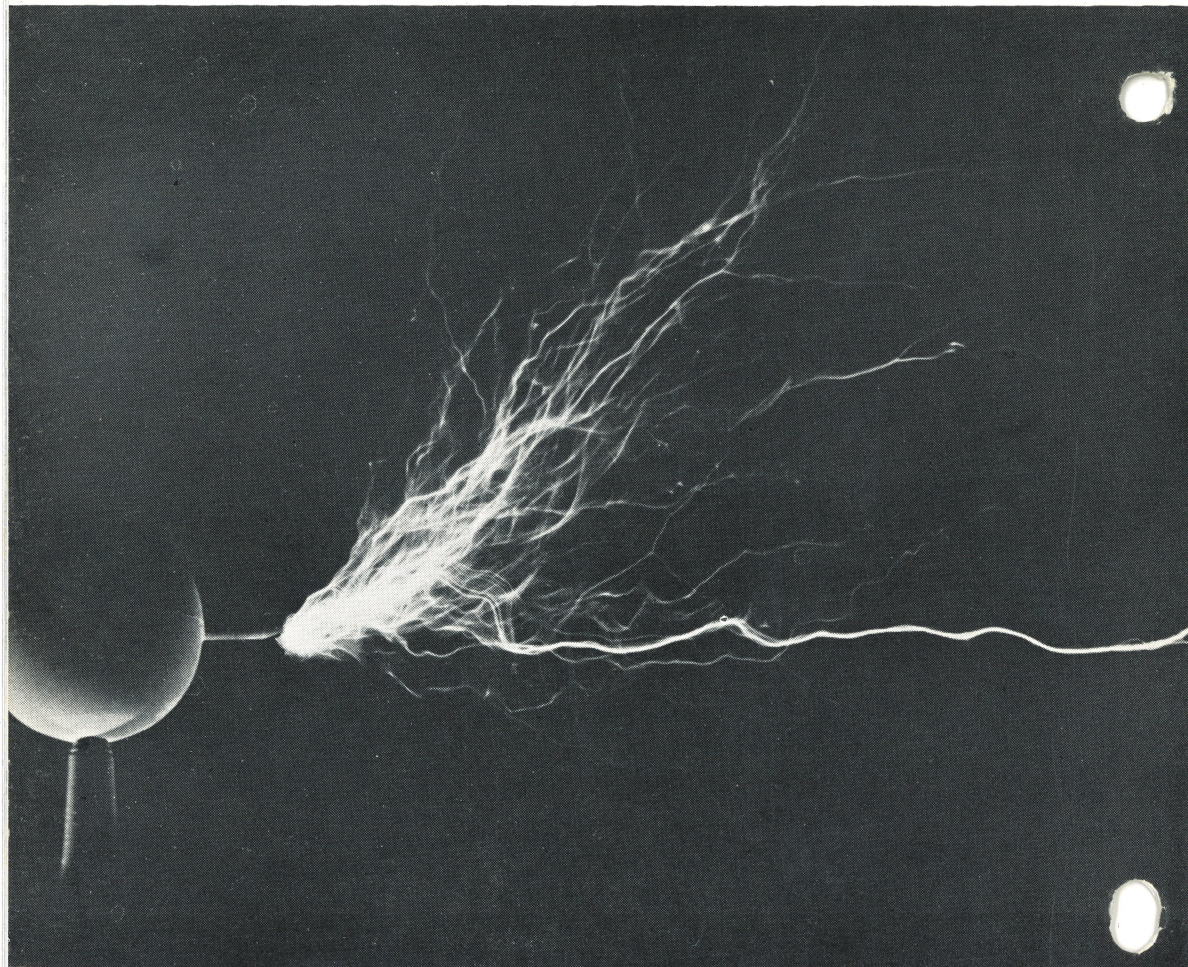
Fig. 7. The avalanches started in Fig. 6 have increased in size and new ones have started.

travel with the speed of light, about 12 billion inches per second. They can cross the gap in the Tesla coil in four billionths of a second. Now we have an ionizing means which travels fast enough to make an ionized path for the spark in the time observed.

Electrons that happen to be in the air between the electrodes when the electrical voltage is applied are accelerated and produce electron avalanches as shown in Fig. 6. In travelling less than one-half inch, an electron can produce a million each of ions and free electrons. When an electron hits an atom and does not completely eject an electron and it falls back into the atom, or when a free electron combines with an ion, photons are produced. When electrons combine with nitrogen ions, the photons produced have an energy which makes them short ultraviolet light. This radiation creates many ions and free electrons which start their own avalanches as shown in Fig. 7.

Now we have a partially conducting path between the electrodes, and a fast space charge streamer, as shown in Fig. 8, develops from the positive electrode towards the negative electrode. This is fed by the ions and electrons from the avalanches. The avalanches have not formed in a straight line but at random in space; so the streamer follows a path of least resistance and the irregular path observed in long sparks is produced. When this streamer reaches the negative electrode and a spot is established on the negative electrode capable of supplying sufficient electrons, a sustained discharge called a spark or arc is established. This has been accomplished without any ion or electron travelling the whole distance between the electrodes until the actual spark or arc occurs. The spark passing along this conducting path travels near the speed of light. In this very short time in the order of a millionth of a second, all the formation and passage of a spark has occurred. As shown in Fig. 5 this can occur on the voltage peak of the radio frequency wave.

When we demonstrate the Tesla coil in the Hall of Science, the demonstrator holds a fluorescent lamp in his hand. The intense field between the ball on top of the coil and the ground causes sufficient current to flow in the tube to light it. The lines of the potential or voltage field flow out of the ball to the earth somewhat like a low pressure water fountain. Along each of these lines there is a voltage



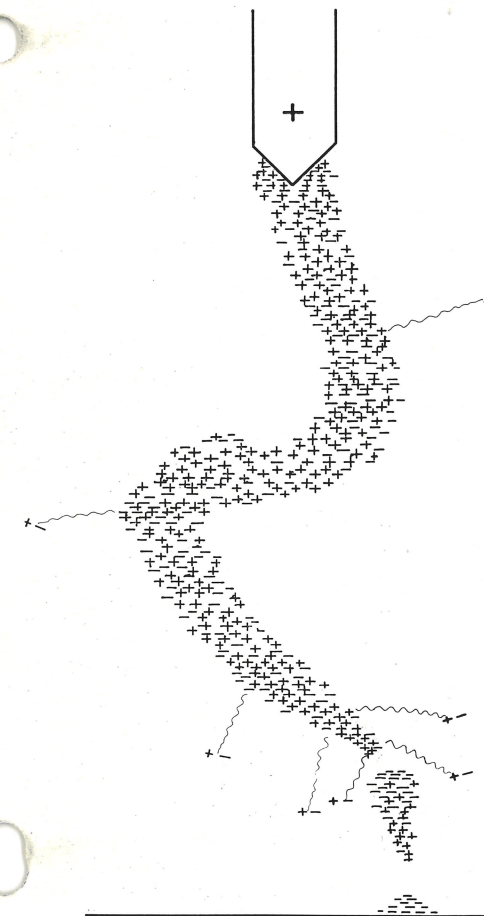
A closeup of one-half of the discharge. The long bright lower line is a spark to ground. The double appearance of some of the sparks is caused by heating of the air by the discharge. The rising, heated, ionized air from a previous spark has provided a low resistance path for a subsequent spark.

equal to the difference of potential between the ball and the earth. If a conductor of electricity, having less resistance than the air, is aligned with the direction of these lines, the current flows through the conductor. The gases in the fluorescent tube and their pressure are chosen to provide a low resistance path for the passage of electrical current. The current flows into the upper end of the tube, through the tube and the body of the demonstrator to the

ground. This is only a small part of the total output of the coil.

Some very spectacular demonstrations have been given where the demonstrator allows the full current to pass through his body. He may hold a piece of metal up to the ball and allow the spark to jump from the ball to the metal and pass through his body to the earth. He may sit on the ball and allow the spark to jump

POSITIVE POINT



NEGATIVE PLANE

Fig. 8. The streamer has progressed from the positive point following the ionized paths of the avalanches almost to the negative plane. A spot is being formed on the negative plane which will supply the electrons for the spark.

from a piece of metal held in his hand to the ground. It is necessary to prevent the spark from jumping directly to the skin, as this will cause a deep burn. In this latter case, the demonstrator's hair will stand on end. Each hair is charged to the same polarity, positive

or negative. The hairs repel each other and separate themselves so that they stand as far from one another as possible. This demonstration is not given at the Griffith Observatory because of the risk involved. A slight fault in the circuit can cause the 60-cycle current from the transformer to flow through the person and cause serious injury.

—Leon Hall, Associate Director

SUPPLEMENTARY READING

- J. S. Townsend, *Electricity in Gases*, Oxford University Press, 1915.
- G. W. Pierce, *Electric Oscillations and Electric Waves*, McGraw-Hill Book Co., 1920.
- J. J. Thomson, *Conduction of Electricity Through Gases*, Cambridge University Press, 1928.
- J. D. Cobine, *Gaseous Conductors*, McGraw-Hill Book Co., 1941.
- L. B. Loeb, *The Mechanism of the Electric Spark*, Stanford University Press, 1941.
- J. M. Meek, *Electrical Breakdown of Gases*, Oxford University Press, 1953.
- L. B. Loeb, *Basic Processes of Gaseous Electronics*, University of California Press, 1955.

COVER PAGE

This Tesla Coil was given to the Griffith Observatory in 1937 by Dr. Frederick F. Strong, who inherited it from the builder, Earl L. Ovington.

SKY CALENDAR FOR AUGUST

(Pacific Daylight Time)

PHASES OF THE MOON

First Quarter	August 3	2248
Full Moon	August 12	0123
Last Quarter	August 19	2051
New Moon	August 26	1151

THE PLANETS

Mercury appears too near the sun to be observed this month, being in inferior conjunction on August 15.

Venus, magnitude -3.4 , is in the early evening sky, setting in the west less than two hours after the sun.

Mars, magnitude $+1.2$, is in Virgo, passing 2° north of Spica on August 8. It sets in the west about three hours after the sun.

Jupiter, magnitude -1.7 , is in Taurus, rising about four hours before the sun.

Saturn, magnitude $+0.9$, is in Aquarius, rising in the early evening.

Uranus, magnitude $+6$, is in Leo, setting too soon after the sun to be easily observed.

Neptune, magnitude $+8$, is in Libra, setting about four hours after the sun. It changes its position from R.A. = $15^{\text{h}}01^{\text{m}}$ and Decl. = $-15^{\circ}17'$ on August 1 to R.A. = $15^{\text{h}}02^{\text{m}}$ and Decl. = $-15^{\circ}24'$ on August 31.

METEORS

The Perseid meteor shower can be observed during the second week of August, but the occurrence of full moon on August 12 will cut down the number of meteors visible. The shower reaches a maximum around that date, when about 50 meteors an hour can be seen under favorable conditions. The best time to see them is after midnight, when Perseus is above the northeastern horizon.

CHILDREN'S BOOKS

Every person who has the privilege of knowing a child intimately—whether parent, teacher, or fond grandma—knows the pleasure and the often bewildering search to satisfy the child's curiosity concerning the world about him. In helping the child's mind to grow, the adult finds that he himself is learning and growing. Whether widening horizons by actual experience or by reading, the process is doubly gratifying if shared. The following are a few of the many books in the Los Angeles Public Library which you and your children can enjoy together.

FOR THE YOUNGEST

The Big Dipper, by Franklyn Branley. (Crowell, 1962)

When I Go to the Moon, by Claudia Lewis. (Macmillan, 1961)

Andy's Wonderful Telescope, by G. W. Schloat. (Scribner, 1958)

You Among the Stars, by Herman and Nina Schneider. (W. R. Scott, 1951)

Space, by Marian Tellander. (Follett, 1960)

Let's Go to a Planetarium, by Louis Wolfe. (Putnam, 1958)

MIDDLE-AGED BOYS AND GIRLS

Worlds in the Sky, by C. L. Fenton. (Day, 1963)

Exploring the Planets, by R. A. Gallant. (Doubleday, 1958)

Telescopes and Observatories, by Patrick Moore. (Day, 1962)

The World is Round, by Anthony Ravielli. (Viking, 1963)

Patterns in the Sky, by W. M. Reed. (Morrow, 1951)

Find the Constellations, by H. A. Rey. (Houghton, 1962)

Stars, by Herbert Zim. (Golden Press, 1956)

JUNIOR HIGH

The Riddle of Time, by T. H. Bell. (Viking, 1963)

Point to the Stars, by J. M. Joseph. (McGraw, 1963)

The Stars in Our Heaven, by Peter Lum. (Pantheon, 1948)

This Way to the Stars, by John M. Schealer. (Dutton, 1957)

The Solar System; Our Newest Front Yard, by Clifford Simak. (St. Martin's, 1962)

The Search for Planet X, by Tony Simon. (Basic Books, 1962)

All of these books are available in the Children's Room, Los Angeles Public Library, 630 West Fifth Street, and in many of the City's 61 branch libraries. Ask your local children's librarian about these and other books relating to astronomy. If the book you want is not available there may be others equally as suitable. This book list was compiled by the Children's Services Office of the Los Angeles Public Library.

LOS ANGELES ASTRONOMICAL SOCIETY

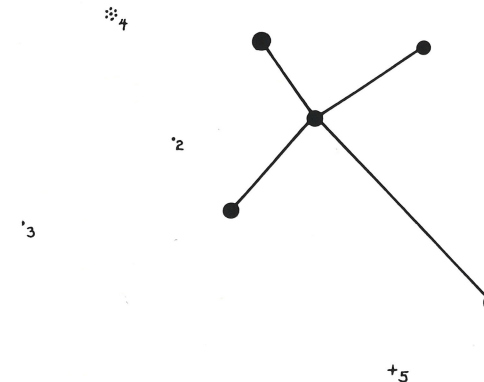
No meeting at Griffith Observatory in August.

STAR PARTIES

The Los Angeles Astronomical Society will hold star parties at Mount Pinos on the following Saturday evenings: July 31, August 28 and September 25. There will also be one at Mill Creek Summit on October 23.

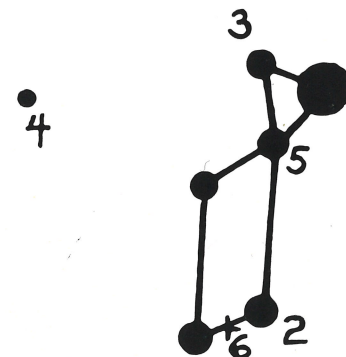
SOME TELESCOPIC OBJECTS FOR JULY, AUGUST, AND SEPTEMBER

The summer constellations along the Milky Way offer top-notch hunting with a telescope. This list provides some specific targets. However, try scanning the Milky Way with binoculars to locate good objects for your telescope. The Sagittarius region is rich in star clusters and nebulae.



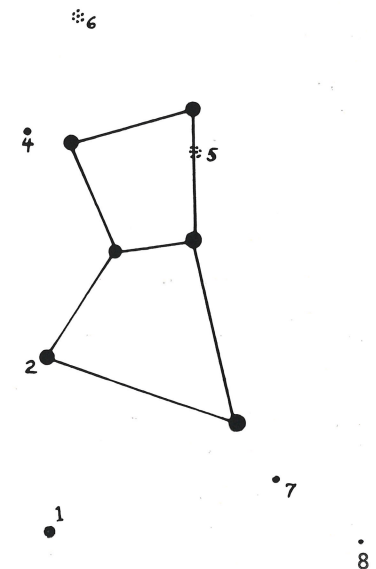
Cygnus:

1. Beta Cygni (Albireo). Double Star. Magn. 3.2 and 5.4. Sep. $34''$.
2. 61 Cygni. Double Star. Magn. 5.6 and 6.3. Sep. $22''$.
3. Mu Cygni. Triple Star. Magn. 4.7, 6, 7. Sep. A-B $2''$, A-C $217''$.
4. Star Cluster M 39.
5. Dumbbell Nebula M 27.



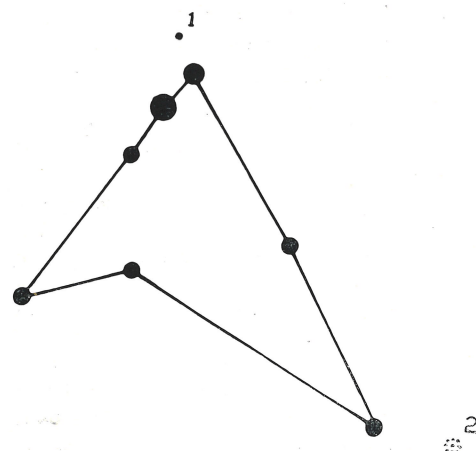
Lyra:

1. Alpha Lyrae (Vega). Double Star. Magn. 0.1 and 10. Sep. $43''$.
2. Beta Lyrae. Triple Star. Magn. 6.7 and 9.2. Sep. A-B $46''$, A-C $67''$.
3. Epsilon Lyrae. Quadruple Star. Magn. 5, 6, 5 and 5.
4. Eta Lyrae. Double Star. Magn. 5 and 8. Sep. $28''$.
5. Zeta Lyrae. Double Star. Magn. 4 and 6. Sep. $44''$.
6. Ring Nebula M 57.

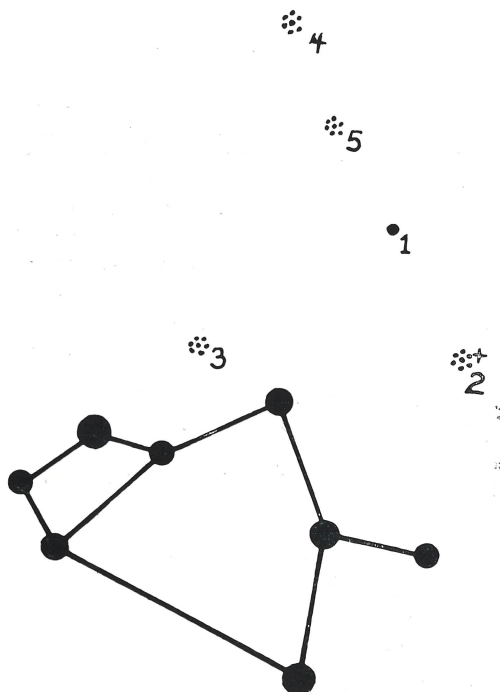


Hercules:

1. Alpha Herculis. Double Star. Magn. 3.5 and 5.4. Sep. $4''$.
2. Delta Herculis. Double Star. Magn. 3.2 and 8. Sep. $15''$.
3. Mu Herculis. Double Star. Magn. 3.5 and 8. Sep. $31''$.
4. Rho Herculis. Double Star. Magn. 4.5 and 5.5. Sep. $4''$.
5. Star Cluster M 13.
6. Star Cluster M 92.
7. Gamma Herculis. Double Star. Magn. 4 and 8. Sep. $40''$.
8. Kappa Herculis. Double Star. Magn. 5 and 6. Sep. $31''$.

**Aquila:**

1. Pi Aquilae. Double Star. Magn. 6 and 7. Sep. 1.5".
2. Star Cluster M 11.

**Scorpius:**

1. Alpha Scorpii. Double Star. Magn. 1.2 and 7. Sep. 3".
2. Beta Scorpii. Double Star. Magn. 3 and 5. Sep. 14".
3. Nu Scorpii. Quadruple Star. Magn. 4, 6.5, 7 and 8. Sep. A-B 1", C-D 2", AB-C 41".
4. Xi Scorpii. Triple Star. Magn. 4.6, 5.5 and 7.1. Sep. A-B 1", A-C 7".
5. Star Cluster M 80.
6. Star Cluster M 6.
7. Star Cluster M 7.
8. Sigma Scorpii. Double Star.

Sagittarius:

1. Mu Sagittarii. Quintuple Star (small telescopes may only reveal two components) Magn. 3.5 and 9.5. Sep. 48".
2. Cluster and Nebula M 8.
3. Star Cluster M 22.
4. Omega Nebula M 17.
5. Star Cluster M 24.

AN APPEAL FOR OBSERVATIONS OF THE MOON

By WINIFRED SAWTELL CAMERON

NASA Goddard Space Flight Center
Greenbelt, Maryland

In the past few years, particularly the last year and a half, there have been a number of reports of lunar transient phenomena. Various anomalies have been observed, such as white or gray obscurations, blue or violet haze and reddish spots or glows. Most have been observed against the lighted portions of the moon, but some have been seen on the dark side. Unequivocal and permanent records of some of these phenomena were made by the Russian astronomer, N. A. Kozyrev, who obtained spectra of phenomena occurring in the craters Alphonsus and Aristarchus. Z. Kopal of Manchester, England, also obtained photographs in the red and green regions of the spectrum by the use of filters, in which the brightness of extended regions of the moon appeared to be significantly enhanced in the red photographs for short periods of time, on the order of minutes or an hour.

The importance and scientific significance of the knowledge of the nature of these temporary phenomena need hardly be emphasized. Hence, the **National Aeronautics and Space Administration** has provided funds for the development and manufacture, by Trident Engineers Associates, of a device called **Moon-blink**, a conception of Dr James Edson of NASA Headquarters. It utilizes the blink technique used for detecting motions of celestial bodies. The color blink is obtained by a rotating filter wheel composed half of red and the other half of blue filters. The light after passing through the filters falls on the surface of an image converter tube which the observer watches or photographs. If a red or blue color event occurs it should appear as a blinking spot. In the past six months one certain and another less certain phenomena were detected by a Moon-blinker.

Six of these Moon-blinks are already in operation at stations throughout the country, most of which are amateur observatories manned by groups or individuals. Two of these stations are on the **Network for Confirmation of Lunar**

Transient Phenomena. The Network is composed of sixteen observatories, twelve professional and four amateur, which have agreed to turn their telescopes on the moon if alerted, by a conference call, that a phenomenon is in progress on the moon. Confirmation may be reported during the call or a standard form may be sent in by mail. The information is sent to the **NASA Collection Center**, c/o Mrs. Winifred S. Cameron, Goddard Space Flight Center, Greenbelt, Maryland 20771, Code 641.

We are appealing to you, as amateurs, to observe the moon as much as possible and to send in reports of transient events after they have been thoroughly checked as to reality of occurring on the moon, not terrestrially, and confirmed by one or more observers at the time, to Mrs. Cameron at the above address. The standard form is reproduced here and forms may be obtained by writing to her for them.

There are, perhaps, certain features on the moon that are now likely to show temporary anomalies if these are due to internal causes. Such features may be craters with central peaks that have a summit crater, mountains with summit craters, or sinuous rills, which originate in a crater. Areas that have been reported in the literature more than once are: the central peak and eastern (I.A.U. convention for all directions) floor of Alphonsus; central peak and southwest rim or Aristarchus; Atlas, Plato, Piton, Schroter's Valley, sinuous rill just outside southeast wall of Herodotus, Ross D, Linné, Cape Agarum in Mare Crisium. Perhaps sinuous rills in general should be frequently observed, also black-haloed craters like those in Alphonsus and around Copernicus. Photographs, spectrograms or any permanent records of transient events would be especially valuable.

DATA SHEET RECORD

Time of observation (standard time):
Name, and location within or around,
of formation:
Selenographic position (astronomical):

Hour Angle (or Right Ascension) and

Declination of moon:

Altitude of Moon:

Phase of Moon:

Color—variations:

Shape—variations:

Estimation of brightness of phenomenon—
variations:

Duration:

Location of observer:

Name of observer:

Experience in observing:

Seeing conditions—poor, fair, good, very
good, excellent:

Transparency (faintest magnitude with eye):

Wind conditions:

Telescope aperture and kind and power:

Others called:

Remarks and sketch:

MESSIER OBJECTS IN SAGITTARIUS

In 1787 Charles Messier published a list of about 100 objects, containing most of the brighter nebulae and star clusters which lie north of the 35th parallel of south declination. In Sagittarius there are 15 of them, more than in any other constellation.

The accompanying illustration was made from parts of two photographs taken at the Lick Observatory. It includes eight Messier objects in Sagittarius and two of them in Scorpius. Their positions are shown in the chart which covers the same area as the picture.

TABLE I

M	R.A.	Decl.	Distance
6	17 ^h 36 ^m .8	−32° 10'	1,500
7	17 ^h 50 ^m .7	−34° 48'	780
8	18 ^h 00 ^m .6	−24° 23'	3,200
20	17 ^h 59 ^m .4	−23° 02'	3,200
21	18 ^h 01 ^m .6	−22° 30'	2,800
22	18 ^h 33 ^m .4	−23° 57'	22,000
28	18 ^h 21 ^m .4	−24° 53'	54,000
54	18 ^h 51 ^m .9	−30° 32'	63,000
69	18 ^h 28 ^m .1	−32° 24'	61,000
70	18 ^h 40 ^m .0	−32° 20'	63,000

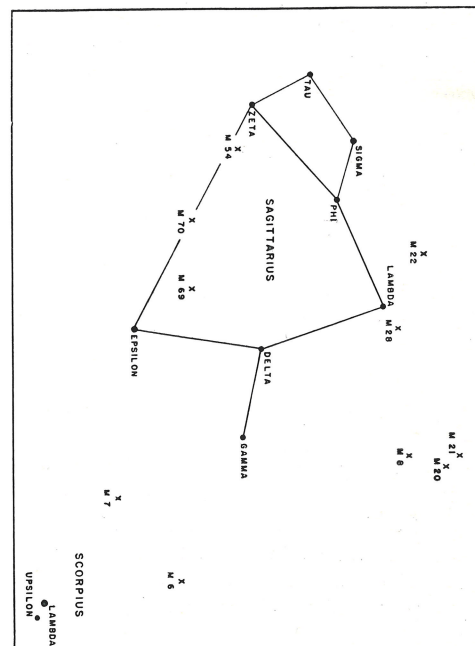


Table I lists for each of these ten objects its Messier number, right ascension, declination, and distance in light-years. These figures have been taken from Leaflet No. 240 of the Astronomical Society of the Pacific. Numbers 6, 7, and 21 are open star clusters. M 8 is the "Lagoon" nebula and M 20 is the "Trifid" nebula.

The last five in the list are globular star clusters, which are located just outside our galaxy. The first five objects are in our galaxy.

PLANETARIUM SHOWS

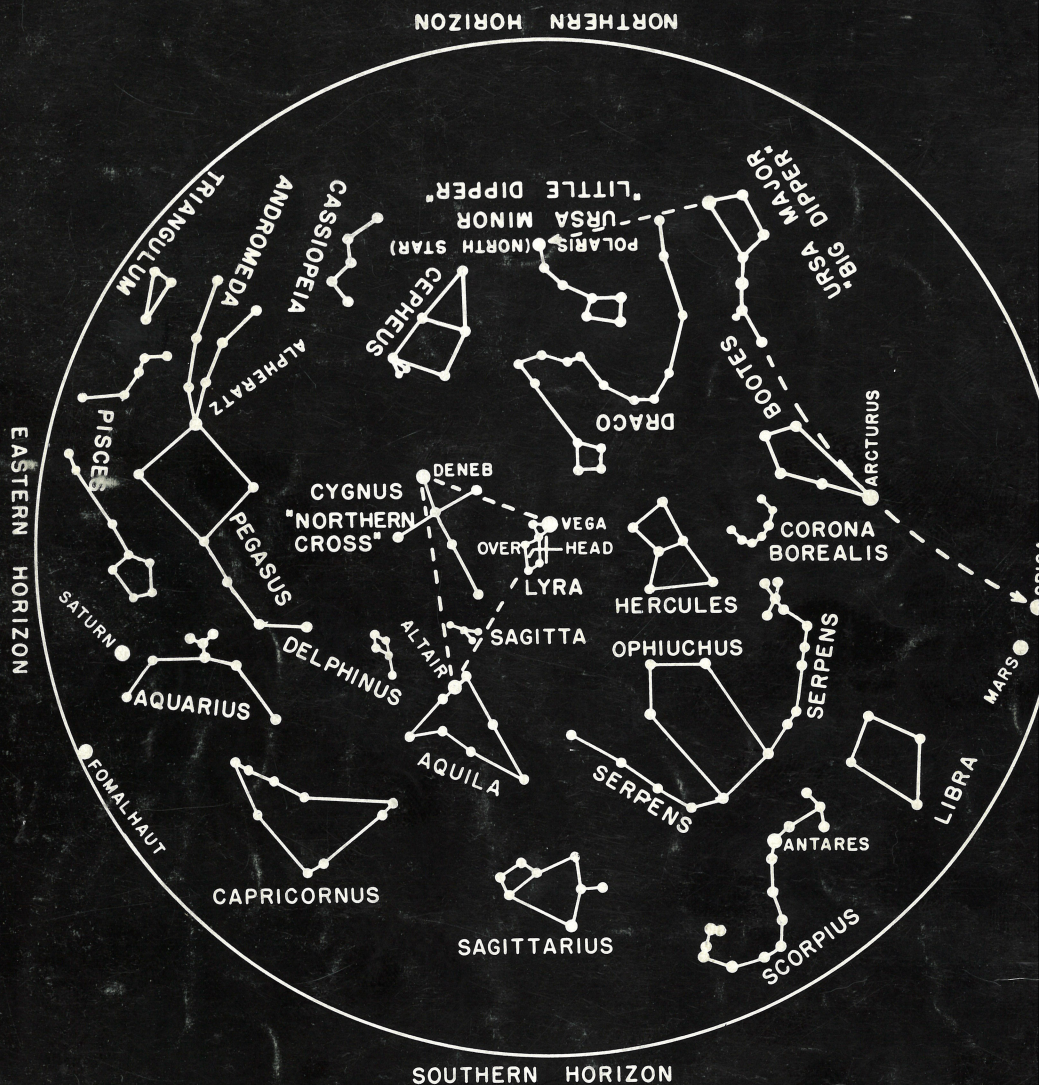
June 22 - September 12

A TRIP TO THE MOON AND SATURN

Monday through Friday at 3:00, 8:00, and 9:15 p.m. Saturdays, Sundays, and Labor Day at 1:30, 3:00, 4:30, 8:00, and 9:15 p.m.

ADMISSION: Adults 75 cents. Children from 5 to 18, 30 cents. Children under 5 not admitted. No advance sale or reservation of tickets. Box office opens a half hour before each show.





THE NIGHT SKY IN AUGUST

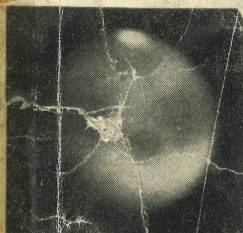
THIS MAP SHOWS THE PRINCIPAL STARS AND PLANETS WHICH ARE ABOVE THE HORIZON AT LATITUDE 34° NORTH AT ABOUT 9 P.M. STANDARD TIME IN THE MIDDLE OF THE MONTH. IT IS PRACTICAL ANYWHERE IN THE UNITED STATES THROUGHOUT THE MONTH, SHOWING THE SKY AT 10 P.M. ON THE FIRST AND AT 8 P.M. ON THE LAST OF THE MONTH. TO USE IT, HOLD IT VERTICAL AND TURN IT SO THAT THE POINT OF THE COMPASS TOWARD WHICH YOU ARE FACING SHOWS ON THE BOTTOM OF THE MAP.

THE

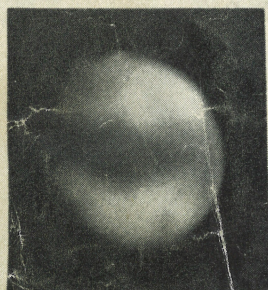
GRIFFITH OBSERVE

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April, 1948



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E.

MARS AT 1941 OPPOSITION

(See page 44)

spark display in its alcove at the Griffith Observatory, he sees the spark jump from the ball at the top of the coil to the walls of the alcove, a distance of about five feet. The walls are plaster on metal lath on steel framework. The metal in the walls is well grounded electrically and provides a ready path for the spark discharge to reach the ground.

There are a great many fundamental principles of electricity and magnetism involved in the Tesla coil. We shall spend a little time here and there with discussions of the principles which we need to know in order to understand the operation of the coil. We shall be using the terms **voltage** and **current** a great deal, so, briefly, let us learn their meaning. An analogy that is often used may serve us well in this case. Voltage and current are likened to **pressure** and **flow** of water in a pipe. The voltage is a measure of the electrical pressure, and current is the volume of electricity flowing. An electric current consists of a flow of electrified particles called **electrons**. These are too tiny to be seen by any means, for they are thousands of times smaller than atoms, but we can measure the number of them moving past a point in any length of time, and this measurement we define as the **current**. The unit of electrical flow or current is the **ampere**. The voltage is the force or pressure that causes the particles to move, and the higher the voltage, the more of them we find passing a given point, or the higher is the current. Also, the higher the voltage, the farther these electrons will jump between two conductors through the air. Ten thousand volts of pressure will cause a spark to jump between two needle points about 1/3 inch apart, or between two balls about 1/8 inch apart.

The description of the instrument should begin with the source of power. It is the 110-volt house lighting supply. It is called 60-cycle alternating current because the current reverses its direction 120 times per second instead of flowing uniformly in one direction. It is this alternation of the direction of flow that makes it possible to step up or step down the voltage by the use of **transformers**. It is the changing current in the primary coil of the transformer that induces a similarly changing current in the secondary coil. We shall see how

this is accomplished a little later when we consider the currents in the Tesla coil itself. For the present, let us skip the "how" and trace the circuit through the first transformer. The 110-volt house supply is stepped up to 10,000 volts by a transformer in the basement of the building. This transformer is capable of providing 2000 **watts** of power. We may compare this with the transformers used to power toy electric trains which ordinarily use about 50 watts.

The Tesla coil is a transformer and serves to step up the voltage. But when we reach voltages of the order of a million, the insulation of one coil from another becomes a serious problem. Ordinary transformers consist of two coils wound on an iron core. The voltage appearing at the terminals of one coil has the same ratio to the voltage put into the other coil as the ratio of the number of turns of wire in one coil to the number in the other coil. At a million volts it becomes next to impossible to use an iron core, for such high voltage would jump through most insulation to the iron in the core. The Tesla coil is an **air core** transformer, and contains no iron. Such a transformer is exceedingly inefficient at a frequency of 60 cycles, but at very much higher frequencies becomes as efficient as the iron core transformer is at low frequencies. Most Tesla coils operate at frequencies above 30,000 cycles per second or 60,000 alternations per second. The coil at the Griffith Observatory operates at about 35,000 cycles per second.

Our next consideration will be the method of producing the high frequency alternations from the ten thousand volt 60-cycle current we have available from our first (an iron core) transformer. We produce this high frequency by a method that may be compared to the plucking of a violin string. The string is drawn aside and released. The string will vibrate at a pitch or frequency that depends upon two things: its length or mass (since one depends upon the other) and the tension. The violinist tunes the string by adjusting the tension, then produces the pitches of the various notes of the scale by changing the length of the string. This latter he does by squeezing the string against the finger board with his fingers. In

the case of the Tesla coil, we build up a tension or electric charge and release it to flow through the primary coil of the Tesla coil.

The electric charge is built up and stored in condensers called **Leyden jars**. These are glass jars with a layer of copper foil on the inside and outside surfaces. A wire is connected to each foil so that it may be connected to the circuit. The inside foil is connected to one side of the ten thousand volt output of the first transformer and the outside foil to the other side. As the alternating current swings to a maximum in one direction, we find that instantaneously there is a voltage of ten thousand existing between the inner and outer foils in the Leyden jars. Whichever foil is negative will have an excess of electrons. The other foil which is positive will have a dearth of electrons. By using more than one Leyden jar, we may increase the number of electrons stored up. Now if we suddenly connect the Leyden jars to the primary coil of the Tesla coil, all those electrons will flow through the coil to the other foil which was positive. This initial flow is like the first snap of the violin string when it is plucked. The string moves too far and swings back, oscillating about its normal position. The electrons have inertia and they pile up on the foil that was originally positive, making it negative, so they rebound and flow back through the coil to the other foil. They will oscillate back and forth through the primary of the Tesla coil at a frequency which depends on two physical quantities: the **capacity** of the condensers, and the **inductance** of the coil. These quantities correspond somewhat to the length and tension of the violin string, though the parallelism is not too close. The frequency of oscillation of the circuit may be "tuned" by adjusting the capacity of the condensers (putting in or taking out condensers) or by adjusting the inductance of the coil (increasing or decreasing the number of turns). This is where the frequency is increased to 35,000 cycles.

This is not an arbitrary frequency, but is the frequency at which the secondary coil of our particular Tesla coil (see Fig. 1) will oscillate most naturally. It is called the natural frequency of the coil, and may be compared to the frequency at which a tuning fork will oscillate

when it is struck. When the frequency of the primary circuit is adjusted to the natural frequency of the secondary coil, the efficiency of the whole Tesla coil is at a maximum.

From the foregoing it is evident that we need some sort of device that will open and close the primary circuit so that the electrons will have a chance to pile up and then surge through the coil when the circuit is closed. The "rotary spark gap" (see Fig. 1.) serves this purpose. It consists of a motor-driven wheel studded around its periphery with metal rods which pass between two stationary rods as the wheel rotates. The rods do not actually touch the stationary contacts but the gap between them is only about 1/16 inch so that the ten thousand volt current jumps across without difficulty.

There remains only the necessity of explaining how the secondary current is "induced" and we are through with the coil itself. When an electric current flows in a wire, there exists a circular **magnetic field** around the wire. If electrons are moving toward the observer, the magnetic field is in a clockwise direction. (The current is said to be moving in the opposite direction from the direction of the motion of the electrons. This negative relationship is due to a mistake on the part of the very early physicists who knew nothing about electrons, and since it does not really matter much, it never has been corrected.) If we bend a wire into a circle and pass a current through it, the magnetic field inside the loop will be all in one direction and outside the loop in the opposite direction. If we increase the number of loops, we will increase the magnetic field. Also, if we increase the current, we will increase the magnetic field. We can detect the direction of a magnetic field by the use of a magnetic compass. The north seeking point of the compass needle will point in the direction of the magnetic field.

Just as an electric current will produce a magnetic field, so also a **changing magnetic field** (which may be called a **magnetic current**) will produce an electric field. And if a conductor such as a piece of copper wire is brought into the electric field, an electric current will flow through it. In a transformer, we pass an alternating electric current through the primary winding. This current is constantly changing;

PICTORIAL ASTRONOMY

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THE OPPOSITION OF MARS

Each opposition of Mars attracts much public attention and the one just past has been no exception, despite the fact that February oppositions are the poorest of all. In this year's opposition the large distance has been partly compensated by the size of one of the polar caps. Perhaps 15,000 people will have looked at the planet through the 12-inch refractor of the Griffith Observatory before it has swung enough farther away that we cease to use it as an object for public observation.

The usefulness of even such a moderate instrument for planetary observation is shown by the photographs reproduced on the cover. They were made by Dr. Herbig, using our telescope, while he was a student in 1941, the last year of an unusually good opposition.

The effects of the Martian air are brought out by the difference between pictures B and E, which were almost simultaneous. E was made through a blue-green filter, but B, A, and C were made through a red one. Despite the thinness of the Martian atmosphere, it absorbs and scatters the blue-green light sufficiently that no surface detail is visible.

The data follow:

PLATE	DATE	FILTER	EQUIVALENT MARTIAN DATES
A	1941 Sept. 2	red	Dec. 18
B	Sept. 12	red	Dec. 24
C	Sept. 23	red	Dec. 31
D	Nov. 7	red	Jan. 26
E	Sept. 12	blue-green	Dec. 24

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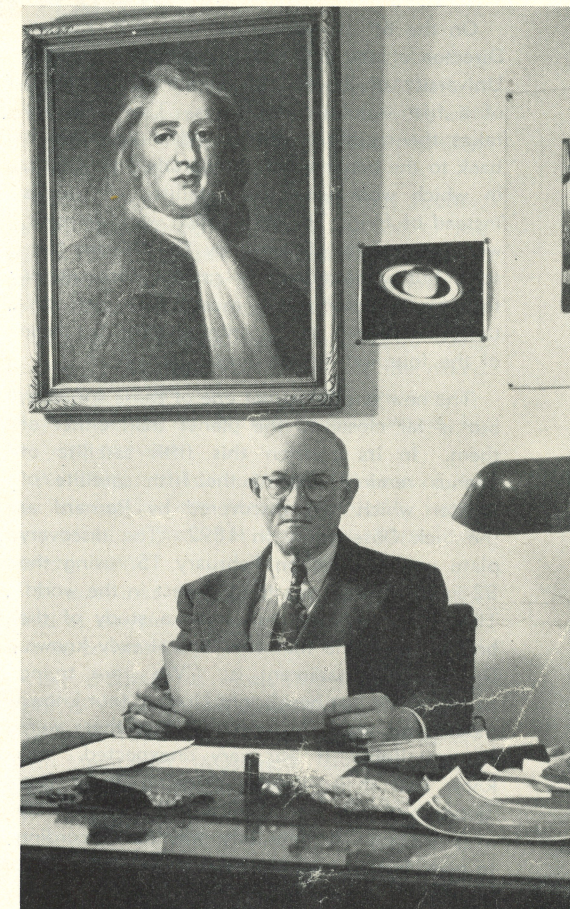
MR. NEWTON RETIRES

In February Mr. Archibald M. Newton became the first member of the staff of the Griffith Observatory to reach the retirement age. Mr. Newton's services to amateur astronomy in Los Angeles have been conspicuous enough that it seems proper to publish a sketch of his life. He was born in Kalamazoo, Michigan, in 1878, and became interested in astronomy when he entered the prep school of Kalamazoo College, where he was able to use a four-inch refracting telescope. The death of his father interrupted his schooling, and a few years later he transferred his college credits to the University of Chicago and began further work in their Extension School. As a student there, he met Dr. Hale, Professor Michelson, Professor Moulton, and Professor Chamberlin. His acquaintanceship with these men tinged his future life.

He came to California in 1901 and did newspaper work until about 1935. In 1925 he helped to organize the Amateur Telescope Makers Society of Los Angeles, which a few years ago changed its name to Los Angeles Astronomical Society. He served as their first secretary and was president of the society for four terms. During this time he took up the part-time manufacture of astronomical instruments and constructed a number of very nice telescopes.

When the Griffith Observatory was opened in 1935, he took part-time work as a guide. His explanations of exhibits were given with an oratorical enthusiasm which was contagious, and were very much enjoyed by his audiences. For the last few years Mr. Newton has held a full-time position on the staff as Head Guide, in charge of the training and supervision of all the guides of the Observatory.

With his retirement he plans to continue his work in manufacturing astronomical instruments, and has a shop at the home which he purchased about a year ago. The address is 1048 Dexter Street, Los Angeles 42.



Everyone of us on the staff of the Observatory and the many persons who have known him in the Society are wishing both him and Mrs. Newton the very best of fortune for many years to come.

—Dinsmore Alter

LOS ANGELES ASTRONOMICAL SOCIETY

Monthly Meeting — Tuesday, April 13, 7:45 P.M.

Meeting Place — Griffith Observatory.

Program — What can we find out about Mars?
Dr. Edison Pettit.

DISCOVERY OF THE FIFTH URANIAN SATELLITE

On the 8th of March, Dr. Gerard P. Kuiper, Director of the McDonald Observatory of the University of Texas, announced the discovery of a fifth satellite of Uranus. This discovery takes the memories of the oldest astronomers back to the books which they studied as youths, in which were listed six satellites of Uranus instead of four. The two, which were dropped, were supposedly glimpsed by Sir William Herschel but without definite enough observations to compute their paths, except that their distances appeared to be intermediate to those of the four well-known ones.

The new satellite is not one of those suspects, but is far closer to the planet than either of them. In its position this fifth satellite of Uranus reminds one of the fifth satellite of Jupiter which was discovered by Barnard at the Lick Observatory in 1892. The discovery plate was exposed on February 15, using the 82-inch reflector, the third largest in the world. The photograph was made for a study of the brightness of the four satellites already known. Dr. Kuiper's statement is: "We were trying to determine just how bright Uranus' four known moons are, when it turned out that there were five satellites. It was very unexpected. You know how it is. You're thinking about four moons and not expecting a fifth to show up in the plate. It definitely was not according to plan, but we didn't mind finding it any way. Naturally, we were quite pleased."

Final confirmation of the discovery was by means of a plate exposed on March 1st. The new satellite is very small with a diameter roughly of 300 miles and a distance of about 75,000 miles from the planet's center. This would place it only 60,000 miles from the surface. Its period of revolution about its primary is approximately 30 hours. Its magnitude is +17, and this faintness, coupled with the fact that it is not more than 9 seconds from the planet, makes it a very difficult visual object, even in the largest telescopes. However, it is readily photographed by the giant reflector.

(Continued on page 47)

SKY CALENDAR FOR APRIL

(The times given are Pacific Standard Time)

PHASES OF THE MOON

Last Quarter	April 1	0225
New Moon	April 9	0516
First Quarter	April 16	1142
Full Moon	April 23	0528

TIMES OF SUNRISE AND SUNSET AT LOS ANGELES

Date	Sunrise	Sunset
5	0536	1817 (6:17 P.M.)
10	0529	1820 (6:20 P.M.)
15	0523	1824 (6:24 P.M.)
20	0516	1828 (6:28 P.M.)
25	0511	1832 (6:32 P.M.)
30	0505	1836 (6:36 P.M.)

THE PLANETS

Mercury appears too near the sun to be observed this month, reaching superior conjunction on April 28.

Venus reaches greatest eastern elongation on April 14, when it is 46° east of the sun. Although this separation of Venus from the sun corresponds to about three hours, Venus will set nearly four hours after the sun at that time. The reason is that when Venus is an evening star in the spring, it is farther north in the sky than the sun and this makes it set correspondingly later.

Mars is again moving eastward among the stars, having just ended its retrograde motion which lasted for nearly three months. By the end of April it will be 5° northwest of Regulus.

Jupiter rises at about midnight on April 1. It begins its retrograde motion on April 15.

Saturn ends its retrograde motion on April 16. It is just a few degrees west of Mars.

Uranus, magnitude +5.8, changes its position from R.A. 5^h 27^m and Decl. +23° 23' on April 1 to 5^h 32^m and +23° 27' on April 30.

Neptune, magnitude +7.7, is in opposition on April 1. It changes its position from R.A. 12^h 45^m and Decl. -3° 08' on April 1 to 12^h 43^m and -2° 51' on April 30. Its path among the stars from March 1, 1948 to December 31, 1949 is shown in the March issue of this magazine.

Planetarium Show for April, 1948

TRAVEL TO THE PLANETS

Each planetarium show, regardless of the subject to be discussed, begins with a gorgeous sunset which fades to the darkness in which are seen the stars of the clearest of nights. At the end of the hour dawn comes beautifully to the sky, the stars fade, and the sunlight reddens the clouds in the east.

"The setting sun is the death of a day

Despite its pomp and its gold.

Darkness brings rest our fears to allay

After the tale has been told.

The stars are a life we can see from afar,

A life we can glimpse in our sleep,

A life so majestic earth's strife cannot mar,

A life with a beauty we wish we could keep.

The dawn has driven the stars from the sky

With rebirth of life that is real not a play.

A day which is new has come from on high,

Reflected by clouds from the sun's early ray.

The day which was old and the day which is new

Bring to riddle of being a meaningful cue."

This show does not attempt to create the illusion of travel in interplanetary space, but does demonstrate the sort of vistas which some day may be opened to the gaze of explorers from future generations. Despite the predictions so commonly published, it seems probable that this generation will go to its grave without any more such travel than can be taken through a telescope tube.

During April the planet Venus, which has been so conspicuous all winter, reaches its greatest distance east of the sun. It changes during the month from a gibbous phase to a crescent as it swings much closer to the earth. Our views of this twin may be disappointing to many because its surface appears to be covered with clouds. Speculations concerning the surface conditions will be told.

Mars still is in good position but receding from its close approach of February. Always in any popular discussion of the planets, Mars with its polar snow caps and its surface markings will try to "hog" the discussion.

Farther out in space we shall find Jupiter, rapidly approaching its closest position of the year. Its lacy detail of cloud belts and its satellite system make it extremely interesting to all who see it through a large telescope.

In a one-hour show there is no time to travel beyond Saturn, the most distant of the naked eye planets, but any visit which did not include closeups of its ring system would be far from complete.

We shall not risk the scorching heat of the sun to observe little Mercury in detail, taking only a casual glance at that tiny, airless, sun-burned world.

In each case the question uppermost in the mind of everyone—that of possibility of life—will be considered.

The program of music for the month of April is: Romeo and Juliet Overture (Tschai-kowsky), Tannhauser-Fest March (Wagner), Thais-Meditation (Massenet), and Peer Gynt Suite No. 1—Morning (Grieg).

SATELLITE DISCOVERY

(Continued from page 46)

The first two of the four previously known satellites were discovered by Herschel in 1787, the other two by Lassell in 1851. The original four are larger, having diameters of about 600, 400, 1000, and 900 miles. Ariel, the innermost of the four, is about 1½ times the distance of the newly discovered moon from Uranus. Except for the six outer satellites of Jupiter, this is the only satellite which has been discovered during this century. The next previous such discovery was the ninth satellite of Saturn in 1898 by William Pickering.

—Dinsmore Alter

GRIFFITH OBSERVER

February, 1977

Vol. 41, No. 2 50 Cents



The Case of the Peculiar Pickets

John B. Irwin

Department of Earth and Planetary Science
Kean College of New Jersey

HONORABLE MENTION

HUGHES GRIFFITH OBSERVER CONTEST

In the October, 1976, issue of the GRIFFITH OBSERVER we published the first of Dr. Irwin's two prizewinning articles and noted that Dr. Irwin seems to make a perennial appearance in these pages. This year resulted in a bumper crop, and we here present Dr. John Irwin's second offering, which concerns a subject close to the heart of any astronomer: spectroscopy.

The story is told of an astronomer's young bride who had just listened to her first popular lecture on astronomy, one that had been given by a distinguished astronomical spectroscopist. Afterwards, on being quizzed by her husband as to whether or not she had gotten anything out of the lecture, she expressed surprise that she had understood just about all of it, "but," she added, "what were all those peculiar picket fences that were shown on the screen?" I suspect that most people are puzzled by the spectra of stars—these celestial fingerprints can be frightfully complex, and just how either the stars or the telescope or the astronomer can produce such peculiar pickets is not immediately obvious to the uninitiated. Despite complexities of analysis that may be far beyond the understanding of the average man in the street, the working astronomical spectroscopist knows that, nevertheless, the study of the spectra of the stars is richly rewarding. It leads, directly or indirectly, to basic data on the stars: temperatures, chemical compositions, luminosities, distances, velocities, masses, sizes, densities, and even rotations.

My purpose here is to focus on the simple, rather than the complex, and an example of each is given in Figure 1. The top spectrogram is that of a "garden variety" AO star that has a temperature of 10,500 degrees Kelvin (about 18,400 degrees Fahrenheit). Its spectrum shows eleven absorption (dark) lines, ten of which are about equally strong and which converge in a curiously regular fashion towards the left. It

has been known for over a century that these lines are produced by hydrogen, the lightest and simplest of all the atoms. Similar strong lines at exactly the same wavelengths can be produced in the physics laboratory by analyzing with a spectrograph the light from a tube full of heated hydrogen gas. The experimental physicist produces the lines in emission; the stars—with a few exceptions—"manufacture" the same lines in absorption. The weak line in the spectrogram of the AO star, conforming neither in intensity nor position to the hydrogen lines, is called the K line of ionized calcium. It has a wavelength of 3933 angstroms, corresponding to about one sixty five thousandth of an inch. The ten hydrogen lines that are visible range in wavelength from 4340 angstroms on the right for H-gamma to 3722 angstroms on the left for H-mu. These are incredibly small lengths; an angstrom is equal to one ten billionth of a meter.

The lower of the two spectrograms in Figure 1 is that of a KO star, less than half as hot as the AO star but displaying a considerably more intricate pattern of lines. The hydrogen lines are there, but weak or obliterated to the point of being impossible to identify at some wavelengths. The K line of ionized calcium is now **very** strong, and the H line of ionized calcium, its twin companion at 3968 angstroms, swamps the weak H-epsilon line at the same wavelength. There are, rather obviously, large quantities of information here. If a more powerful spectrograph, one that spreads out the few inches of

The GRIFFITH OBSERVER is a publication of the Griffith Observatory, which is operated by the Board of Recreation and Park Commissioners of the City of Los Angeles. Established in 1937, the OBSERVER strives to present astronomy and related subjects in such a manner as to stimulate and maintain an enduring interest in the physical sciences. All submitted articles and observational results will be considered for publication in an effort to encourage an active and progressive participation in the subject.

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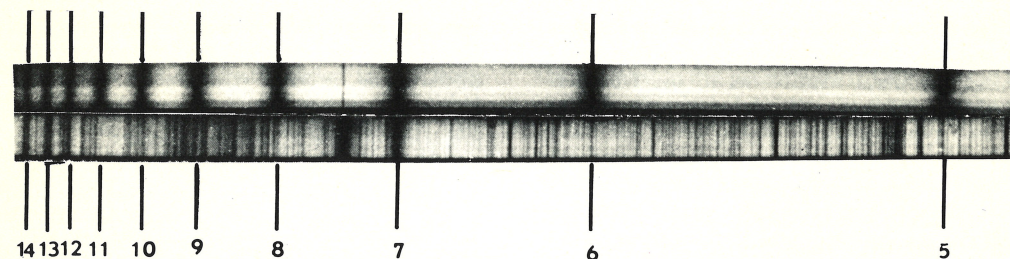


Figure 1. The upper spectrogram is that of an AO star ($T=10,500^{\circ}\text{K}$), and the lower is that of a KO star ($T=5,000^{\circ}\text{K}$). The Balmer series of hydrogen is outstanding in the spectrum of the hotter star, 10 Balmer lines being shown, from H-mu at 3722 Å on the left to H-gamma at 4340 Å on the right. The hydrogen lines are so weak in the spectrum of the cooler star that, along with the presence of so many lines of other elements, the Balmer pattern is not at all evident. The values of m in the Balmer formula are given for each line.

spectrum that we see here to many tens of feet, is used, tens of thousands of lines are seen. Their wavelengths, when precisely measured, can be matched against those produced in the laboratory. A match, both in wavelength and intensity, identifies element after element in the star and finally obtains the chemical composition of the star. Yet less than a century and a half ago, the great French philosopher Auguste Comte noted that the chemical composition of the stars would forever be beyond human knowledge!

At this point we will leave high dispersion spectroscopy of "cool" stars and the clouded crystal ball of a French philosopher and return to the AO star with its ten curiously converging hydrogen lines. This series of lines extends to the left, off the picture, and there are also two lines at longer wavelengths to the right that are not shown here: H-alpha in the red at 6563 angstroms and H-beta at 4861 angstroms. This series, extending from 6563 Å to 3646 Å at the series limit, is called the Balmer series. It played a key role in developing our knowledge of the atom and its internal structure and behaviour.

The story is a most remarkable one. In 1885 a Swiss schoolmaster did a bit of numerology with just four numbers (wavelengths), which he was able to use to predict an **infinite** number of wavelengths in the Balmer series. Shortly thereafter his simple equation was shown to predict an infinite number of series, each series having an infinite number of accurately predictable lines! The Balmer regularity was modified and extended to explain the much more complex spectra of heavier atoms. Further, it led Niels Bohr, some 28 years later, to explain in detail the inner workings of the

hydrogen atom and just how it could produce such remarkably sharp and peculiarly spaced series of lines.

Johann Jakob Balmer was a mathematician and a secondary school teacher in Basel, Switzerland from 1859 until his death in 1898. He also lectured on geometry at the University of Basel. His famous paper was published in 1885 when he was 60 years old and may conveniently be found in W. F. Magie's **A Source Book of Physics**. The four numbers that Balmer had to work with were Ångstrom's "very exact wavelengths" of the first four lines of the hydrogen series: 6562.10, 4860.74, 4340.1, and 4101.2. The reader is urged at this point to take a good long look at these four numbers and see what can be conjured up as an explanation or formula! To prepare your mind, let's look at some typical, simple sequences of numbers. For example, what are the next numbers in a very famous series that goes , 1, 2, 3, ? Does it seem "obvious" that they are 4, 5, 6, 7, **et cetera** and that the number before 1 is a zero? You're wrong! The numbers given are part of the Fibonacci series that goes 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144 . . . where each number, after the first two, is the sum of the two preceding ones. This sequence of numbers was published in 1202 A.D. by Fibonacci (also called Leonardo of Pisa) and results from the question, "How many pairs of rabbits can be produced from a single pair in one year if, every month, each pair begets a new pair which from the second month becomes productive?!" Although there is an extensive literature on the Fibonacci numbers, I am not aware that there are direct practical applications, the multiplication of rabbits, perhaps, excepted.

The following series should cause few troubles in the way of identification and extension — unless one plays tricks — as in the Fibonacci series given above,

1, 4, 9, 16,
2, 4, 6, 8,
1, 2, 6, 24,
9000, 4500, 3000, 2250,

They represent, respectively, n^2 ; $2n$; $n!$ (factorial n); and $\frac{9000}{n}$. There is however, no actual guarantee that any of these identifications is correct. For example, the second series **could** be: $n^4 - 10n^3 + 35n^2 - 48n + 24$, in which case the next number would be 34 rather than 10. Similarly, the fourth series could be: $-375n^3 + 3750n^2 - 13125n + 18750$, in which case the next number in the series would be zero, rather than 2000. Any mathematician worth his or her salt could come up with a variety of expressions in n , almost without limit, that could represent any one of these sequences of four numbers. A series of four numbers can always be fitted with an expression involving four constants. In any physical situation, however, if only **one** constant is needed, the implication is strong that the correct solution or relationship has been found. The real test of what is right and what is wrong depends on how the relationship, whatever it is, predicts entirely new data. A classical example of this in astronomy is Kepler's Third — or Harmonic — Law. Kepler knew the periods and semi-major axes of six planets. Mathematically, he could have solved for and obtained an expression for the semi-major axis in terms of a constant and five coefficients of P , P^2 , P^3 , P^4 and P^5 . Although such a complicated expression would have fit the observational data exactly, it would have failed utterly for Uranus, Neptune, and Pluto and, further, would have led to no theoretical insight into the law of gravitation, for example. The simpler expression, $P^2 = a^3$, that Kepler obtained was correct. More precisely, it is closer to the fundamental truth but is **not** completely accurate. It took the genius of a Newton to show later that Kepler's Third "Law" was only an extraordinarily good approximation and that the masses of the planets and their mutual perturbations had to be considered. Although the correction, at most, is less than a twentieth of a percent (for Jupiter), Newton's modification of the Harmonic Law made it pos-

sible to obtain the masses of the sun and planets and, later, binary stars, something that Kepler's Law, in itself, could not do.

Returning to our Swiss schoolmaster and the problem of the "peculiar pickets", Balmer "gradually arrived at a formula, which at least for these four lines, serves as an expression of a law by which their wave lengths can be represented with striking precision." He found that one fundamental number, 3645.6, when multiplied in succession by $9/5$, $4/3$, $25/21$, and $9/8$, represented the observed wavelengths with a maximum error of only one part in 40,000! Balmer paid tribute, at this point, to "the great scientific skill and care with which Ångstrom must have gone to work." And well he might, because if Ångstrom had been accurate to only one part in a 100 or even to one part in a thousand, the simple series of coefficients involving ratios of **integers** almost certainly would have been missed.

At first sight the above four coefficients do not "ring a bell", but Balmer had the insight to notice that if the second and fourth were multiplied by 4 in both numerator and denominator, the coefficients become $9/5$, $16/12$, $25/21$, and $36/32$. This led him to the general expression that the wavelength was equal to 3645.6 multiplied by the quantity

$$\frac{m^2}{(m^2 - n^2)}$$

where n is 2 and m is successively 3, 4, 5, and 6. At this point in the numerology game one can see that this expression predicts, for ever larger values of m , an **infinite** number of lines, their wavelengths getting closer and closer together as the series limit of 3645.6 is approached. This was a truly remarkable prediction and probably a most unexpected one. Balmer calculated a fifth line of hydrogen, using the next coefficient of $49/45$, which yielded a wavelength of 3969.65 angstroms and in his paper he first wrote, "I knew nothing of such a fifth line." In the next paragraph however he tells of having learned through Professor Hagenbach that many more hydrogen lines had been observed in the "white stars" by Vogel and Huggins. In a postscript Balmer makes a comparison between his expression and 12 lines observed by Huggins (starting with 4340 and ending at 3703). The observations of Huggins systematically deviated more and more from

Balmer's prediction, and at $m = 16$ the difference was 3.9 angstroms. Parenthetically, Balmer was actually much closer to the truth than Huggins was. It should also be noted that if one uses modern wavelengths, the first four lines can be fitted, using the constant 3646.003, with a maximum error of 0.005 angstroms, or one part in 820,000!

Balmer tried $n = 1$ in his formula, but this just gives, in a reduced form, every other line in the $n = 2$ series. He also tried $n = 3, 4$, **et cetera**, which predicted lines in the infrared, but all these theoretical series converge to 3645.6 and were — and are — not observed. He was tantalizingly close to another neurological breakthrough, however. If he had rearranged his expression in a way that any high school algebra student could have done, he could have enormously expanded his predictions. If one factors out n^2 in the denominator and divides both numerator and denominator by m^2 , the following suggestive expression for the wavelength results

The wavelength equals

$$911.4 \left(\frac{1}{\frac{1}{n^2} - \frac{1}{m^2}} \right)$$

This new formula for calculating the wavelengths is the exact mathematical equivalent of the original one, provided n^2 is set equal to 4. At first glance it looks more complex, or at least more unwieldy, to use. Its unwieldiness is in its double reciprocal nature and suggests perhaps that it would be more fundamental to use inverse wavelengths, or wave numbers. This is what we now do. Modern data today replaces 911.4 by 911.76 and switches from angstroms to centimeters, so that the wave number (the number of waves in a centimeter) is simply equal to:

$$109678 \left(\frac{1}{n^2} - \frac{1}{m^2} \right)$$

where the constant 109678 is now called the Rydberg constant. It should be emphasized

again that this is essentially the same as Balmer's original expression, except that the n^2 taken outside the parenthesis is kept fixed at 4 and is **absorbed into the Rydberg constant**, while the n still inside the parenthesis can be not only a 2 but other positive integer. The change is a subtle one, but what a difference it makes! For each value of n a completely new **series** is predicted, and best of all, Mother Nature agrees with this revised prediction. There is no **a priori** reason why the universe should have agreed with $(1/n^2 - 1/m^2)$ rather than

$$\frac{m^2}{m^2 - n^2}$$

where in each case, m is always taken to be larger than n . Also, there is no **a priori** reason why the universe should have agreed with either one. The proof of the pudding is in the eating, or rather, in the observing.

Balmer's formula suggested that the spectra of other, more complex atoms might have similar regularities. Five years later in 1890 the Swedish physicist Johannes Rydberg showed, for a large number of series of spectral lines for various atoms, that the wave number (in cm^{-1}) took the form

$$\bar{\nu} = \bar{\nu}_\infty - \left[\frac{R}{(m + \mu)^2} \right]$$

where

$$\bar{\nu}_\infty$$

is the wave number at the series limit, R and μ are as in the Balmer formula, and

$$\mu$$

M is **another** constant, different for different atoms and determined empirically from wavelength measurements made in the laboratory. This expression reduces to the Balmer formula

when

$$\mu = 0$$

and clearly it was of tremendous practical importance in sorting out and understanding overlapping series of complex atoms.

Other series of hydrogen were not known at the time of Rydberg's work; it was Ritz as well as Rydberg who suggested that n , as well as m , in the (re-arranged) Balmer formula might also take on running values, for example:

$$\frac{1}{\nu} = \frac{R}{1^2} - \frac{R}{m^2}$$

where $m = 2, 3, 4, 5, \dots$

or

$$\frac{1}{\nu} = \frac{R}{3^2} - \frac{R}{m^2}$$

where $m = 4, 5, 6, 7, \dots$

or

$$\frac{1}{\nu} = \frac{R}{4^2} - \frac{R}{m^2}$$

where $m = 5, 6, 7, 8, \dots$

The first of these predicted series was discovered in the infrared in 1908 (for $n = 3$) by Friedrich Paschen. The $n = 1$ series, in the astronomically unobservable ultraviolet, was discovered by Professor Theodore Lyman in the laboratory at Harvard, and the Brackett ($n = 4$) and Pfund ($n = 5$) series are named after their discoverers. Figure 2 gives a schematic look at the various series, which get longer in extent and go further and further into the infrared as n becomes larger. All of these series and all of the wavelengths of each line in each series can be accurately predicted from Balmer's formula, based on the wavelengths of just 4 lines. Quite a prediction and quite an extrapolation!

One might hazard a guess at this point that the various series would become less and less important as n becomes larger and larger, but this not necessarily so. One can accurately predict a line at 5.985 centimeters for $n = 109$ and $m = 110$ and a nearby line at 5.990 centimeters for $n = 137$ and $m = 139$. These lines are designated as H109-alpha and H137-beta respectively and are called radio recombination lines. Such lines have been observed in emission in the center of the great nebula in Orion within the past ten years, and they are a powerful new tool in observational astrophysics.

Some of the Nineteenth Century spectroscopists realized that the sharp, discrete spectral lines originating from an atom must eventually lead to an understanding of what an atom was like. The next major breakthrough was made in 1913 by Niels Bohr with his model of the hydrogen atom. In this model the electron moved about the nucleus, consisting of one proton, in a circular orbit and, contrary to classical electromagnetic theory, this accelerated electron did **not** radiate. If it did radiate, "as it should (!)", the lifetimes of atoms could be calculated in straightforward fashion and would be ridiculously short. In Bohr's theory only **certain** circular orbits were permitted or possible, and these orbits were related in size as the squares of integers. Emission, or absorption, takes place only when a transition is made from one of these permitted circular orbits to another such orbit. The frequency of the emitted or absorbed radiation is proportional to the difference in energy between the two orbits involved, the constant of proportionality being Planck's constant, h . Making use of the calculated orbital energies of the electron, Bohr derived a theoretical expression for R , the Rydberg constant, in terms of h , the mass of the electron, the charge on the electron, and the velocity of light. This calculated value of R was in complete agreement with the observed value of R within the uncertainties of the quantities involved.

In 1896 E. C. Pickering had discovered a series of lines in the spectrum of the very hot star Zeta Puppis, whose wavelengths are closely related to the Balmer series, but with the addition of intermediate lines. Rydberg was the first to show that if m were allowed to become $2\frac{1}{2}$, 3 , $3\frac{1}{2}$, 4 , $4\frac{1}{2}$, 5 , et cetera that the

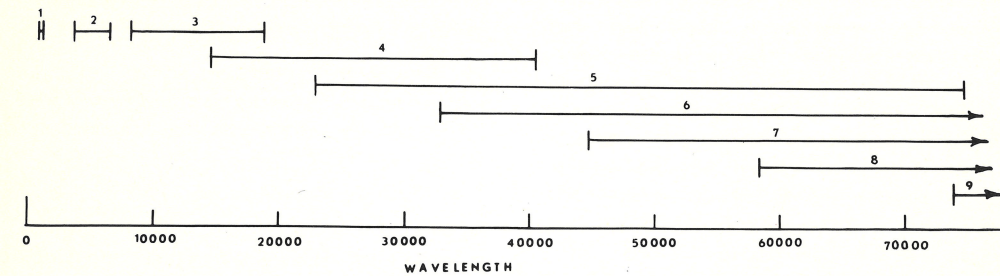


Figure 2. The limits of the first nine series of hydrogen show how the length and amount of overlapping of these series increase as n increases. At 74,000 Å there are five overlapping series. Only the Balmer series ($n=2$) has lines in the visible region of the spectrum.

agreement between the calculated and observed wavelengths was extraordinarily good. The Pickering series was attributed to some new form of hydrogen not found on the earth. Bohr showed that if one considered ionized helium, consisting of a nucleus of 2 protons and 2 neutrons with a **single** electron in a circular orbit, then R would be replaced by $4R$, and the Pickering series would ensue for $n = 4$ and $m = 5, 6, 7, 8, \dots$. Bohr's suggestion was soon confirmed in the laboratory, not only for lines of singly ionized helium but also for doubly ionized lithium, which behaved in somewhat the same manner except that R was now replaced by $9R$. The additional factor in each case (4 and 9) is the square of the number of positive charges on the nucleus. Slight discrepancies between observed and calculated wavelengths were removed by taking account of the motion of the atomic nucleus. The value of R is slightly larger for helium than hydrogen because the electron is not completely massless. The nucleus has a slight motion of its own, greatest for hydrogen and smaller with increasingly more massive nuclei. The Pickering series is shown in Figure 3, where it is compared to the Balmer series. The helium lines do not coincide exactly

with the hydrogen lines for the above mentioned reason but are shifted slightly to shorter wavelengths, the amount of the shift at H-alpha being 2.6 angstroms.

We will bring our story to a close at this point except to say that it is a never-ending and still exciting story. **Elliptical** orbits are permitted as well as circular ones. The entire orbit picture is a fiction, but it is an extraordinarily useful and convenient fiction. The hydrogen energy levels are split; H-alpha, for example, is split into three observable components. There are effects due not only to the spin of the electron but also to the spin of the nucleus and to the extraordinarily important fact that there are such things as isotopes. Balmer's integers are now called quantum numbers, and the mechanics of the atom is called quantum mechanics.

Astronomical spectroscopy began in 1666 when Sir Isaac Newton allowed sunlight to pass, in succession, through a small hole, a prism, and a lens, to produce a band of colors on a screen. Had Newton used a narrow slit rather than a circular hole he almost certainly would have seen what we now call the Fraunhofer spectrum of the sun, a discovery first made by Wollaston

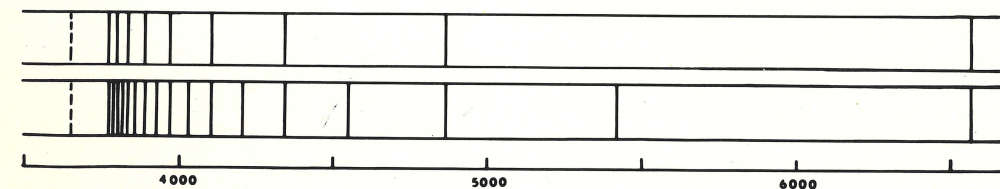


Figure 3. The lower pattern represents the Pickering series of ionized helium, and it partially resembles the Balmer series of hydrogen above. The series limit at 3636 Å is indicated by a dashed line. The first line of the Pickering series in the infrared at 10,123 Å is not shown.

more than a century later in 1802. Spectroscopy has been so extraordinarily fruitful and has played such a fundamental role in our understanding of the universe and in our ability to apply the properties of the universe to our own practical needs that it is tempting to speculate that we would have reached our present high level of science and technology many many years sooner—if only Newton had let that sunlight into his prism through a narrow slit!

Be that as it may, we should pay tribute to our Swiss schoolmaster, who 90 years ago discovered, built into the very structure of the

universe, two sets of integers in the form $\frac{m^2}{m^2 - n^2}$. 6562, 4861, 4340, 4140 . . . could you have done so well?

The Los Angeles Astronomical Society will meet at Griffith Observatory on Monday, 14 February, at 7:30 p.m. Dr. Donald Yeomans, of J.P.L., will speak on the history of Halley's Comet and its 1986 return.

Nikola Tesla and His Famous Coil

Bob Koppany

Griffith Observatory and U.C.L.A.

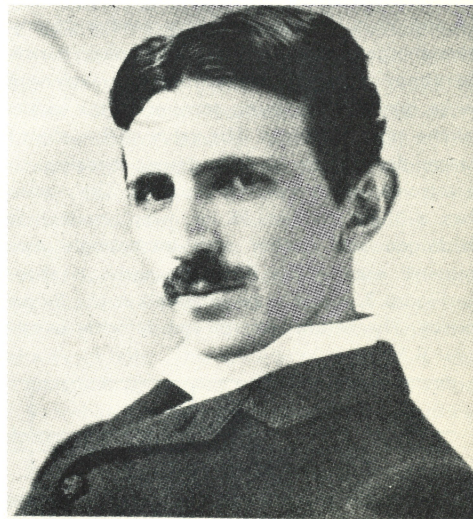
Griffith Observatory's Tesla coil has been on public display since 1937, the year publication of the GRIFFITH OBSERVER was inaugurated. This article is therefore also a fitting reminder that this issue marks 40 years of publication of the GRIFFITH OBSERVER, the first issue of which was dated, February, 1937.

Lightning, yards of blinding white color shooting through the sky accompanied by thunder crashes, is certainly Nature's fury and beauty at its peak. The people living in the 1800s were more impressed by the unique phenomenon of lightning than are people of today. After all, we know about cloud seeding, electric current, atmospheric agitations, and enough other scientific information to turn lighting into a commonplace event instead of the wonder and mystery it truly is.

Even as late as the 1890s people were not as technologically oriented as we are today. Many people at that time did not know what electricity is, let alone what it has to do with lightning. In fact, virtually all of America was using kerosene lamps at that time to light homes. Ironically, amidst the electrical ignorance of the 1890s a scientist, Nikola Tesla harnessed and reproduced lightning with a device he himself had created. This device is today called a "Tesla Coil" in honor of its inventor, and the Tesla Coil generated, during its operation in 1899, more power than **any** other electrical device known to this date, more than 76 years later.

Nikola Tesla was born July 9, 1856, in Yugoslavia, and was educated in European schools and universities. He came to America in 1884 with top honors in school, fluency in

eight languages, and a remarkable ability: a photographic memory. When called upon to test his memory, Tesla would glance at a random page from any book given to him and then repeat, verbatim, every word written on the page.



Nikola Tesla in 1894

Nikola Tesla, along with his associate, George Westinghouse, was responsible for generating acceptance of the widespread use of alternating current.

(Yale University School of Engineering Serial #83, Oct., 1943)

Perhaps the best description of Tesla was written by Frank Chester, who described Tesla as,

"... more than six feet tall and very slender. Yet he possesses great physical power. His hands are large, his thumbs abnormally long . . . his hair is black and straight, a deep shining black. His cheekbones are high and prominent, the mark of the Slav: his skin is like marble that age has given the first searing of yellow. His eyes are blue, deeply set, and they burn like balls of fire. Those weird flashes of light he makes with his instruments seem also to shoot from them. His head is wedge shaped. His chin is almost a point.

"Tesla is, above all things, a serious man, undoubtedly the most serious man in New York. Yet he has a keen sense of humor and the most beautiful manners. He is the most genuinely modest of men. He knows no jealousy. He has never decried the accomplishments of another, never refused credit.

"When he talks, you listen. You do not know what he is saying, but it entralls you. You feel the importance without understanding the meaning. He speaks the perfect English of a highly educated foreigner, without accent and with precision."

Upon Tesla's arrival in America, he immediately went to the New York laboratory of Thomas Alva Edison and got a job that very day. Edison is remembered today for his discovery of the electric light in 1879. After Tesla worked for Edison for a short while, he grew disinterested in direct current, with which Edison was experimenting. Tesla also received little recognition under the shadow of Edison and left his employ. Working on his own, Tesla refined a polyphasic motor, which used alternating current (which had never been used before) and patented it on May 1, 1888. Today, Tesla is credited by many as the "Father of Alternating Current."

Alternating current, or "AC", is used today in almost every electrical device, from television sets and radios to light bulbs and clocks. In the 1880s, however, a controversy raged for 5 years between the proponents of direct current (Edison) and the partisans of alternating current (Tesla and his associate, George Westinghouse). In this "war of the currents" Edison was cast as the aggressor. Edison stated publicly that alternating currents were dangerous, and Tesla and Westinghouse spent much of their time defending AC. This feud finally ended when Tesla and Westinghouse used alternating current to light up over 250,000 light bulbs at the Chicago World's Fair of 1890, the first World's Fair

ever to be lighted by electricity. Twelve dynamos were needed, each 10 feet high and 150,000 pounds in weight. The opposition winced, but when Tesla passed 1,000,000 volts of AC current through his body at the fair to show the public how harmless AC was, everyone then knew that alternating current was here to stay.

By no means did the "war of the currents" wholly occupy Tesla's time during the early 1890s. In May, 1891, he displayed, before the American Institute of Electrical Engineers, at Columbia College, a small invention, the Tesla Coil. This coil produced 5-inch sparks at 100,000 volts.

In 1892, Tesla discovered the principle of the radio and published his plans and experiments 3 years before Guglielmo Marconi did. Marconi received the first patents (the famous British patent, #7777), however, and, consequently, credit for the discovery also.

Three years later, in 1895, from atop the 170 foot high torrent of Niagara Falls, electricity was delivered for the first time to the people of the surrounding area. The total output of 3 AC generators was 15,000 horsepower, and they were acclaimed as "the supreme electrical engineering feat of the time." Of the 13 patents listed on the front plate of the generators, 9 belonged to Tesla.

During 1895 Tesla's broad range of interests was revealed. In Wilhelm Roentgen's famous paper on X-rays, it was shown that the human body could be X-rayed to show fractures of bones. Shortly after the paper was published, Tesla sent Roentgen a packet of X-ray photographs of the human body with a note attached asking, "Like this?"

During the latter 1890s, monumental experiments were made by Tesla on resonance, which occurs when an object vibrates at its natural frequency. Many of these studies were made with a small electric vibrator Tesla built. When Tesla was ready to share the results with the press, he ordered a quality steel link two feet long and two inches thick for demonstration. This link was estimated to be able to bear the weight of over 200,000 pounds. The vibrator was then fastened to the link.

According to reporter A.L. Benson, the vibrator,

"... was so constructed that the frequency of vibrations could be altered at will. He

(Tesla) set the vibrator in "tune" with the link. For a long time nothing happened — vibrations of link and machine did not chance to coincide, but at last they did and the great steel link began to tremble, increasing its trembling until it dilated and contracted like a beating heart — and finally broke.

"Sledge hammers could not have done it; crowbars could not have done it, but a fusillade of taps, no one of which would have harmed a baby, did it. Tesla was pleased. He had something. He wanted to learn more. He put his little vibrator in his coat-pocket and went out to hunt a half-erected steel building. Down in the Wall Street district, he found one — ten stories of steel framework without a brick or stone laid around it. He clamped his vibrator to one of the beams, and fussed with the adjustment until he got it.

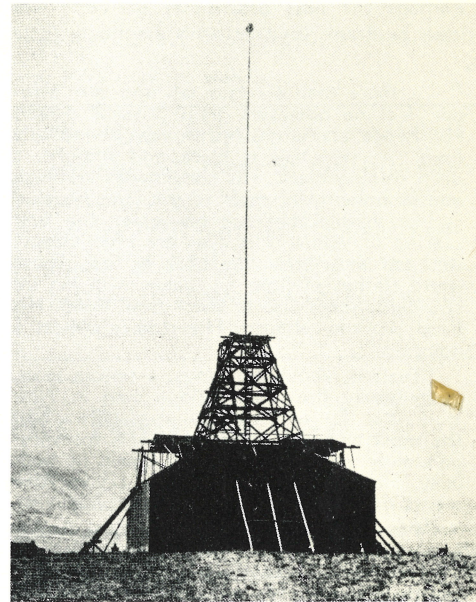
"Tesla said finally the structure began to creak and weave and the steel-workers came to the ground panic-stricken, believing that there had been an earthquake. Ten minutes more and he could have laid the building in the street. And, with the same vibrator he could have dropped the Brooklyn bridge into the East River in less than an hour."

Though New York had much to offer Tesla: proximity to the leading scientists and half-erected buildings of the period, on May 17, 1899, he moved his laboratory to Colorado Springs, Colorado. He moved because he was offered free electricity and rent-free land by the Colorado Springs Electric Company.

The laboratory Tesla built was 125 feet square. Towering above the laboratory was a wooden pole 200 feet tall (20 stories) with a copper ball three feet in diameter at the top. At the bottom of this mast, in the center of the laboratory, was the largest Tesla Coil ever built.

It was on October 22, 1899, when everything was ready for an experiment using the Tesla Coil. The experiment was to see "the fixation of atmospheric nitrogen and to look at lighting-like discharges."

It was late evening when the preparations passed Tesla's close scrutiny and he gave out final instructions. Tesla, always a perfectionist, was clad in full evening dress for the experiment. An exception to his formal attire were his shoes. They each had one inch of insulation on them for protection. Tesla's assistant was Kolman Czito, who was positioned next to a large circuit breaker which connected the current from electric company to the Tesla Coil. A wall of insulation separated Czito from the Coil. "When I give you the word," Tesla said to Czito, "Close the switch for one second — not longer."



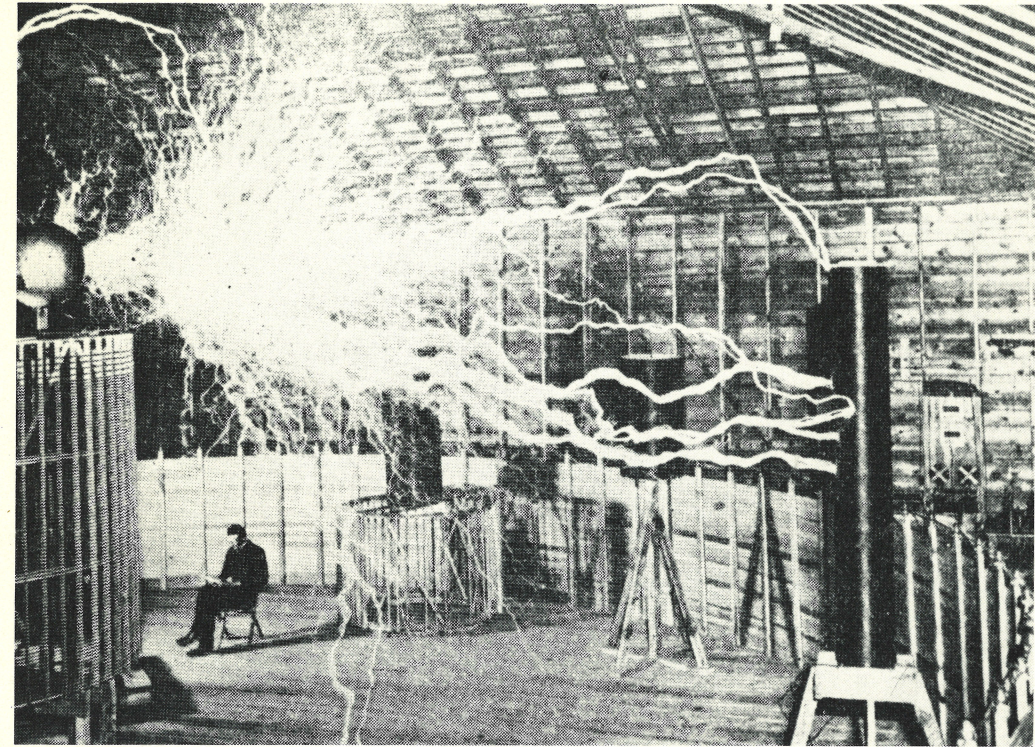
Although New York was a favorable environment for Tesla, he moved his laboratory, shown here, to Colorado Springs, Colorado, on the promise of free electricity from Colorado Springs Electric Company.

(Reprinted from March 5, 1904 issue of *Electrical World* © Copyright 1976 McGraw Hill, all rights reserved).

Czito nodded in acknowledgement. Tesla and Czito both knew the hazards involved in the experiment, but they also knew that the experiment could answer many questions . . . if they did not die in the process. Tesla said, "Now!" Czito closed the switch, then jerked it open as fast as he could. A loud sound was heard to resound from the ball above, but no short circuits occurred. A corona could be seen around the wiring, but Tesla decided that it was safe to proceed.

Tesla then went outside to get a better view of the ball, remarking to Czito, "I will give you the signal, and you are to leave the switch closed until I signal you to open it." When in place, Tesla yelled from inside, "Czito, close the switch — now!" Czito closed the switch and jumped back to safety near the insulation, still remaining an arm's length from the switch.

At first, nothing happened, but then a crackling sound, similar to the one from the test, was heard. As the power increased, the sounds increased in volume to thunderous proportions and increased in frequency to a machine-gun



The first test of Tesla's coil in his Colorado laboratory burned up the electric company's generator and plunged Colorado Springs into darkness.

(Century Illustrated Magazine, June 1900)

staccato that shook the building. Twenty miles away, the people over a ridge at Cripple Creek looked up from their windows into a clear night sky and wondered why they kept on hearing thunder.

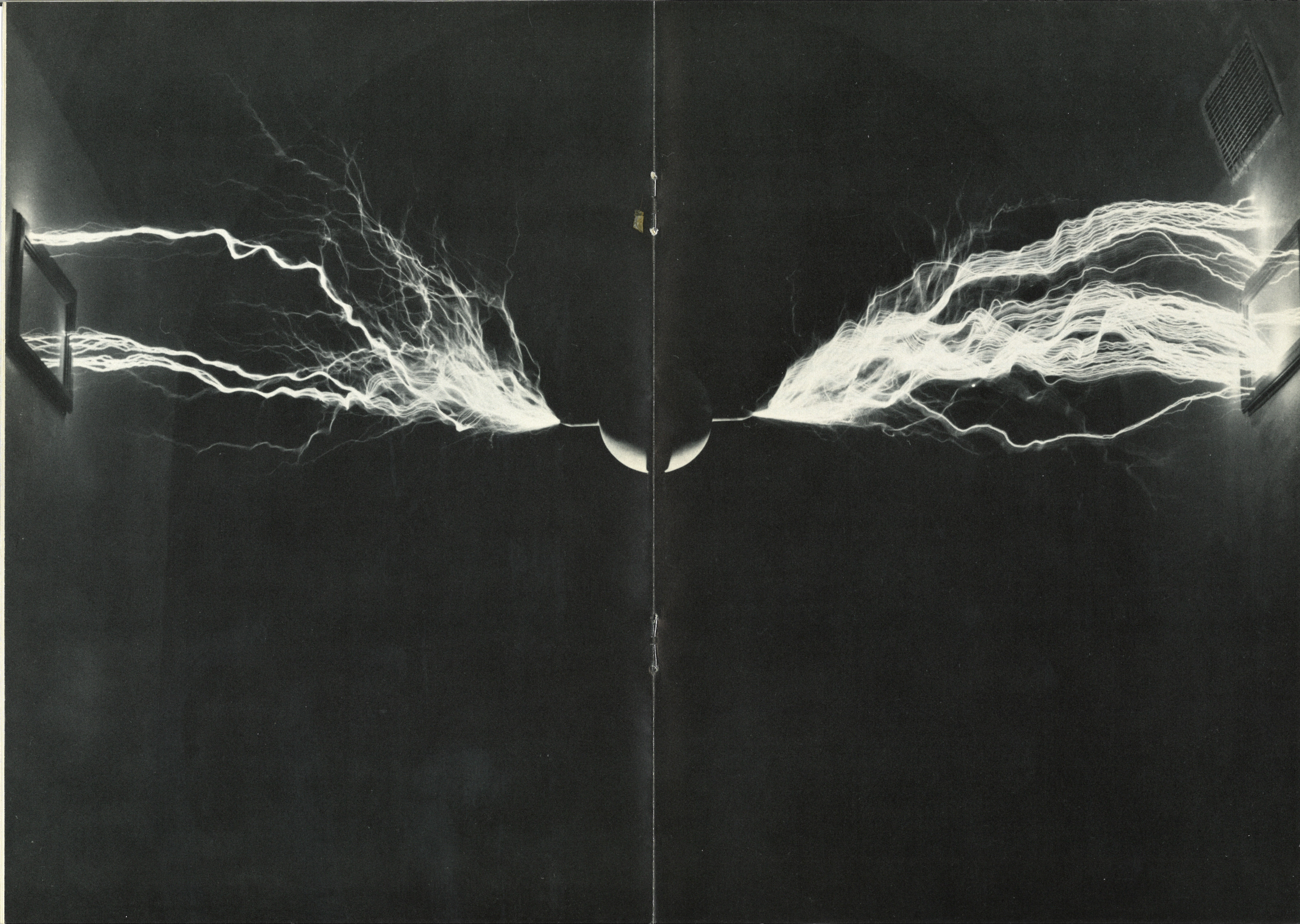
Tesla, looking at the ball, watched flames shoot from the ball and get larger and brighter as the power surged. Tesla also noticed a thin spark ten feet long shoot out from the ball. Before he could congratulate himself on a successful experiment he saw another spark, then another, and more occurring at closer intervals. Each lighting bolt was thicker and longer than the one before until lighting as thick as an arm came from the ball for more than 135 feet in all directions.

Suddenly, there was silence.

Tesla ran inside the laboratory shouting at Czito, "I did not tell you to open the switch!" Czito answered by pointing to the switch, which was still closed, but the ammeter and voltmeter on the switchboard read zero. Tesla then made a

frantic call to the electric company to beg them not to cut off his power. The call brought an irate reply, for the men working the night shift at the powerhouse now had their hands full extinguishing a blazing generator. Though Tesla's equipment was able to handle the large currents, the powerhouse's generator wasn't. It got hotter until the copper wires melted. Colorado Springs was plunged into darkness, and the generator was ruined. Tesla was told by the Electric Company that a separate generator would be needed for future experiments. This additional generator would be the one he just burned up — if and when he could repair it (which he immediately did).

This Tesla Coil operated with a frequency of 100,000 cycles per second and a potential of 135 million volts. By comparison, a household socket operates at 60 cycles per second with a potential of 117 volts. No one has succeeded in building up currents with even one-third of the Tesla Coil's voltage since the 1889 experiment.



The coil could also "light up 200 incandescent lamps 26 miles away from the laboratory without the use of wires," according to Tesla. This was due to an electric field originating from the coil. Electricity without wires did not catch on, however, and now one must visit Griffith Observatory to see the fabulous coil of Tesla in action.

CENTER PHOTOGRAPH

The electrical discharge from Griffith Observatory's Tesla Coil remains, after 40 years, one of the Observatory's most popular demonstrations. This spectacular result of electrical resonance is presented numerous times daily, with wit and knowledge, by the Observatory's guide staff. (Photograph by Paul Roques)

The Tesla Coil: Its Care and Feeding

Mark Barton
Engineer — Radical Electronics
Long Beach, California

In 1937, a Tesla Coil was installed in the Hall of Science at the Griffith Observatory. To date, over 25 million visitors have watched it in operation, throwing its lightning-like discharges to the walls of the exhibit. In response to visitor interest, two articles have been published in the **Griffith Observer** on the Tesla Coil, which originally belonged to Dr. Frederick Finch Strong. The first article appeared in the April, 1948, issue, and it contained a diagram as well as specifications of the coil as it was then. The second article, published in August, 1965, gave a more detailed explanation and a more up-to-date diagram. Both articles on this Tesla Coil are now outdated, however.

The following information can guide anyone in building his or her own Tesla Coil, and so a few words of caution are in order. The currents involved in the operation of even the smallest Tesla Coil can be lethal. Even if one has experience with electronics, someone familiar with high tension currents should be consulted before starting construction.

Neither of the early articles in the **Griffith Observer** explained the most important concept behind the operation of a Tesla Coil. This is the phenomenon of resonance. Resonance can be demonstrated simply by using a set of tuning forks, each of a different pitch. These tuning forks are arranged so they are free to vibrate, and then a single note of music is sounded. If one tuning fork is tuned to exactly the same pitch as the musical note, the forks will vibrate while the other forks remain motionless and quiet. The most efficient transfer of this resonant power occurs only if the tuning fork (receiver) is tuned to the same frequency as the musical note (transmitter).

The Tesla Coil uses two windings of wire: one is the transmitter and the other is the receiver of resonant power. We shall call the transmitter of power the primary winding, and the receiver of this power the secondary winding. If a capacitor, which is capable of storing an electrical charge, is connected to the primary winding, a current flows through the primary and sets up a magnetic field around it. When this capacitor is depleted of charge, the magnetic field around the winding collapses, and a current flows back through the winding, but this time in the opposite direction. This current recharges the capacitor, and the process repeats itself until the oscillations finally die out. The resonant frequency at which these oscillations occur is given by the formula, $f_0 =$

$$\frac{1}{2\pi\sqrt{LC}}$$
 where f_0 equals the resonant frequency of the winding in cycles/second, L equals the winding's value in Henries (the unit of inductance), and C equals the capacitor's value in farads (the unit of capacitance).

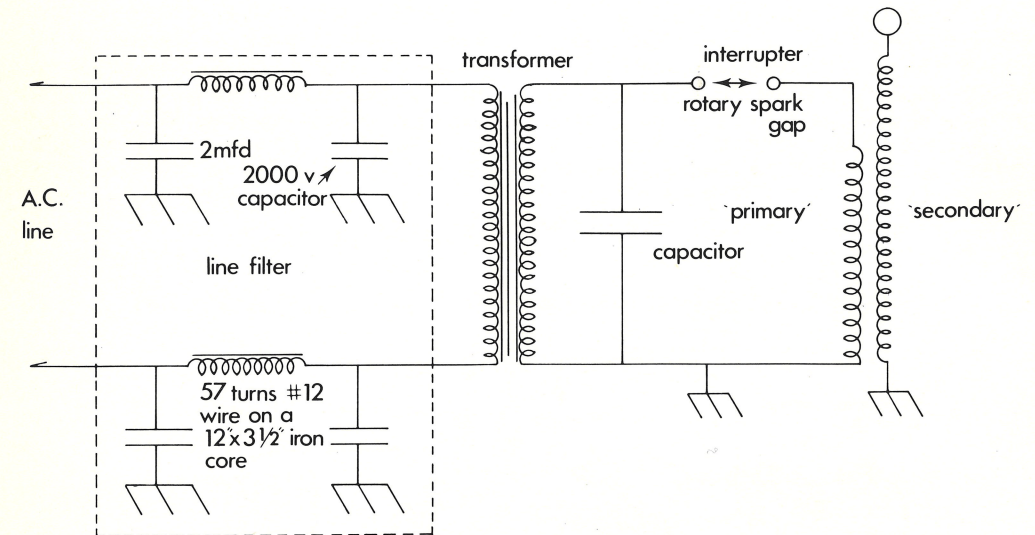
The secondary winding utilizes an electric property, the principle of mutual induction. Although this sounds complex, it really isn't. If we take a wire and run a current through it, a magnetic field forms around the wire. If we change the amount of current flowing through the wire, the strength of the magnetic field changes proportionately. Then, if we take another wire and place it within this changing magnetic field of the first wire, electricity will run through the second wire (even though it is not in physical contact with the first). So, electricity is being "induced" in the second wire because it is within the moving magnetic field, or influence, of the first wire.

The secondary winding of the Tesla Coil is located within the magnetic field of the primary winding. By mutual induction, it obtains a charge from the primary winding. The secondary winding consists of many turns of wire wound in a helix on some sort of cylindrical or conical form, with the bottom end of the wire being connected to the ground. The upper end is connected to a sphere (or some other type of elevated terminal).

Tesla's formula, $f_0 = c/4l$, where f_0 again equals the resonant frequency of the winding in cycles per second, c is the speed of light in feet per second, and l is the length of the secondary winding in feet. By first building a primary winding and measuring its frequency on an oscilloscope, a secondary winding with the proper length of wire can be found by substituting into the above formula.

The simplest way to visualize the type of

SCHEMATIC DIAGRAM



This is a schematic diagram of a Tesla Coil. Although the line noise filter is not necessary to the coil's operation, it is a nice feature, for it prevents static and hash from getting back onto the A-C line.

The secret of tuning the secondary winding to the primary winding was publicly revealed by Tesla in 1900. He wrote,

"The exact attunement of the two circuits (windings) secures great advantages, and, in fact, it is essential in the practical use of the system . . . In order to attain the best results it is essential that the length of wire, from the ground connection to the top, should be equal to one-quarter of the wavelength of the electrical vibration of the wire."

In other words, to make the secondary winding a resonant receiver of the primary winding, the length of the secondary winding must be related to the resonant frequency of the primary winding. This value can be found by

resonance in a Tesla Coil is to think of a child on a swing with the father pushing. The child and swing represent the secondary and the father, the primary. The motion begins with the first push with the child going forward, then returning. Just as the child is changing direction and about to go forward again, the father gives another push of equal force. This time the child goes higher. If the father keeps pushing in time with the child, using equal force on each push, he keeps adding energy to the system. Soon, the child is doing loops around the swing. The same sort of action happens in a Tesla Coil, with the primary adding energy to the secondary in time with each vibration. This

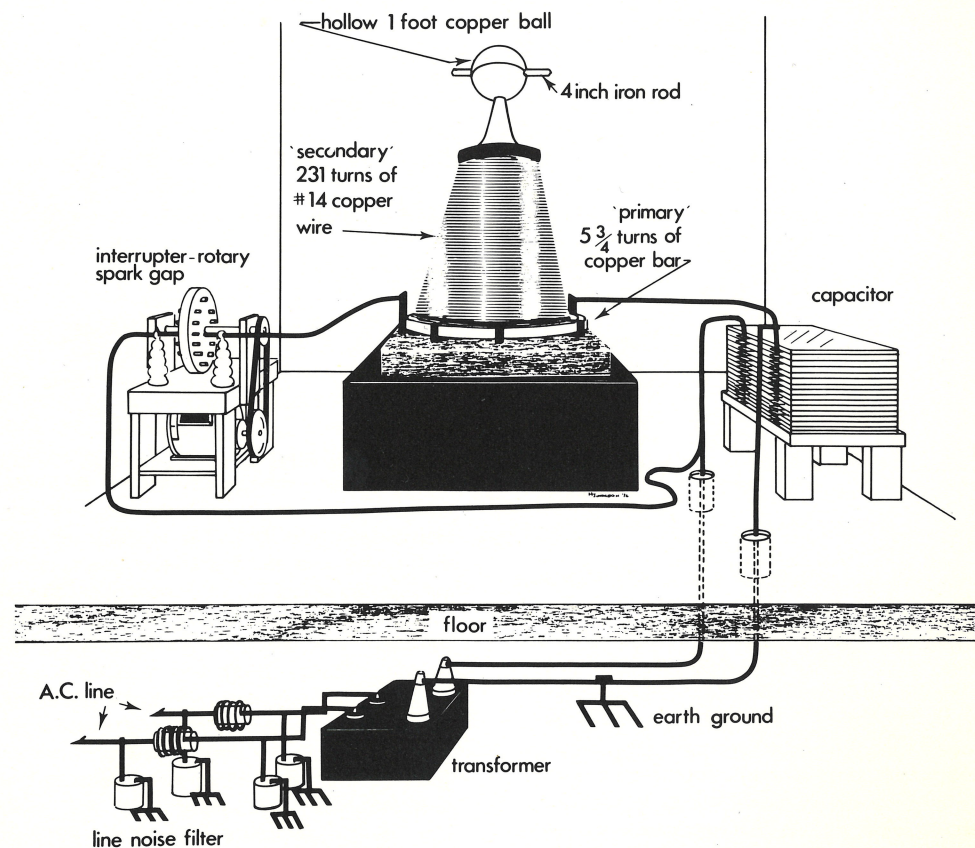
amplification of energy occurs if, and only if, the primary and secondary windings are synchronous, that is, have the same resonant frequency.

If the windings are not synchronous, no great voltages are produced. For example, if the father is blindfolded and cannot see the right times to push, the primary is out-of-tune with the secondary. Occasionally the father pushes at the right time, but sometimes he stops the child altogether because he is trying to push forward when the swing is on the way back. The importance of exact tuning cannot be over-emphasized.

The Tesla Coil at Griffith Observatory operates on standard 117 volt 60 cycle alternating current. This current is stepped up by a transformer, which is oil encased and located beneath the floor of the exhibit, to 15,000 volts. This

transformer is capable of delivering 2,000 watts of power, and it has a special type of winding, which is called current-limited. If more than 2,000 watts of power is attempted to be drawn from the transformer, the output voltage will drop to keep the output energy limited at the 2,000 watt peak. Luminous tube transformers, those used for neon signs, have this type of winding and are suitable for use in building a Tesla Coil.

Current from the transformer goes into charging a capacitor. This capacitor consists of 29 copper plates, 14 inches x 15 inches x .002 inches thick, each sandwiched between sheets of glass 24 inches x 30 inches x $\frac{3}{8}$ inches thick. Located between the capacitor and the primary winding is a rotary spark gap, also called an interrupter. This spark gap has two electrodes, with a 1-inch phenolic wheel con-



The Griffith Observatory Tesla Coil naturally includes all of the vital components, some of which are located below the floor and are not visible in the museum.

taining 14 copper bars on its edge and situated in between the electrodes. The phenolic wheel turns at 1800 revolutions/second. Every time one of its copper bars crosses between the two electrodes, a spark jumps across the electrodes, and this delivers a charge to the primary winding. The primary winding is $5\frac{3}{4}$ turns of $\frac{3}{4}$ inch x $\frac{3}{16}$ inch copper bar. The primary winding oscillates when the spark jumps across the interrupter because the spark is actually a set of bursts of alternating current, which flows back and forth from the capacitor to the primary.

With each pulse of the interrupter, the secondary winding builds up its oscillations until a burst of electricity bridges its way across each side of the copper ball to the two grounded plates at the walls of the exhibit. The only way to estimate voltages of this kind is by measuring the length of the spark that is produced, and we find that the voltage produced by the

Observatory's Tesla Coil is approximately 750,000 volts at its peak.

Though most of the energy produced is dissipated in the spark, an electric field is also produced, and it surrounds the coil. If a fluorescent tube is brought within this electric field, the tube lights up. Electricity travels the path of the least resistance, and within the electric field, it is easier for electricity to travel through a conductor of electricity (the fluorescent tube) than through the air, which is relatively a non-conductor of electricity. That is why the four gas tubes in front of the Observatory's Tesla Coil exhibit light up.

Though Tesla prophesied the development of such devices as television, robot war machines, radio telescopes, and the laser, and even though he was responsible for thousands of patents and inventions, to many people Dr. Nikola Tesla will always be remembered as the man who produced "lightning in his hands."

Astronomical Anecdotes, Curiosities, and Quotations

Ronald A. Oriti
Griffith Observatory

An Expensive Nap

The cruise ship, the S.S. Canberra, carried 1900 passengers to see the total eclipse of the sun on June 30, 1973. The passengers viewed the eclipse from the ship's deck from a location 300 miles west of Africa. On the night before the eclipse a group of students from an astronomical club set up their telescope on the deck of the ship so as to be prepared for totality, which was due to occur at about 10:30 in the morning. To make sure that nothing happened to their telescope, the young men took turns sitting up with it during the night.

In the morning, about 3 hours before totality, one of the students who had been up for some hours on "guard duty" decided to get some sleep before the big event. He asked his friends to wake him before totality, but in the excitement of the event, his friends forgot to call him. He had travelled all the way across the Atlantic to see an eclipse and slept through it.

Ref: Little, R. W., Alpha, Ohio, letter dated 27 June 1976.

Halley's Comet—Second Brightest in 1910

The brightest comet of 1910 was not the famous Halley's comet, which put on such a grand show during the month of May, but rather a comet which was known by the unpretentious name of Comet 1910 I. This comet was discovered during the middle of January, from South Africa. On January 18, it was plainly visible in the daytime at about 11 a.m., 4° east of the sun, and appeared much brighter than Venus. At this time the comet had a short tail about 1° long which was also easily seen with the unaided eye. Later on, near the end of January, Comet 1910 I became too faint to be seen in the daytime, but it developed a long tail, and, like Halley's Comet, four months later, it made a fine sight in the nighttime sky. Halley's comet, however, while spectacular, was never bright enough to be seen in the daytime.

Ref: Oliver, Charles P., Comets, 1930, p. 178.

Fossil Meteorites?

The fall of meteorites onto the surface of the earth no doubt occurred in the geologic past with at least the frequency observed at present. Yet, geologists have never uncovered a meteorite in strata of pre-Pleistocene age. This paradox is probably explained by the rarity with which meteorites, in general, are found on the earth's surface and by the relative rapidity with which they are altered by oxidation so as to be unrecognizable.

Ref: Mason, Brian, *Meteorites*, 1962, p. 4.

* * *

In Spite of a Handicap

In 1783, at the age of 18, the Dutch astronomer, John Goodricke, was awarded the Copley medal, the highest award of the Royal Society. This honor was bestowed upon him for measuring the period of variability of the star Algol in Perseus. Algol had been known as a variable star, but Goodricke was the first to determine that it followed a period of 2 days, 20 hours, and 49 minutes, during which its brightness changed by 1.2 magnitudes. In the following year he discovered the variability of two more stars, Beta Lyrae and Delta Cephei. The discoveries of this youthful astronomer are all the more remarkable when it is realized that he had been a deaf-mute from birth. Unfortunately, for astronomy, he died early in 1786 at the age of only 21.

Ref: Furness, Caroline E., *An Introduction to the Study of Variable Stars*, 1915, p. 269.

* * *

Discovered First by an Englishman

The first prediction of the return of a comet was made by Edmund Halley in 1705, who had noticed remarkable similarities between the orbits of comets seen in 1531, 1607, and 1682, from which he confidently predicted the comet's return in 1758. Realizing that he would not live long enough to see the return of the comet, Halley commented: "If it should return, according to our predictions, about the year 1758, impartial posterity will not refuse to acknowledge that this was first discovered by an Englishman." The comet was indeed seen again, on Christmas Day, in 1758, by Johann Georg Palitzsch of Saxony, although it did not become a spectacular object until about March, 1759. The comet now known as "Halley's" was seen again in 1835 and in 1910, and its next return is scheduled for spring of 1986.

Ref: Ball, Robert S., *Great Astronomers*, 1895, pp. 179-180.

Not Enough Latitude

America's first eclipse expedition was organized in 1780 by Professor Samuel Williams of Harvard College. The eclipse he intended to observe was the total solar eclipse of October 27, of that year, visible through a portion of Maine. The American Revolution was in progress at that time, and the British controlled the region of Penobscot Bay where Williams wanted to go to make his observations. He therefore sought out and obtained permission from the British garrison at Penobscot Bay so that expedition might pass through the British lines to see the eclipse.

The British gave permission for the expedition to observe from Long Island, a small island in the bay, and permitted them to stay only for the minimum time necessary to complete their observations. Upon arriving at their destination, the eclipse party set up their instruments and waited for totality, only to find that their location fell outside the path of totality by about 5 miles. The eclipse they saw was 99 percent total and most impressive, but it fell short in grandeur to the total eclipse they missed.

The path of totality for this eclipse was about 60 miles wide and the eclipse expedition, ideally, should have been located about 35 miles farther north. The largest factor contributing to the error in the eclipse party's location appears to have been the use of maps with inaccurate latitude data.

Ref: Todd, Mabel Loomis, *Total Eclipses of the Sun*, 1900, pp. 112-114.

* * *

Pleasant Memories

Of all people, students probably most appreciate the use of memory aids to help them in their studies. The famous American astronomer, Henry Norris Russell, proposed a mnemonic to help astronomy students remember the 7 classes of stars, which are designated by the letters, O, B, A, F, G, K, M. He suggested using the first letter of each word in the following romantic plea, Oh, Be A Fine Girl. Kiss Me. Needless to say, this mnemonic has had great appeal to students who remember it long after their college days are over. When 3 more classes of stars, designated by the letters R, N, and S, were added, the mnemonic was altered to Oh, Be A Fine Girl. Kiss Me, Right Now. Smack!

Ref: Abell, George, *Exploration of the Universe*, 1969, p. 408.

The Rescue of Galileo's Telescopes

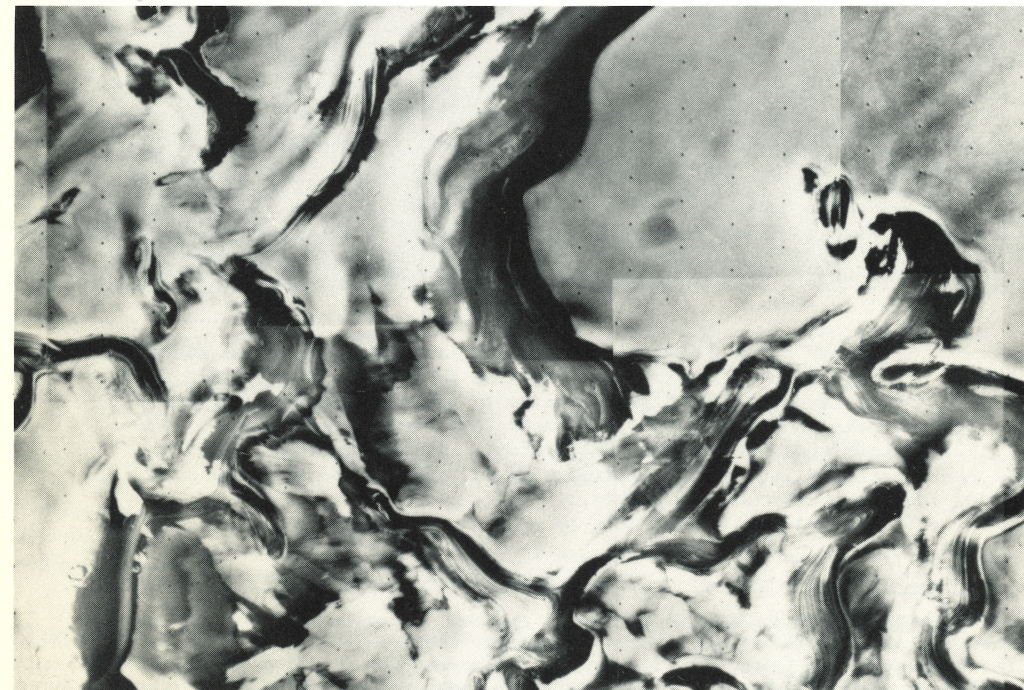
Every two or three centuries, or so, the city of Florence, Italy, is ravaged by extraordinary floodings of the Arno River. Such floodings took place on November 4, 1333; September 13, 1557; November 3, 1844; and again on November 4, 1966, when the greatest flood of all occurred. The loss produced by this latest flood was staggering to the imagination; thousands of priceless paintings and frescoes were damaged by oily and mucky waters. Statues were swept away and broken, over two million old books in various collections throughout the city were damaged, and countless art items and antiques were lost in the flow of mud and water.

Thanks to the heroic efforts of a great number of people, many priceless treasures were saved. One such heroine whose efforts will be appreciated by the astronomical world, is Dr. Maria Luisa Righini Bonelli, Director of the Institute and Museum of the History of Science, who at the risk of her own life, braved rapidly mounting waters, to rescue, among other things, several of Galileo's telescopes and an Arabian celestial globe of the Eleventh Century.

Ref: Judge, Joseph, "Florence Rises from the Flood," *National Geographic*, July, 1967, pp. 18-19.

Eclipse Cruise — October, 1977
Discount through L.A.A.S. Call
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The H. H. Astronomical Association is conducting its Annual National Astronomy Fair Paper and Photo Competition, open to any high school and college student. Write: H. H. Astronomical Association, P.O. Box 492, Hibbing, Minn. 55746

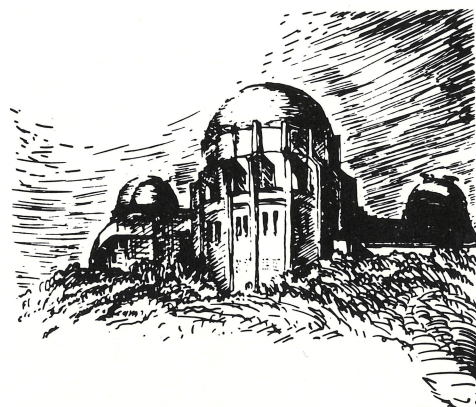


The Viking 2 Orbiter reveals a new Martian surface feature, unlike anything ever seen before. The polar ice cap consists of deposits of ice and defrosted layers of soil. On top of these appear to be translucent streaks of wind-distributed soil and ice (N.A.S.A., J.P.L. photograph).

THE GRIFFITH OBSERVER

VOL. I NO. I

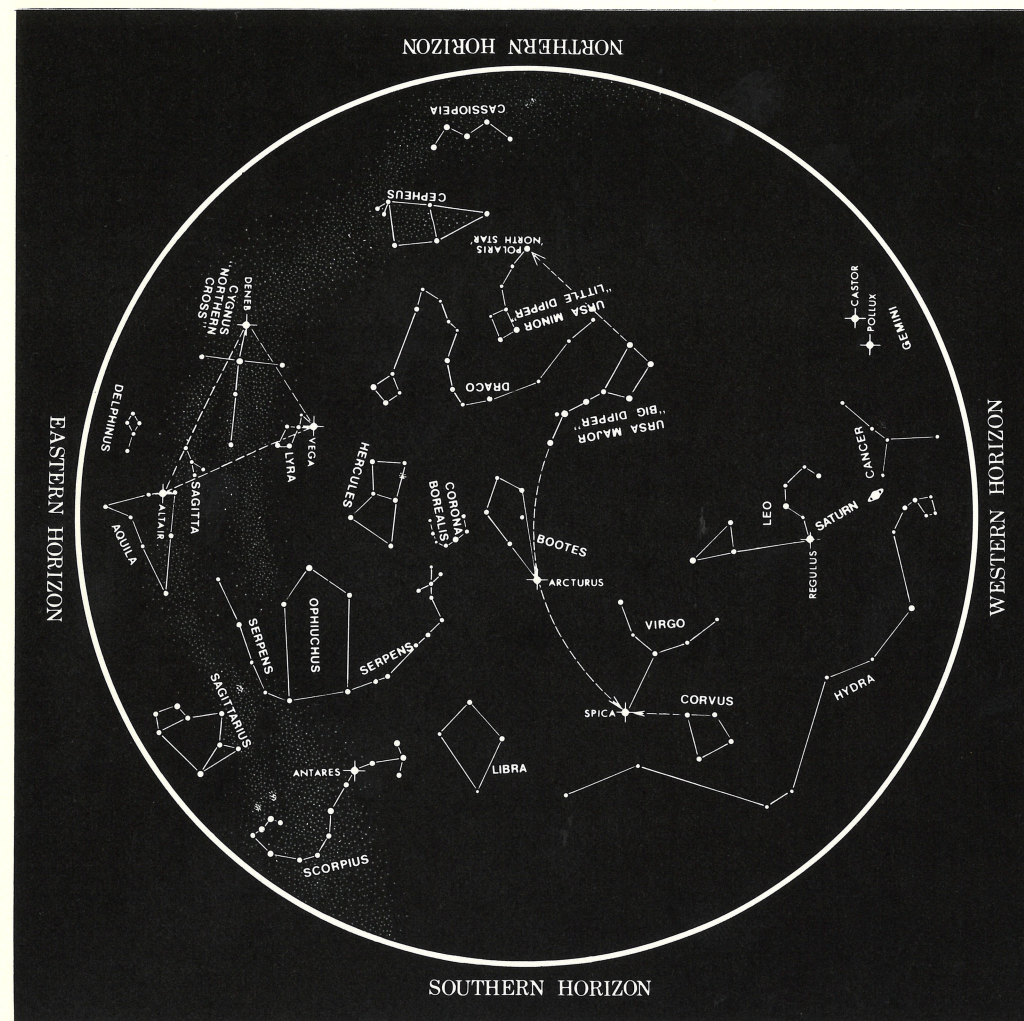
FEBRUARY 1937



Many of our guests have requested that we prepare an outline each month of the planetarium demonstration. Due to the fact that the main part of the demonstration is what one sees in the artificial sky, it is impossible to comply exactly with the request. In this bulletin, however, there is included an entirely non-technical statement of the astronomical facts which are illustrated by the demonstration, so that one reading the article, either before or after seeing the planetarium demonstration, will understand better what is shown.

The issue of this bulletin is an experiment. If it proves successful, it will be continued. Otherwise there will be only two or three issues. Attention is called to the configurations of the planets and the phases of the moon that are given here and to the schedule of the Griffith Observatory. If the bulletin should be continued, there will be from time to time special articles concerning astronomical events.

Forty years ago the first GRIFFITH OBSERVER appeared. Its pages were larger (8½ inches x 11 inches) and fewer (4) than those of today's magazine. The first issue included an article entitled, "The Romance of the Calendar", which served as program notes for the current planetarium show. The first incarnation of the Sky Calendar appeared, along with a schedule of Observatory programs and events. The price for a GRIFFITH OBSERVER in those days was 10¢ or \$1.00 per year. Although today's rates are five times greater, the magazine is five times larger too, with better printing. By comparison the cost of mailing a first class letter has increased from 3¢ in 1937 to 13¢ today. The price is 4½ times greater, but the stamps are not much larger.



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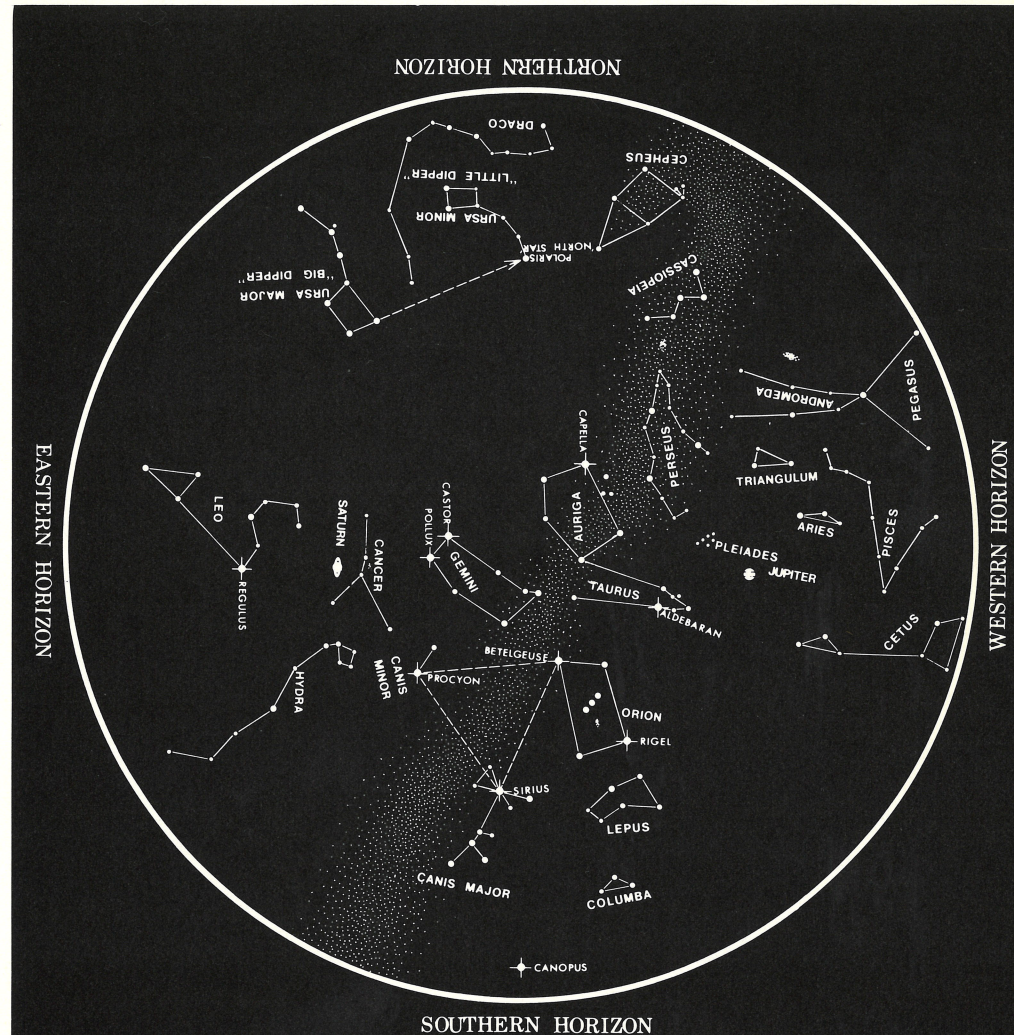
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COVER ILLUSTRATION

In commemoration this month of 40 years of publication of the GRIFFITH OBSERVER we present the third poster in a series by Observatory C.E.T.A. display artist, John Lubs. This nostalgic design is a vision of three symbols of old Los Angeles: the red car, palm trees, and Griffith Observatory. Sadly, only the last two of these are still in operation.

**MOVING? PLEASE
 SEND US YOUR
 NEW ADDRESS.**



THE NIGHT SKY IN FEBRUARY

Latitude of chart is 34°N, but it is practical throughout the continental United States.

To use: Hold chart vertically and turn it so the direction you are facing shows at the bottom.

Chart time (Local Standard):

10 p.m. First of month
9 p.m. Middle of month
8 p.m. Last of month

SKY CALENDAR FOR FEBRUARY AND MARCH

(Pacific Standard Time)

Corrections to be applied to all Sky Calendar times by observers not located in the **Pacific Standard Time** zone:

Mountain Standard Time add 1 hour
Central Standard Time add 2 hours
Eastern Standard Time add 3 hours

* * *

SUN

During February and March the sun moves from Capricornus through Aquarius and into Pisces.

MOON

Lunation No. 669

Full Moon Feb. 3 7:56 p.m.
Last Quarter Feb. 10 8:07 p.m.

Lunation No. 670

New Moon Feb. 17 7:37 p.m.
First Quarter Feb. 25 6:50 p.m.
Full Moon Mar. 5 9:13 a.m.
Last Quarter Mar. 12 3:35 a.m.

Lunation No. 671

New Moon Mar. 19 10:33 a.m.
First Quarter Mar. 27 2:27 p.m.

* * *

MOON-PLANET PASSAGES

Feb. 3	8 p.m.	Saturn 6° N.
Feb. 16	4 a.m.	Mars 6° S.
Feb. 16	9 a.m.	Mercury 7° S.
Feb. 21	9 a.m.	Venus 3° N.
Feb. 24	2 p.m.	Jupiter 2° N.
Mar. 3	1 a.m.	Saturn 6° N.
Mar. 17	4 a.m.	Mars 6° S.
Mar. 21	5 a.m.	Venus 8° N.
Mar. 24	7 a.m.	Jupiter 2° N.
Mar. 30	9 a.m.	Saturn 6° N.

* * *

PLANETS

Mercury

During most of February, Mercury can be seen in the early morning twilight. Superior conjunction occurs on March 15. This makes the planet essentially unobservable during most of March.

* * *

Venus

Venus is visible in the evening sky until the end of March, when it becomes too close to the sun for observations.

Mars

The planet Mars rises just ahead of the sun during February and March. Mars moves through Capricornus and Aquarius during these months.

* * *

Jupiter

Jupiter can be seen near the meridian at sunset. Its location a few degrees southwest of the Pleiades makes an interesting evening configuration.

* * *

Saturn

The planet Saturn is near the eastern boundary of Cancer. Saturn is in opposition on February 2 which makes it available for observation all night.

* * *

Uranus

Uranus is located in Libra at R.A. 14^h38^m, Dec. -14° 57'.

* * *

Neptune

Neptune, in Ophiuchus, is at R.A. 16^h59^m, Dec. -21° 13'.

* * *

Pluto

Pluto is located approximately four degrees east of the star Epsilon Virginis at R.A. 13^h17^m, Dec. 10° 39' (chart epoch 1950.0).

BACK COVER ILLUSTRATION

A curious feature, "the Man in Mars", was photographed by the Viking I Orbiter, and in lighting-quick response, with all the grace of a storm trooper, ANCIENT ASTRONAUTS magazine has mercilessly exploited this eroded, mesa-like rock formation. It is, claims ANCIENT ASTRONAUTS, a colossal match to Egypt's celebrated Sphinx. According to ANCIENT ASTRONAUTS other formations nearby are pyramids to accompany this enigmatic face, just as its counterpart on the Nile shares the landscape with the pharaohs' mountain-like tombs. "Doubtless," goes the scenario, "both terrestrial and Martian sphinxes were left as a clue for us by visiting astronauts from long ago." The Mars Man's face might not be so animated, with his well defined hairline, right nostril, and dimpled chin, if the telemetry noise (all the black dots) had been removed from this picture before its release.

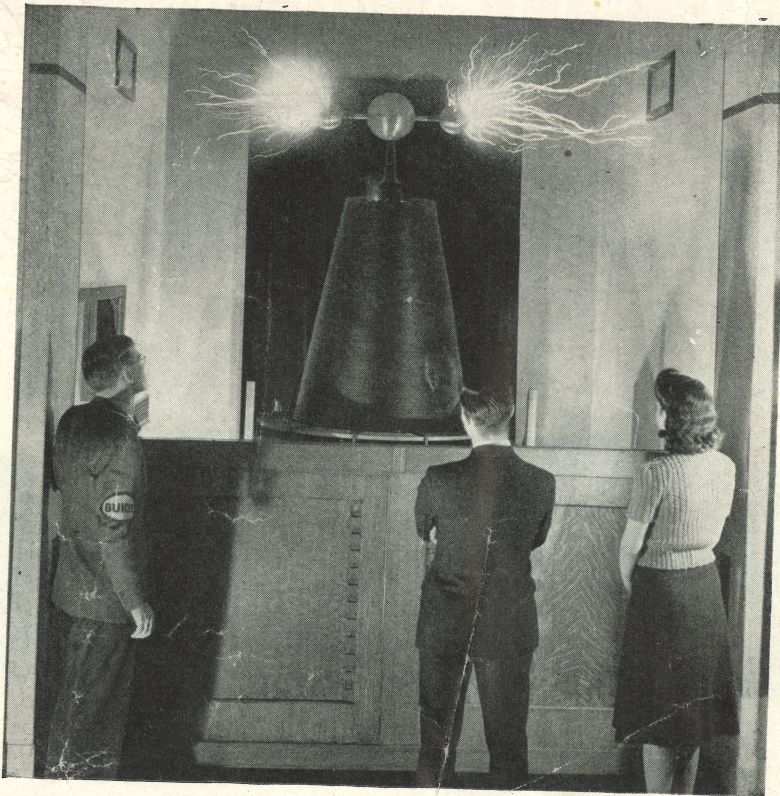
(N.A.S.A., J.P.L. photograph).

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THE TESLA COIL



One of the most spectacular exhibits in the Hall of Science at the Griffith Observatory is the Tesla coil. Hundreds of thousands of visitors have thrilled to the flash of the giant spark produced by this device. They have marveled at the lighting of a fluorescent tube held in the hand of the demonstrator as he held it near the coil. They have been puzzled a bit perhaps when they have been told that the current lighting the tube travels over the surface of the skin of the demonstrator and therefore he feels nothing and is unharmed by the current. There is

never time for the guide to give a thorough explanation of the exhibit, and if he did, very likely most of his audience would become bored and stroll off to seek "amazement" elsewhere.

This article is written in answer to many requests for information regarding the Tesla coil. In it an effort will be made to answer all the various questions that have been asked in the past years, and to anticipate some that may be asked in the future.

The first and perhaps the most surprising bit of information about the Tesla coil at the

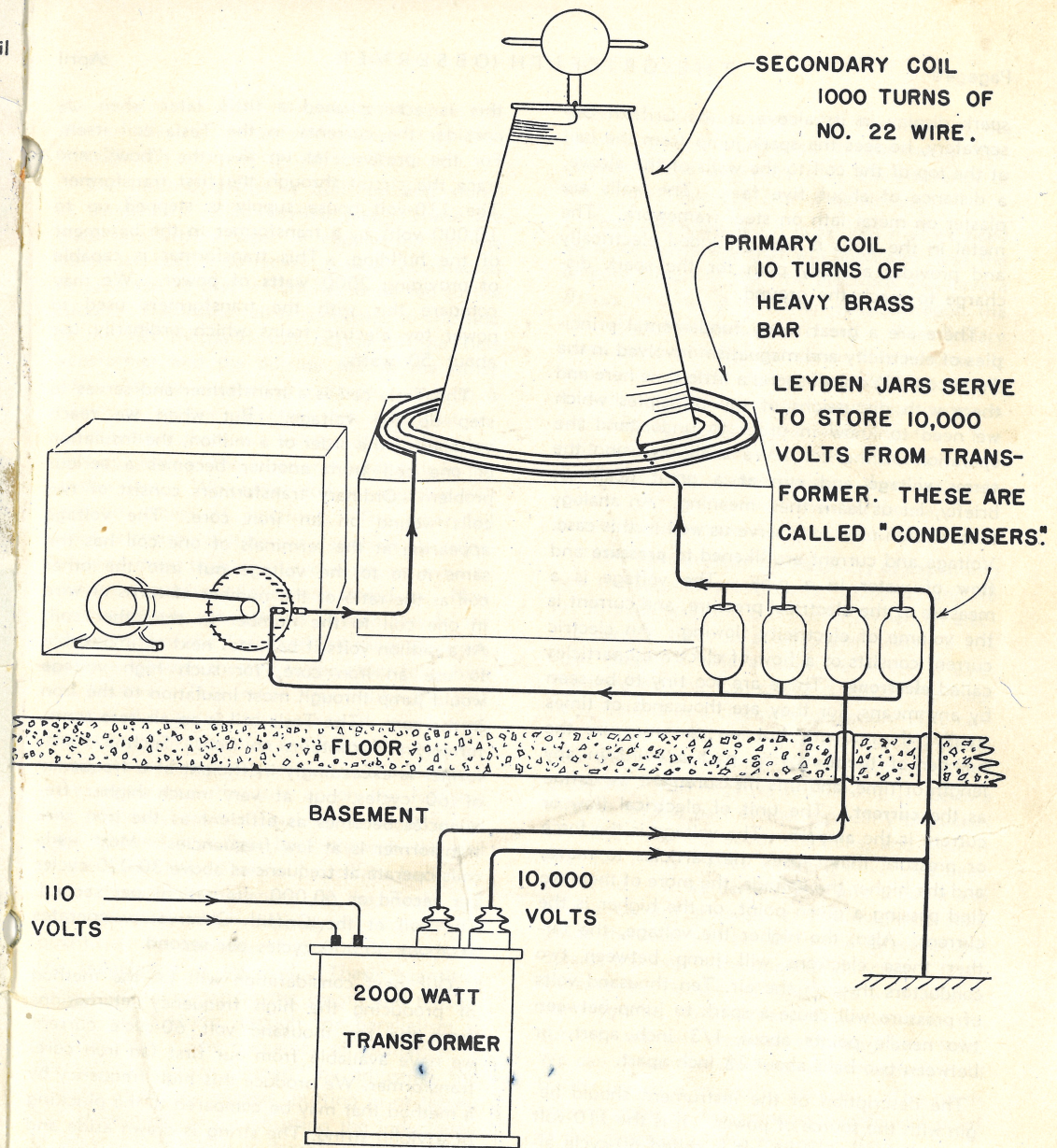


Figure 1.

Griffith Observatory is that it is not strictly a "Tesla" coil. While the term **Tesla coil** is applied generally to all high frequency air-core transformers used to produce a high voltage spark, the coil at the Griffith Observatory should be called an "Oudin" coil. The difference between the two types is not great. The Tesla coil is double ended and the spark jumps from

one end of the coil to the other, and the center of the coil is connected to ground. The Oudin coil is single ended, just half of a Tesla coil, one end being connected to ground and the spark jumps from the free end to ground. The coil at the Griffith Observatory is one-half of an actual Tesla coil. There was not enough space available to install both parts. As one watches the

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APRIL, 1948

increasing, decreasing, reversing, and increasing again. This means that the magnetic field produced by this current is constantly changing.

The secondary winding is intimately imbedded in the changing magnetic field of the primary, and a changing electric current is set up in this winding. The voltage is proportional to the number of turns. The frequency is the same as that in the primary, but the direction of the induced current in the secondary is opposite to that in the primary.

The ratio of turns in our Tesla coil is about 1 to 100, so the voltage is stepped up a hundred times, from 10,000 to 1,000,000.

The lighting of the fluorescent tube in the hand of the demonstrator is produced by the intense electric field in the neighborhood of the coil. The field existing between the ball at the top of the coil and the ground is only partially relieved by the current flowing through the spark. Any conductor brought near the coil will carry some current. The gases in the fluorescent tube are at a much lower pressure than the air outside and, therefore, provide an easier path for the current than through the air itself. The demonstrator standing on the floor completes the path from the upper end of the tube to the ground. The small amount of current flowing through the tube and the demonstrator is enough to light the tube. In this case, only a small fraction of the total current in the secondary coil passes through the demonstrator. Very spectacular demonstrations are possible where the demonstrator allows the full current to pass through his body. He may hold a metal rod up to the ball and allow the spark to jump to the rod and thence through himself to the ground; or he may sit on top of the ball and allow the spark to jump from his finger tips to the walls. In the latter case, he must wear metal thimbles on his fingers to take the impact of the spark, for the spark is hot and will produce a burn if it jumps directly to the flesh. Also, in this latter case, the demonstrator's hair will stand on end, and not from fright either. The electrons, in attempting to escape to the ground, flow out to the tips of the hair. Electrons are all negatively charged and, being of the same polarity, repel one another. The highly charged hairs on the head of the demonstrator

separate themselves and stand out as far from one another as possible. This demonstration is not given at the Griffith Observatory because of the risk involved. **It is perfectly safe if nothing goes wrong.**

The flow of electric current through nerve fibers produces a stimulation that may lead to paralysis if strong enough. If sufficient current flows through the nerves controlling the heart and respiratory system, death is the result. The amount of **direct** current, or alternating current of low frequency, which will flow through the human body varies, depending upon the voltage (or pressure) and the resistance of the body. Body resistance is usually of the order of 50,000 ohms. At 110 volts, 60-cycle alternating current, the body will pass $110/50,000 = 0.0022$ amperes, which is sufficient to kill if it flows through vital parts. At 1,000,000 volts, 60-cycle A.C., the body would pass $1,000,000/50,000 = 20$ amperes, which would not only kill but also would cook. If the resistance of the body remained at 50,000 ohms, the body would be dissipating 20,000,000 watts in the form of heat.

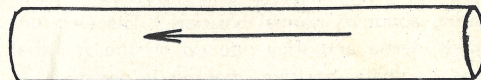
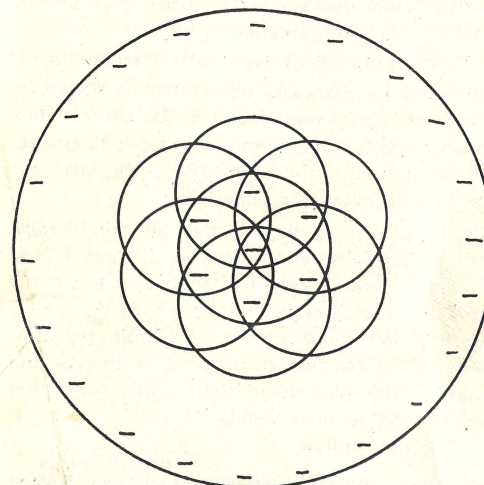


Figure 2.

To understand why high frequency alternating current is less harmful, we must realize what happens when current flows. Let us imagine a conductor (a short piece of wire as in Fig. 2.), in which electrons are moving uniformly in the direction of the arrow. This is a direct current. Any charged particle in motion produces a circular magnetic field.

If the electron is forced to stop, the magnetic field is said to collapse. This collapsing of the magnetic field urges the electron on in its original direction giving it, in effect, a little extra inertia. Likewise, if an electron is set in motion, there is simultaneously built up a circular magnetic field, and the building up tends to retard its motion. The effect of the magnetic field upon the electron is one of stabilization, that is, the field tends to resist an acceleration or deceleration of the electron.

Let us see what happens when a high frequency alternating current is allowed to flow through a conductor. Each electron is producing its own magnetic field, and in order for the electron to change its direction of motion, the field must collapse and build up again in the opposite direction. The changing magnetic field associated with each electron does not confine itself to one electron but affects all nearby electrons.

Figure 3.
Cause of "skin" effect.

If we examine a greatly enlarged cross section of a conductor carrying high-frequency alternating current, we will see that the innermost electrons are affected the most because they are surrounded by other electrons and are affected by the field of each. (See Fig. 3.) But the electrons at the surface of the conductor are affected by fields of electrons on only three sides or actually a little less than three sides. These "skin" electrons are retarded less than the inner ones. Therefore, the current tends to crowd to the surface of the conductor where the electrons may flow more freely. This is known as the "skin effect". It is because of this effect that one may apply a high voltage of high frequency to his body without being killed or injured. The current crowds to the surface of the body and does not pass through interior organs or nerves.

The current available in the spark of the Tesla coil is about 0.002 amperes, which would be sufficient to kill if it were not high frequency. The power is 2000 watts, and, except for small losses, the power dissipated in the spark is equal to the power fed into the transformer from the house line.

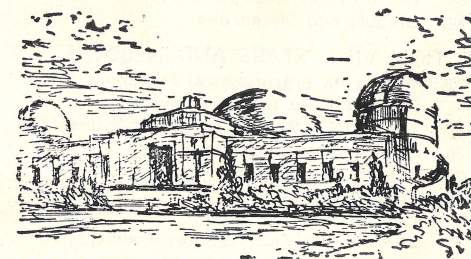
A seeming anomaly is that the current in the primary of the Tesla coil is deadly, and yet it, too, is high frequency (the same frequency as in the secondary). But the voltage is lower and the current is higher (about 0.2 ampere). The same forces producing the skin effect in the secondary are existent in the primary, but the available current is so large that it cannot all flow on the surface of the conductor and so spills over into the interior. Thus vital organs and nerves would be affected. Despite the skin effect, there must for each frequency be some available amperage at which the current becomes deadly. Also, theoretically, for any amperage there must be some frequency high enough for the current to be safe. The practical limit to such a solution arises because eventually we reach a frequency where the molecules of the body themselves begin to fall into resonance and heat is produced within the cells. This is the principle of the diathermy machine and of the high frequency furnace.

—George W. Bunton,
Technician, Griffith Observatory.

PICTORIAL ASTRONOMY

By Dinsmore Alter and C. H. Clemminshaw

A text on descriptive astronomy for the layman, published by Griffith Observatory, approximately one-third pictures. 288 pages 7 $\frac{3}{4}$ " x 10 $\frac{1}{2}$ ". Two bindings: fabricoid \$3.00 plus 15c mailing charge; leatherette (tough, heavy paper), at price to be announced. It is hoped that it may be possible to sell the cheaper edition for \$1.50, but price must await cost statement from printer.





THE NIGHT SKY IN APRIL

THIS MAP SHOWS THE PRINCIPAL STARS AND PLANETS WHICH ARE ABOVE THE HORIZON IN LATITUDE 34° NORTH AT ABOUT 9 P.M. ON APRIL 15, BUT IT IS PRACTICAL ANYWHERE IN THE UNITED STATES ON AN APRIL EVENING. TO USE HOLD IT VERTICALLY AND TURN IT SO THAT THE POINT OF THE COMPASS TOWARD WHICH YOU ARE FACING SHOWS AT THE BOTTOM OF THE MAP, FOR INSTANCE, IF YOU ARE FACING TOWARDS THE EAST, THE WORDS "EASTERN HORIZON" SHOULD BE AT THE BOTTOM.