The Video Encyclopedia *of* Physics Demonstrations™

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Chapter 43

Voltage Drops and I^2R Losses

Demo 18-01 Voltage Drop Along Wire

The voltage is measured between one end of a uniform wire connected to a battery and a series of equally spaced points along the wire, as shown in *Figure 1*, illustrating that the voltage drop along a wire is uniform.†

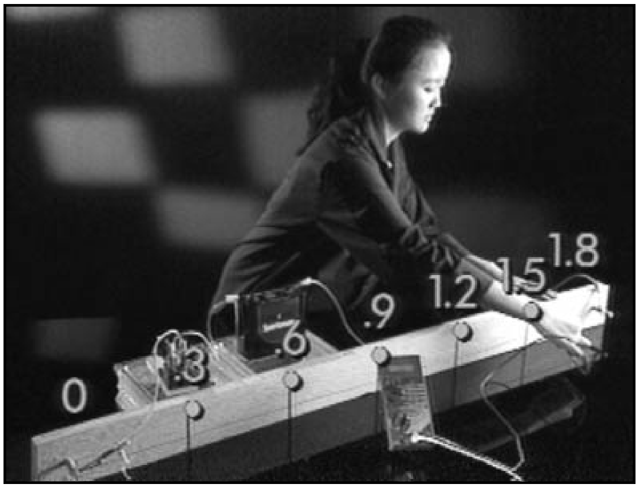

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstrations E-158, Resistance Measurement Using Voltmeter and Ammeter—Potential Drop along a Wire.

This long resistance wire is connected to a battery. There is therefore a voltage along the length of the wire, but how does the amount of voltage drop vary with the distance along the wire?

We'll mark the wire off into equal sections and look at the voltage relative to one end of the wire at five points.

The voltmeter shows that the amount of voltage drop is directly proportional to the distance along the wire.

Equipment

1. Length of copper wire with no insulative varnish and mounted on a framework.
2. Voltmeter.
3. A switch, telegraph type.
4. Battery.
5. Appropriate electrical leads.

Demo 18-02 Sum of IR Drops

The algebraic sum of the voltage drops around a circuit loop must be zero.† This rule, known as Kirchoff's Voltage Law, is illustrated in this demonstration, using the apparatus shown in *Figure 1*. The voltage across each of the circuit elements around the loop is measured for two different configurations.

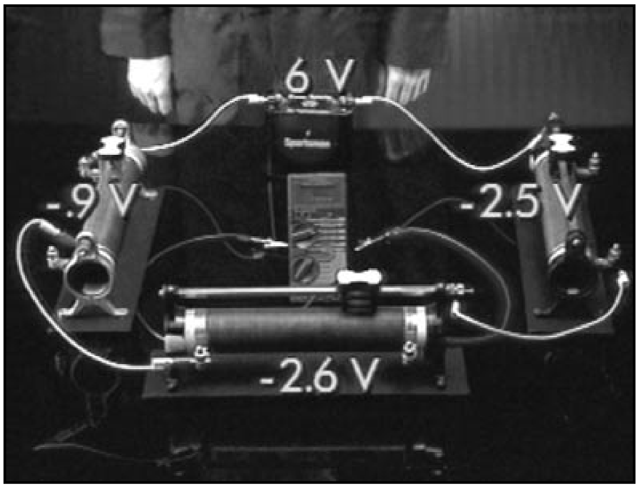

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Eo-2, Kirchoff's Voltage Law.

We'll hook these three variable resistors in series with this battery, and measure the voltage drop across each resistor to see how their sum compares to the applied voltage. The battery supplies a constant 6 volts.

Let's go around the circuit and measure each of the voltage drops.

The first resistor has a voltage drop of minus 0.9 volts.

The second, minus 2.6 volts.

And the third, minus 2.5 volts.

The sum of the voltage drops minus 6 volts is the opposite of the applied voltage.

Now we'll change the resistors and repeat the process.

The first resistor now has a voltage drop of minus 2.2 volts.

The second, minus 3.5 volts.

And the third, minus 0.3 volts.

The sum of the three voltage drops is again the opposite of the applied voltage.

Equipment

1. Three slide-wire rheostats.
2. Battery.
3. Voltmeter.
4. Appropriate electrical leads.

Demo 18-03 Internal Resistance of Batteries

When a battery "dies," its internal resistance increases dramatically. The potential across a dead battery and a good battery may be almost the same. However, when the batteries are loaded by a light bulb most of the voltage drop occurs within the battery if the battery is "dead," limiting the ability of the battery to provide current, as shown in the video. The apparatus used is shown in *Figure 1*.

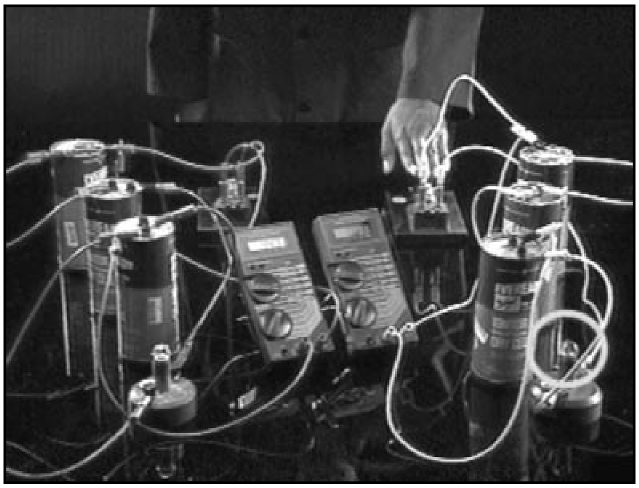

Figure 1

These two sets of batteries appear identical, and show approximately the same reading on a voltmeter. But there is a difference.

When a light bulb is connected to this set of batteries, the bulb lights and the voltage of the batteries remains about the same.

When we do the same with this set, the bulb fails to light, and the voltage of the batteries drops to nearly nothing. This set of batteries has been heavily used, and has a high internal resistance.

Equipment

1. Six 1.5-volt batteries, one in a weakened condition.
2. Two small lamps.
3. Two telegraph-type switches.
4. Two voltmeters.
5. Appropriate electrical leads.

Demo 18-04 Loading by a Voltmeter

A voltmeter samples the voltage across a circuit element, but does not affect the circuit because of its extremely large internal impedance. If the impedance of a voltmeter is too low, it will draw a significant amount of current itself, changing the circuit that it is sampling, as shown in the video and in *Figure 1*. In this case the voltage reads too low, as seen in the Figure.

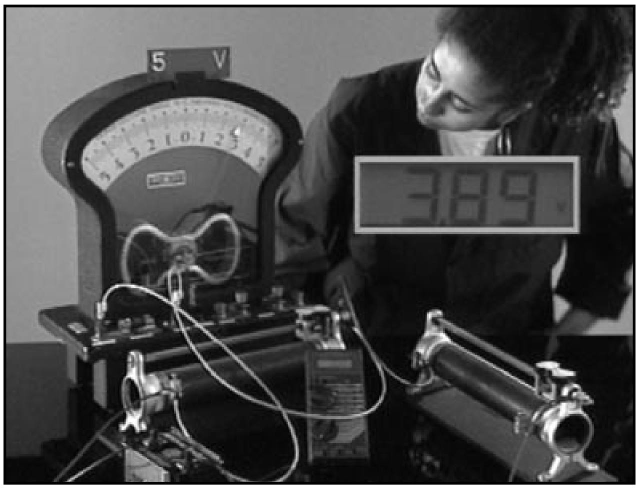

Figure 1

We'll use these two voltmeters to demonstrate what happens when a voltmeter of low resistance is used to measure voltage on a high-resistance circuit.

These two potentiometers are hooked in series with a battery, and the voltage across one of them is measured with this electronic voltmeter, which has a very high resistance.

When this voltmeter with a lower resistance is hooked up to measure the same voltage, it reduces the voltage it is supposed to be measuring.

Equipment

1. Two voltmeters, one with low resistance and one with high resistance.
2. 6-volt battery.
3. Two slide-wire rheostats.
4. Appropriate electrical leads.

Demo 18-05 Voltage Drops in House Wires

In a house the electricity is transmitted along heavy wires to the device being powered. If the house wiring is not of sufficient size, a voltage drop will occur along the wires, so the devices being powered will not obtain enough voltage to run them properly.† This effect is shown in the video, using the apparatus of *Figure 1*. In this case the wires heat up and eventually break.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Eh-4, Transmission of Power.

Have you ever seen your house lights dim when you turned on a heater or heavy appliance?

We'll use this model of house wiring to demonstrate the effect.

Two resistance wires will substitute for the normal copper wires used in a house to increase the effect. They run ordinary household current into this bank of lamps and heaters which can be switched on and off individually.

We'll first switch on the lamps.

Then heaters will be switched on one at a time.

When enough heaters are added to the line, the lamps dim.

The electrical energy lost in the wires which deliver the current is dissipated as heat.

Equipment

1. Two resistance wires mounted on a board, with paper flags.
2. An array of six lamp sockets and six switches mounted on a second board and wired in parallel.
3. Two light bulbs.
4. Four heater coils mounted on a ceramic cone with a standard lamp base.
5. Appropriate electrical leads.

Demo 18-06 I^2R Losses

This demonstration illustrates the power lost in wires with high resistivity.† The heating of copper and nichrome wires carrying the same current is compared on the video using the apparatus shown in *Figure 1*. The nichrome wire, having much higher resistivity, heats up much more than the copper wire.

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-174, Comparison of Heating in Various Conductors.

When a current flows through a wire, heat is generated. We'll use these two different wires hooked in series to show how the amount of heat generated depends on the resistance of the wire.

This wire is made of copper, a low-resistivity metal, while this wire is made of nichrome, a metal with a relatively high resistivity.

We'll put a paper rider on each wire, then run the same current through both wires to see which heats up the most.

The nichrome wire burns its rider almost immediately, but the rider on the copper wire isn't even scorched.

Equipment

1. Copper coil and nichrome coil mounted in series on a board, with paper flags.
2. Variac.
3. Appropriate electrical leads.
4. AC power.

Demo 18-07 Hot Dog Frying

A hot dog is skewered on two nails, across which the 110 VAC line voltage is impressed.† The video shows how the hot dog is cooked by the heat produced when the current is run through the hot dog, as shown in *Figure 1*.

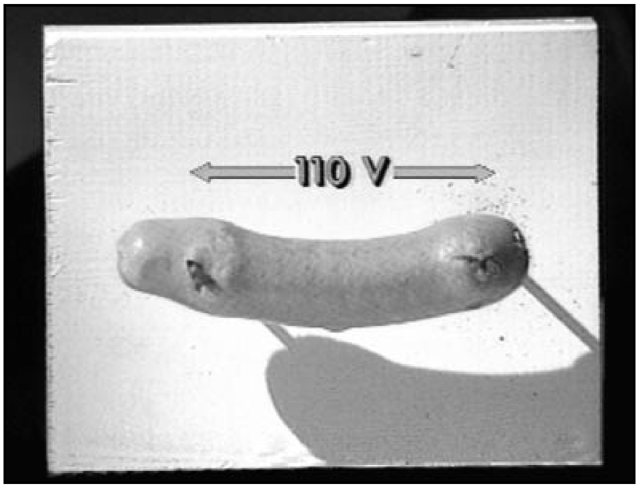

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-176, Heating Effect of Current in Organic Material—"Hot Dog" Cooker.

Hot Dog Frying / Script

We'll skewer this hot dog onto two nails and run a current through it to show the heating produced by the current.

110 volts are applied to the nails, and a current begins to flow through the hot dog.

After a few minutes, the hot dog begins to steam from the heat produced by the current.

Equipment

1. Two 8-penny nails driven into a board at a distance somewhat less than the length of a hot dog.
2. Support system for the board.
3. Power cord.
4. Switch.
5. AC power.
6. Supply of hot dogs.

CHAPTER 44

NON-OHMIC RESISTANCE

Demo 18-08 Neon Bulb Resistivity

A neon bulb will not glow until the potential across the plates reaches about 80 volts, when the neon gas in the tube breaks down. Once the bulb is glowing, the potential can be reduced to about 60 volts and the bulb will continue to glow, as shown in the video and in *Figure 1*.

Figure 1

This neon bulb shows a curious type of conductivity.

We'll apply an increasing voltage to the bulb, to show how its conductance changes with increasing voltage. At low voltages, no current flows and the bulb does not light.

When the voltage reaches about 80 volts, the bulb suddenly lights as a current begins to flow through the neon gas.

Reducing the voltage below 80 volts does not shut off the current. The voltage must be reduced to about 60 volts before the neon gas becomes non-conducting again.

Equipment

1. Neon lamp.
2. Lamp socket mounted on a framework.
3. Voltmeter.
4. Power supply.
5. Appropriate electrical leads.
6. AC power.

Demo 18-09 Carbon and Tungsten Lamps

Tungsten has a positive temperature coefficient of resistance, while carbon has a negative coefficient of resistance. This leads to different current versus voltage curves for these two materials when they are used as the filament in light bulbs.† This difference is illustrated in the video using the apparatus shown in *Figure 1*. Current versus voltage curves for the tungsten and the carbon filaments are shown in *Figure 2*.

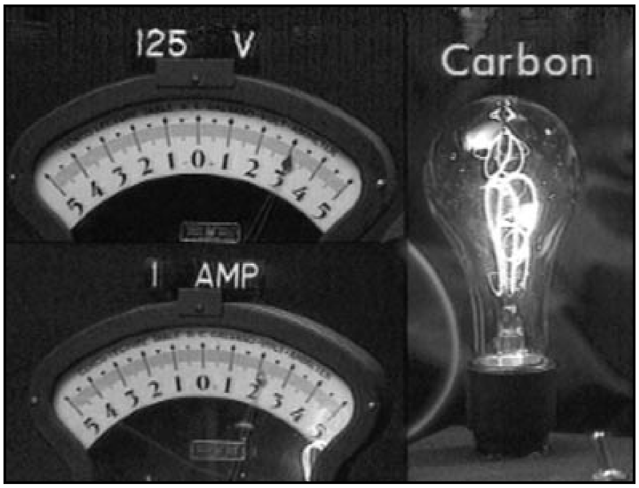

Figure 1

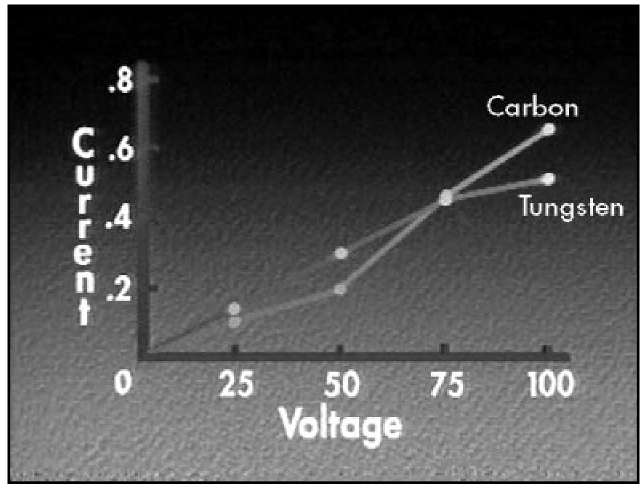

Figure 2

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-167, Negative Temperature Coefficient of Resistance.
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Eg-5, Positive and Negative Resistance Coefficients.

These two light bulbs, with filaments of tungsten and carbon, will be used to show two different ways in which resistance changes with increasing temperature.

We'll apply increasing voltages to each bulb in turn and plot the current that flows vs. the voltage as each bulb gets hotter.

Here is tungsten at 25 volts.

50 volts.

75 volts.

100 volts.

Here is a carbon filament at 25 volts.

50 volts.

75 volts.

100 volts.

This graph shows the amount of current that flows through each bulb as the voltage is increased. The resistance of the tungsten bulb increases with increasing temperature. But the resistance of the carbon bulb decreases with increasing temperature.

Equipment

1. Tungsten lamp.
2. Carbon lamp.
3. Base for the above.
4. Variable voltage supply.
5. Voltmeter.
6. Ammeter.
7. Appropriate electrical leads.
8. DC power.

Demo 18-10 Diode

A diode passes current only in one direction. If a diode is connected to an alternating voltage source as shown in *Figure 1*, current will readily flow in one direction but no current will flow in the other direction, as shown in the video. Four such diodes can be connected in a diamond-shaped configuration to create a "bridge rectifier," which is shown in Demonstration 11: Rectifier Circuit.

Figure 1

Diode / Script ***Demo 18-10***

This solid-state diode has very peculiar conduction properties, which we will demonstrate with this setup.

We're powering a lamp from a ganged potentiometer that allows us to apply either positive or negative voltages. Current flows easily through the lamp in either case.

We'll put the diode in series with the lamp and repeat the demonstration.

Now the current will only flow in one direction.

Equipment

1. Diode.
2. Light bulb and socket base.
3. Ganged potentiometer wired to deliver either positive or negative voltages.
4. Voltmeter.
5. Ammeter.
6. Appropriate electrical leads.
7. DC power.

Demo 18-11 Rectifier Circuit

This demonstration illustrates the operation of a "bridge rectifier" circuit.† The output of the bridge rectifier includes inductive and capacitive filters and a resistive load, as shown in *Figure 1*. The voltage (or current) across circuit elements is shown, along with the output, both unfiltered and filtered.

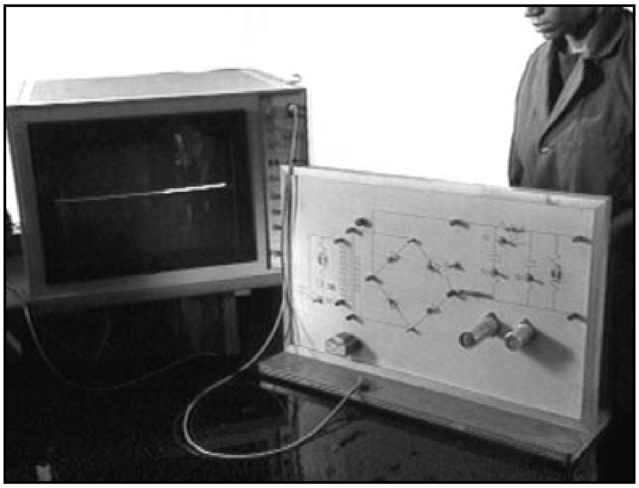

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Eo-10, Bridge Rectifier.

Here is a circuit used to rectify alternating current and transform it into direct current. We'll look at the different components of the rectifier circuit to see what part each plays in the operation.

This transformer puts out alternating current at six volts. We can see the wave form of the current by attaching the output terminals of the transformer to this oscilloscope.

This alternating current feeds into a diamond-shaped bridge of four diodes.

Here is the resulting voltage across one of the diodes.

At the right and left corners of the diamond, the voltages from the individual diodes add together to produce this wave form.

This pulsating current is then filtered by two low-pass filter stages.

When the filter stages are connected one by one, the output flattens into a clean DC voltage.

Equipment

1. Rectifier circuit board.
2. Oscilloscope.
3. Appropriate electrical leads.
4. AC power.

Demo 18-12 Transistor Amplifier

Operation of a transistor amplifier, the circuit for which is shown in *Figure 1*, is illustrated in this demonstration. The amplification factor is the ratio of the collector to emitter current to the base current. The amplification factor can be increased by increasing the collector to emitter voltage. The effects of changes in the input current and the collector to emitter voltage on the amplification are shown in the video.

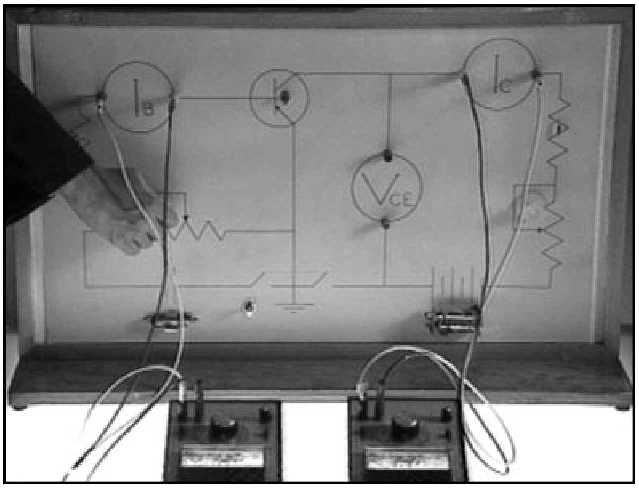

Figure 1

This transistor amplifier circuit will be used to show the properties of transistors.

This leg of the circuit provides the signal, a current which can be varied by turning a potentiometer. This signal feeds into the base of the transistor.

The collector-to-emitter voltage is supplied by this set of batteries and is controlled by turning this potentiometer.

Here is the input signal—the current flowing into the base of the transistor.

Here is the output of the transistor, the current flowing between the collector and the emitter. The output is an amplified version of the input. We can change the amplification by increasing the collector-to-emitter voltage.

Equipment

1. Transistor board.
2. Two ammeters.
3. Appropriate electrical leads.
4. AC power.

Chapter 45

Electrochemical Effects

Demo 18-13 Conductivity of Solutions

Using a light bulb in series with various solutions, as shown in *Figure 1*, the conductivity of the solutions is studied experimentally.[†] Those solutions containing ions are shown to have greater conductivity, as evidenced by the brightness of the light bulb in the circuit of *Figure 1*. Solutions shown are deionized water, salt water, sugar water, water with vinegar in it, and tap water. The sugar water and the deionized water have the smallest conductivity.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ef-1, Conductivity of Solutions.

This light bulb is wired in series with these two metal prongs, so that if something conductive touches the prongs current can flow through the bulb. We'll use this setup to demonstrate the conductivity of different solutions.

Here is distilled water.

Here is distilled water with salt added.

Here is distilled water with sugar added.

Here is distilled water with vinegar added.

Finally, here is ordinary tap water.

Equipment

1. Light bulb and lamp socket mounted on a plastic disc along with two electrical contact probes extending from below the disc, and a power cord.
2. Switch.
3. AC power.
4. Copper plate.
5. Three beakers of distilled water.
6. Supply of salt.
7. Plastic spoon.
8. Supply of sugar.
9. Supply of vinegar.
10. Beaker of tap water.

Demo 18-14 Battery Effect

When strips of various metals (zinc, copper, lead, and iron) are inserted into a dilute sulfuric acid bath, a voltage is created across the two metal strips.† The magnitude of the voltage depends on the particular metals. In this demonstration the effect of the metal on the voltage produced is demonstrated using the apparatus shown in *Figure 1*.

Figure 1

† Freier and Anderson, A Demonstration Hnadbook for Physics, Demonstration Ee-2, Dependence of EMF on Electrode Material.

Most batteries consist of two different materials in contact with an electrolyte. We'll use this pair of windmill arms, each containing four different metals, to show how the voltage of a simple battery changes with different pairs of metals.

A trough of dilute sulfuric acid beneath the windmills provides the electrolyte. We'll dip different pairs of metals into the acid and observe the voltage developed in each case on this voltmeter.

Here is copper and copper.

Here is copper and iron.

Here is copper and zinc.

Here is copper and lead.

Equipment

1. Battery effect unit and tank.
2. Supply of diluted sulfuric acid.
3. Voltmeter.
4. Appropriate electrical leads.

Demo 18-15 Pickle Frying

A pickle is skewered on two nails, in the same way as the hot dog of Demonstration 7, and 110 VAC impressed across the nails holding the pickle. The pickle produces an unusual glow at one end when heated in this manner, as seen in *Figure 1* and in the video.

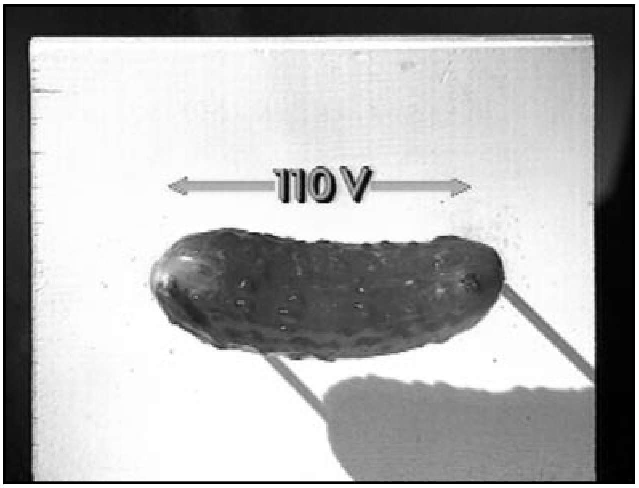

Figure 1

We'll use this pickle and two nails to show an unusual type of electrical discharge.

The nails are inserted in the ends of the pickle, and electrical leads are connected to the nails. When we put a high voltage across the nails, the pickle lights up at one end.

Equipment

1. Same equipment as Demonstration 18-07.
2. Supply of large dill pickles.

Demo 18-16 Electrolysis

If a current is run between two electrodes through a dilute solution of sulfuric acid, the water will be separated into its two chemical components, hydrogen and oxygen.† The hydrogen (left) and the oxygen (right) are collected separately in the two tubes of the apparatus shown in *Figure 1*. After collecting a sufficient amount of the gases, the hydrogen is shown to ignite readily when exposed to a match flame and the oxygen in the air.

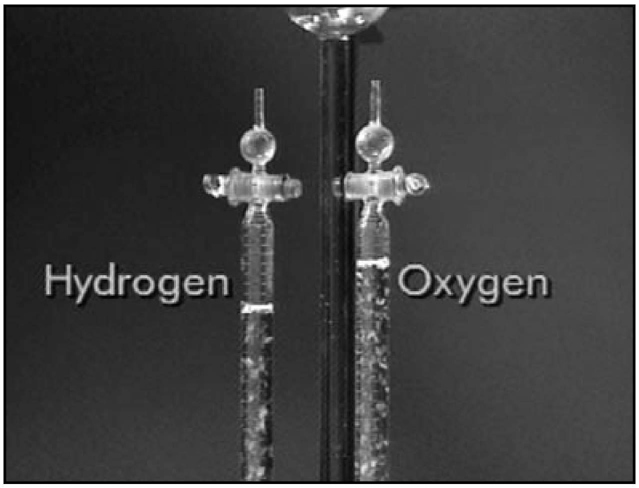

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ef-2, Electrolysis of Water.

When an electrical current is passed through water to which a small amount of acid has been added, the water splits up into its component gases, hydrogen and oxygen.

This glass tube has two electrodes each in a separate leg so that the gases may be collected from each electrode separately. When we run a current through the water, gases build up in the tubes in a volume ratio of two to one.

If the larger of the two volumes of gas is released near a lit match it burns with a pale blue flame.

Equipment

1. Electrolysis unit.
2. Supply of diluted sulfuric acid.
3. Switch.
4. Appropriate electrical leads.
5. DC power.
6. Source of flame.

Demo 18-17 Electroplating

When current is run between a positive copper electrode and a negative carbon electrode immersed in a copper sulfate solution, copper will be electroplated on the carbon electrode. This procedure is demonstrated here using the apparatus shown in *Figure 1*. An animation further clarifies the electroplating mechanism.

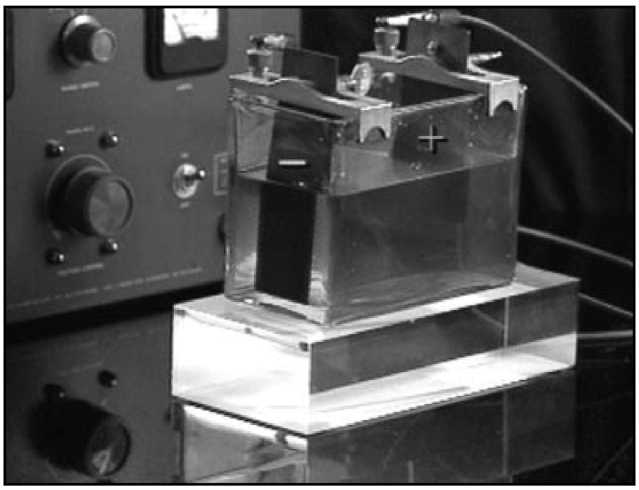

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ef-4, Electroplating Copper.

Electroplated objects are a common part of our everyday lives, such as this chrome-plated car bumper.

We'll use this tank filled with a solution of copper sulfate and two electrodes to show how it's done.

A current supply is hooked up to the electrodes, one of which is copper and the other carbon, and they are placed in the copper sulfate solution.

When a current is run through the solution with the copper electrode positive, a plating of copper builds up on the carbon electrode.

This animation shows how the positively charged copper ions in the solution are attracted to the negatively charged carbon plate where they bond to the surface.

Equipment

1. Small tank containing a solution of copper sulfate and two electrodes—one carbon, one copper.
2. Battery eliminator.
3. Appropriate electrical leads.
4. AC power.

Chapter 46

Capacitance and RC Circuits

Demo 18-18 Leyden Jars on Toepler Holtz

This demonstration shows that a Leyden jar is a type of capacitor, whose purpose is to store electrical charge.† A Toepler-Holtz electrostatic generator initially produces electrical discharges between two small conducting spheres without the aid of the Leyden jar. Upon installing Leyden jars in parallel with the two spheres, as illustrated in *Figure 1*, the sparks occur at greater time intervals, but are much more intense. This shows that the Leyden jars are storing the charge from the generator until the breakdown voltage is reached, which is stronger because of the additional stored charge.

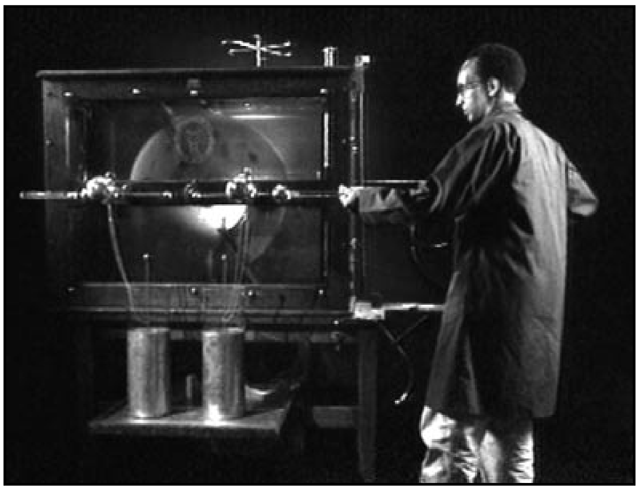

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-63, Leyden-jar Condensor. Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Eb-8, Leyden Jar.

This large electrostatic generator will be used to demonstrate the basic properties of these capacitors.

The generator is first cranked with no capacitors hooked up, and long but weak sparks are seen to jump frequently between the electrodes.

Now we'll hook these Leyden jar capacitors between the electrodes of the machine.

The sparks are now much more intense but come much less frequently.

Equipment

See Demonstration 18-17.

Demo 18-19 Parallel Plate Capacitor

A parallel plate capacitor is formed by two metal sheets held close to each other.[†] One sheet is charged to some potential using a charged dielectric rod, creating a potential difference between the two capacitor plates, as seen in *Figure 1*. When the plates are separated, the capacitance decreases:

$$C = \frac{\varepsilon QA}{d}$$

where Q is the charge on the plates, A is the area of the plates and d is their separation, and ε is the permittivity constant of the air. Therefore the voltage across the plates,

$$V = \frac{Q}{C}$$

increases, as seen by the electrometer of *Figure 1*. An animation supports a helpful description of what is happening as the plates are separated.

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-69, Parallel-plate Condensor. Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ed-1, Field and Voltage.

We'll use this electroscope to show how the voltage on a charged capacitor changes as the distance between the plates is changed.

The two plates of this capacitor are hooked up to the electroscope, and the capacitor is charged by touching it with a charged rubber rod.

If we increase the distance between the plates, will the voltage increase, decrease, or stay the same?

The voltage increases.

If we move the plates together again, the voltage decreases.

This animation shows how the charges move when the separation between the plates is changed.

Equipment

1. Electroscope.
2. Parallel plate capacitor.
3. Appropriate electrical leads.
4. Plastic rod.
5. Wool cloth.

Demo 18-20 Parallel Plate Capacitor Dielectrics

When a dielectric is placed between the plates of a parallel plate capacitor, the capacitance increases, so charge can be stored at a smaller potential.† When sheets of dielectric materials are placed between the plates of the capacitor shown in *Figure 1*, the voltage between the plates, as indicated by the electrometer, is least for the dielectric with the greatest dielectric constant. Dielectrics of acrylic and cardboard are illustrated in the video.

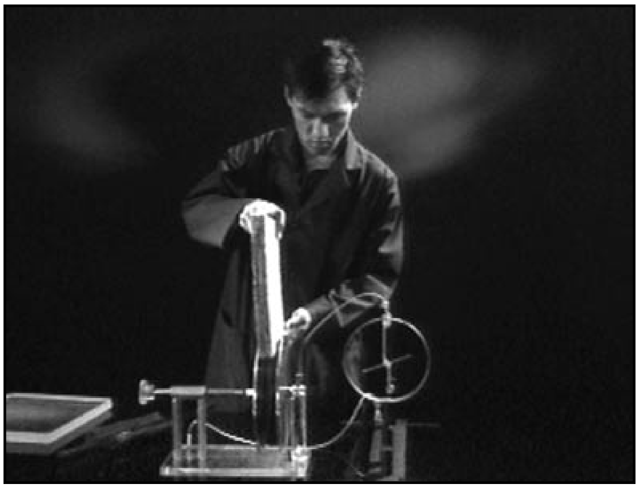

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-70, Dielectric Constant and Capacitance.
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ed-2, Dielectrics.

This electroscope and a large parallel plate capacitor will be used to demonstrate how inserting a dielectric affects the voltage on a capacitor.

We first charge the capacitor by touching it with this charged rubber rod. The electroscope deflects, showing the voltage on the capacitor. If we insert a thick piece of acrylic between the plates of the capacitor, what will happen to the deflection of the electroscope?

The deflection decreases, showing a decrease in voltage. When we remove the dielectric, the voltage returns to its former value.

A sheet of cardboard inserted between the plates shows a similar effect.

This animation shows how the charges move between the electroscope and the capacitor as the dielectric plates are inserted.

Equipment

1. See Demonstration 18-19.
2. Two dielectrics:
   a. Square slab of solid acrylic.
   b. Cardboard—several laminated layers of corrugated cardboard to approximate the dimensions of the acrylic slab.

Demo 18-21 Rotary Capacitor

A rotary capacitor can be used in the experiment of Demonstration 19 to show how the capacitance changes as the overlap between the plates is changed.†
Using the apparatus of *Figure 1*, the potential across the charged plates of the rotary capacitor is observed to decrease as the plates are overlapped (or increase as the plates are separated), indicating that the capacitance increases as the plates are overlapped and decreases as the plates are separated.

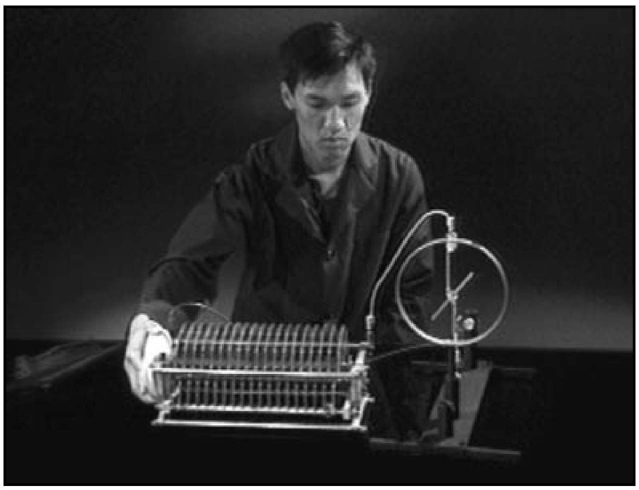

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-75.

We'll use this electroscope and a large rotary capacitor to show how the voltage of a charged capacitor changes as the area of overlap between the plates changes. When we charge the capacitor by passing a spark to it from this charged rubber rod, the electroscope deflects, indicating the voltage on the capacitor. If we rotate the capacitor and decrease the overlap between the plates, what will happen to the deflection of the electroscope?

The deflection increases, indicating an increased voltage on the capacitor.

Rotating the plates back together to increase the overlap reduces the voltage to its former value.

Equipment

1. Rotary capacitor.
2. Electroscope.
3. Appropriate electrical leads.
4. Plastic rod.
5. Wool cloth.

Demo 18-22 Battery and Separable Capacitor

The plates of a parallel plate capacitor used in Demonstration 19 are placed close together and charged using a 300-volt battery.† The electroscope does not deflect, because of the low voltage supplied by the battery. However, when the plates are separated the electroscope deflects, as seen in *Figure 1*, showing that the type of charge obtained from a battery is the same as the type of charge obtained from contact between the materials used in Demonstration 19.

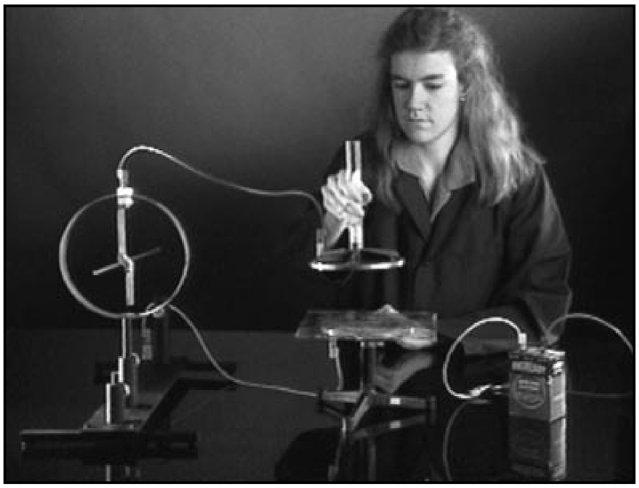

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-116, Identification of Charge from Dry Cells.

We can easily charge this electroscope by touching it with a charged plastic rod that has been rubbed with wool. This is the type of electricity usually called static electricity.

This battery will not ordinarily charge the electroscope, even though it produces 300 volts. We'll use this capacitor to raise the voltage enough to deflect the electroscope.

After the capacitor is charged to 300 volts by the battery, we separate the plates of the capacitor. The voltage on the capacitor is now enough to deflect the electroscope.

Equipment

1. Electroscope.
2. Plastic rod.
3. Wool cloth.
4. Separable capacitor with horizontal plates—the upper one with a non-conductive handle.
5. Thin sheet of mica.
6. High voltage dry cell.
7. Appropriate electrical leads.

Demo 18-23 Exploding Capacitor

Four 1000 μF microfarad capacitors connected in parallel are charged to 400 volts, and then discharged using a metal strip. The discharge is rather violent, creating a large spark and big bang, hence the term “exploding capacitor.” The capacitors in this demonstration, shown in *Figure 1*, hold about 320 joules of electrical energy, which is a lethal amount if the capacitor is discharged through the body, so this experiment is potentially very dangerous.

Figure 1

Large capacitors may look innocent, but they can be very dangerous when they are charged.

This bank of four capacitors in parallel will be charged to 400 volts.

The capacitors are now fully charged, and we will disconnect them from the voltage source.

Though they look benign, these capacitors are now storing a lethal charge.

Equipment

1. Bank of four electrolytic capacitors wired in parallel with copper bars, and fitted with banana plug sockets for charging.
2. High-voltage power supply.
3. AC power.
4. Two electrical connectors equipped with insulated handles.
5. Discharging bar.

Demo 18-24 Force on a Dielectric

When a dielectric is placed between two charged plates, it becomes polarized. Forces develop between the charged plates and the adjacent dielectric surfaces, which have the opposite sign of charge. This force pulls the dielectric into the capacitor, as demonstrated in the video using the apparatus of *Figure 1*.

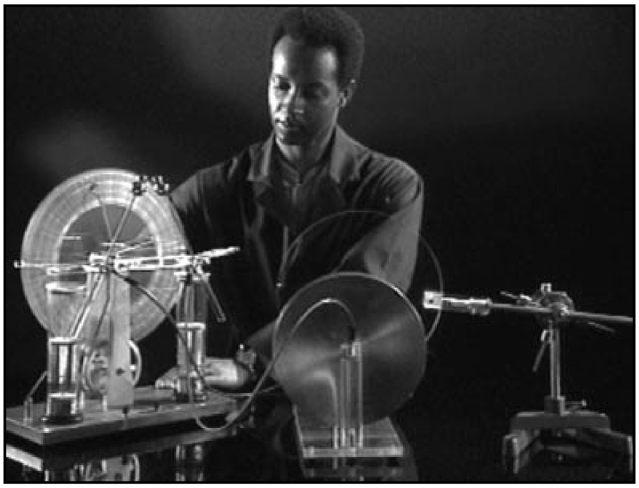

Figure 1

This parallel plate capacitor and an acrylic sheet will be used to demonstrate the force on a dielectric between the plates of a capacitor.

The sheet is attached to the end of a balance arm so that it is free to swing up and down. We'll place it between the plates of the capacitor and charge the capacitor to a high voltage using this electrostatic generator.

When the capacitor is charged, the force on the dielectric pulls it down between the plates.

This animation shows how the polarized molecules of the dielectric are reoriented by the electric field of the plates.

This new orientation results in an attractive force on the dielectric which pulls it down between the plates.

Equipment

1. Parallel plate capacitor with vertical plates.
2. Dielectric disc mounted on a long pivot arm along with a counterbalance and a very low friction bearing pivot, and its support system.
3. Two appropriate electrical leads.
4. Small Wimshurst electrostatic generator.

Demo 18-25 Dissectible Capacitor

This demonstration uses a “dissectible capacitor” to show that the charge in a dielectric capacitor is stored as polarization charge in the dielectric.† A Leyden jar is first charged and discharged to illustrate the effect of the capacitor discharge. The Leyden jar is then charged and disassembled, and all of the parts handled by the demonstrator, as shown in *Figure 1*. The Leyden jar is then reassembled and discharged in the same manner as before, yielding a spark similar to the earlier case. Thus the charge must have been stored in the glass as polarization charge.

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-64, Dissectible Leyden Jar. Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Ed-3, Dissectible Condenser.

We'll assemble a simple capacitor out of these three components.

This high-voltage electrostatic generator will be used to charge the capacitor. A wire is connected from one side of the generator to the outer metal shell of the capacitor, while a loose chain connects the other side of the generator to the inner conductor of the capacitor. Let's charge the capacitor.

Now that the capacitor is fully charged, we can disconnect it from the generator, and use this discharge rod to demonstrate the high voltage which exists between the two metal plates.

We'll now repeat the charging,

but after the capacitor is fully charged and has been disconnected, we will disassemble it into separate parts.

If we now touch the discharge rod to the two metal plates, there is no spark. What has happened to the charge on the plates?

If we reassemble the jar and bring the discharge rod up, we get a spark nearly as long as the first. Since the charge was not on the separated metal plates, it must have been stored on the glass.

Equipment

1. Dissectible capacitor.
2. Connecting chain loop.
3. Insulated handle with a U-shaped conductive rod with small spheres on each end.
4. Alligator clip/banana plug electrical lead.
5. Wimshurst electrostatic generator.

Demo 18-26 Grounded Leyden Jar

A Leyden jar is charged to a high potential and discharged, illustrating the discharge of the electrical energy stored therein. The Leyden jar is then charged again, isolated from any external electrical contact, and each of the plates separately grounded. The two plates are then connected, producing a discharge similar to the original discharge, as shown in *Figure 1*. This shows that the potential between the two plates is the important factor in this process, not the potential between either plate and ground.

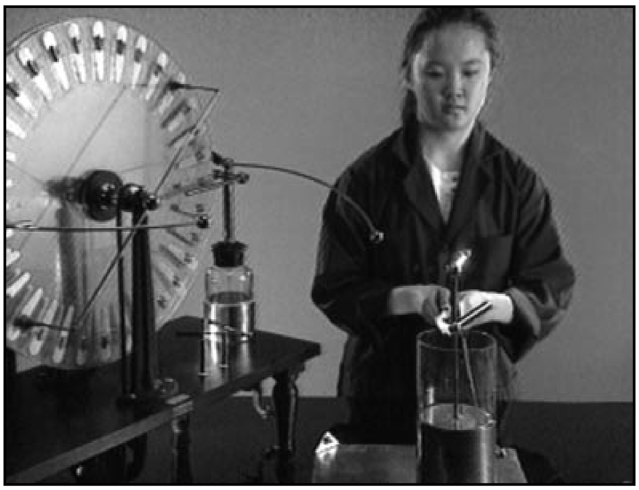

Figure 1

When this Leyden jar holds a charge, a potential difference exists between the two plates of the jar.

We can alternately ground each of the plates, yet the charge on the jar is still there.

The potential difference between the two plates is all that matters, not the absolute potential of either plate.

Equipment

See Demonstration 18-25.

Demo 18-27 Series / Parallel Capacitors

Two identical capacitors are connected individually, in series, and in parallel to the same voltage source, to study the voltage and the charge on the capacitors in each configuration.† We use capacitors of capacitance C, which attain a charge Q when a voltage V is impressed upon them:

$$Q = CV$$

For the case of capacitors in parallel, the voltage across each is V, so each carries a charge Q, for a total charge of $2Q$. For the case of capacitors in series, the voltage V is shared between the two series capacitors, so each feels only half the voltage, $V/2$, and therefore develops only half the charge. Discharging the capacitors in series only yields a charge of $Q/2$. These effects are shown in the video and illustrated in *Figure 1* by the deflection of the galvanometer when the capacitor is discharged.

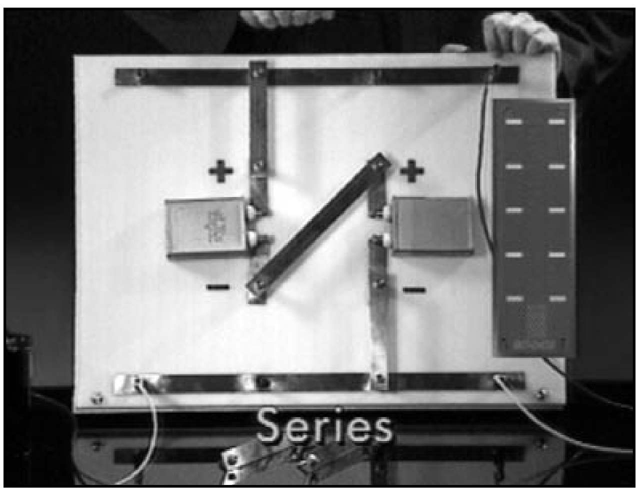

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstrations E-68, Condensers in Series and Parallel, and E-262, Laws of Capacitance with Ballistic Galvenometer.

We'll use these copper strips to hook these two identical capacitors together three different ways. For each hookup, we'll charge the capacitors to the same voltage with this dry cell, then discharge the capacitors through this ballistic galvanometer. The amount of deflection of the galvanometer will be proportional to the charge contained on the capacitors.

Here is a single capacitor being charged.

Here is the galvanometer reading from discharging the single capacitor. How will the reading change if we hook two capacitors in parallel and repeat the demonstration?

The galvanometer reading is doubled.

How will it change if we hook the two capacitors in series?

Now the galvanometer reading is half that for a single capacitor.

Equipment

1. Series/parallel capacitor board, along with its collection of connecting copper bars.
2. Battery.
3. Ballistic galvanometer.
4. Appropriate electrical leads.

Demo 18-28 RC Charging Curve

When a resistor *R* and a capacitor *C* are connected in series across a voltage source the capacitor charges with a characteristic time called the time constant τ, where $\tau = RC$.† The time constant is shown for several values of *R* and *C* using an oscilloscope connected across the capacitor, using the RC board shown in *Figure 1*.

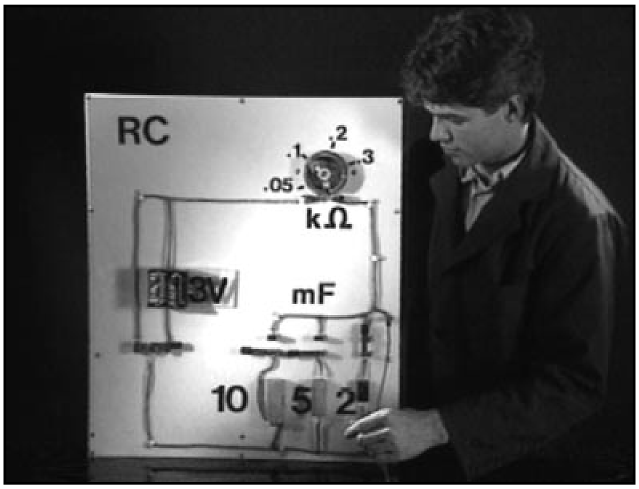

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstrations En-8, Time Constant of a Capacitive Circuit, En-10, RC Time Constant, and En-11, Long R-C Time Constant.

This RC board will allow us to demonstrate the charging and discharging curves of an RC circuit. The circuit consists of a battery, a two-way switch, a variable resistor, and a bank of switchable capacitors. When we close the switch this way, current flows through the resistor into the capacitors.

Flipping the switch the other way drains the capacitors through the resistor.

This oscilloscope will show the voltage on the capacitors as a function of time.

Here is the curve with 2 millifarads and 100 ohms resistance.

Here is the same capacitance with a resistance of 300 ohms.

Now we'll change the capacitance while keeping the resistance constant.

Equipment

1. RC circuit board.
2. Oscilloscope.
3. Appropriate electrical leads.

Demo 18-29 Relaxation Oscillator

A simple relaxation oscillator consists of a series RC circuit connected to a voltage source such as a battery. A neon bulb is connected across the capacitor such that it will flash when the voltage across the capacitor rises to the discharge value for the bulb, partially discharging the capacitor and starting the charging process again.† Such a relaxation oscillator, shown in *Figure 1*, is described and observed in the video as the capacitance and the resistance values in the circuit are changed. Similar devices can be used as flashers to call attention to dangerous conditions on a highway.

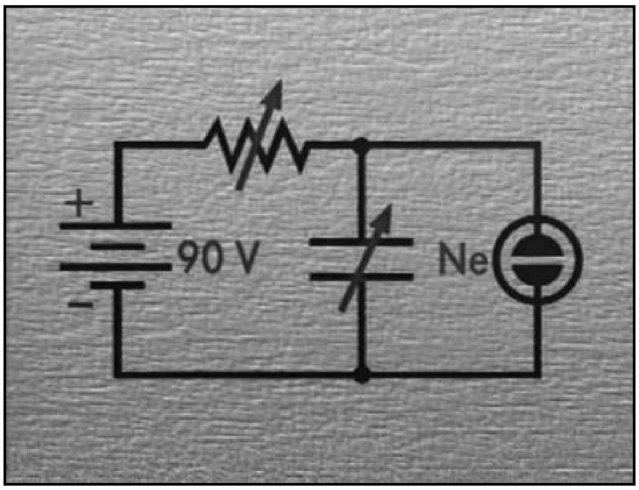

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration E-263, Charging Time of a Condenser in Series with a High Resistance—Flasher Circuit.

This relaxation oscillator uses an RC circuit to flash a neon lamp at regular intervals.

The circuit consists of a 90-volt battery, hooked in series with a variable resistor, and a variable capacitor. A neon bulb is hooked in parallel with the capacitor. The neon bulb flashes at a regular rate. Here's what happens as the resistance is increased.

Here's what happens as the capacitance is increased.

Equipment

1. Neon lamp.
2. Socket base for lamp.
3. Variable resistor.
4. Variable capacitor.
5. 90 volts of dry cells.
6. Appropriate electrical leads.