**HOW THE LINE-WIRES LIGHT LAMPS—A BEGINNER'S
LESSON IN ELECTRICITY.¹**

By F. F. GOOD,
Columbia University.

An effective scheme for introducing a practical study of electricity which we have employed for a number of years begins with the flow of the current in the line-wires. Two heavily insulated wires fifteen feet long are suspended at a convenient height above the lecture table with a throw-switch connection to the 110-volt current. At intervals of about fifteen inches insulation is removed to provide for making convenient contacts. These connections furnish a means of making direct connections on the line-wires at ten or twelve different points. There is very little danger of short circuiting the wires so long as they are kept reasonably tight. For the average lecture table the wires may be suspended from two uprights of wood, $1\frac{1}{2} \times 2\frac{1}{2}$ inches. They should be fastened against the ends of the table in such a way that they may be easily removed when not in use. For purposes of experimentation and as a safety device, two strong binding posts may be placed in the circuit for attaching pieces of 10, 15 or 20 ampere fuse-wire.

Here we have a dozen contact points as sources of current along the wires. They are in plain view of the class with provision for making quick attachments for a great variety of demonstrations and experiments. A voltmeter, an ammeter and a wattmeter may be connected to the wires at one end of the table. They should be movable and of large size with visible connections.

At the edge of the lecture table runs a gas pipe with gas cocks at intervals along the line. These gas cocks will represent on the gas line what the bared spaces do on the electric wires overhead. We may let the gas escape from one or more of these cocks and light them turning some on with a very small flame and others with the cock full open. This gas pipe ends at one end of the table. The other end passes through the floor to the basement and makes connection with the street gas mains. From there it leads back to one of the large city gas tanks. Gas is forced into the pipes by the weight of the heavy steel tank. The amount of gas flowing into our building depends of course upon how many gas cocks are opened and how wide they are opened. If we

¹Part of a Lecture-demonstration before the New York Physics Club.

should break the end of the large gas pipe a great volume would be allowed to escape.

Now when we consider how the gas flows we have a convenient and simple key for explaining how the electric current flows over the wires. In many important respects the electric current flows on the wires like the gas flows in the pipes. It is most convenient to consider that the electric current comes from the power house on the wire nearest to me and returns on the other wire. An examination of these wires will show that the two ends do not touch. The electric current cannot pass off the wire into the air. It must have some conductor to travel upon. Air, like glass, porcelain and rubber, is a very poor conductor. Copper is one of the best substances for carrying the electric current—a good conductor. Silver is even better than copper but it is too expensive. The return wire is like the drain pipe from the water faucet. The current under strong pressure is waiting its chance to get across to the second wire and return to the power house. The current has a chance to flow only when we place a conductor across the two wires—a kind of bridge.

I touch one wire with my thumb and the other with my first finger and note a slight tingling as a very little current passes through them for my fingers are not good conductors. If I dampen the ends of my fingers the contact is made more perfectly. When I again touch the wires more current goes through and I feel a sharp sting. The muscles tend to contract and pull away. Let us try a better conductor. Here is a 16-candle power carbon lamp with two copper wires soldered to it with ends bent to serve as hooks. When I hang it on the wires it lets enough current through to cause the filament to become glowing hot. Thus a lamp on the wires serves the same purpose as opening a gas cock on the gas pipe. By opening the gas cocks we let some of the gas escape from the pipe. By connecting a lamp across we let some of the electric current escape from one wire through the lamp to the other. Hanging more lamps on the wires at other places lets more current across. The ammeter at the end of the table indicates how much current is permitted to pass over. Hundreds of amperes are waiting for a chance to break across but each lamp lets only a small amount through. When we hang a very large lamp on it is like opening the gas cock very wide and letting a large flow pass through. If no lamps are on the wires no current can flow.

Even a lamp is not one of the best conductors. Let us see what happens when we touch the two wires with a small iron wire. A great splash of fire! The piece of iron wire bursts into a thousand sparks and they dance over the lecture table. For a moment a great lot of current leaped across on the good conductor, iron, and heated it beyond its melting point. It fell upon the table. This experiment caused the sudden bursting of our electric pipe but it was only for a moment. As soon as the wire was burned the path was again broken. This shows why the electric wires are very dangerous and should always be handled by some one who understands them. Buildings are sometimes burned because the wires accidentally touch each other at places where they should be well insulated. In buildings all wires should be well covered like these line-wires with some good insulating material.

On the voltmeter at the end of the table we may see how many volts of pressure this current has in its effort to burst over to the other wire. The voltmeter indicates 110 volts of pressure. Most house-currents have a pressure of 110 volts. The pressure on these wires always remains about 110 volts and for this reason is not very dangerous to touch with the fingers. The current which runs the street cars has about 550 volts pressure and is much more dangerous. If I should touch my fingers to the 550-volts current I might receive a bad burn. The high pressure currents must be handled with the greatest care. The pressure used in Sing Sing prison to electrocute murderers is about 2,000 volts. Some may imagine this to be a cruel death but 2,000-volts pressure instantly strikes a man unconscious, so the unfortunate fellow never knows anything about it.

On the lecture table you will see a great many lamps of different sizes, each having wires attached for hanging across the line-wires. The larger the lamp, the more current it lets through. The size of the lamp is marked on a small label. Here is the Midget Mazda lamp. If you watch the ammeter when I hang it over the wires you can see how much current it takes—about one-tenth of an ampere. The Midget Mazda gives as much light as eight candles so it is called an eight-candle power lamp. The filaments of Mazda lamps are made of the rare metal tungsten which becomes heated brilliantly white when enough current passes through it.

How much does it cost to burn the Midget for one hour?

In order to find the cost we must know how many watts are being used. If we know the volts pressure, 110, and how many amperes the lamp lets through we can easily find the watts.

Volts $\times$ Amperes = Watts.

The Midget requires 110 volts and it takes one-tenth of an ampere.

110 volts $\times$ .1 ampere = 11 watts.

Now the electric company charges 10 cents for a 1,000-watt current for each hour—10 cents per kilowatt hour. At this rate one cent would pay for a 100-watt current for an hour. The Midget Mazda takes about 10 watts and would therefore cost about one-tenth of a cent to operate it one hour. It could be run ten hours for one cent.

Our next lamp is twice as large as the Midget. It takes twice as much current, .2 of an ampere, to heat its filament. It is a 16-candle power lamp, and so we have other lamps 32 C. P., 48 C. P., 96 C. P., 150 C. P., 250 C. P., and 500 C. P. We can find how much it costs to operate these in the same way that we did the Midget if we multiply the volts by the amperes and find how many watts each lamp uses.

8 candle power	.....110 volts $\times$ .1 ampere	= 11 watts
16 candle power	.....110 volts $\times$ .2 ampere	= 22 watts
32 candle power	.....110 volts $\times$ .4 ampere	= 44 watts
48 candle power	.....110 volts $\times$ .5 ampere	= 55 watts
96 candle power	.....110 volts $\times$ 1. ampere	= 110 watts
150 candle power	.....110 volts $\times$ 1.5 amperes	= 165 watts
250 candle power	.....110 volts $\times$ 2.5 amperes	= 275 watts
500 candle power	.....110 volts $\times$ 5. amperes	= 550 watts

If it costs one cent per hour for a 100-watts current, what will be the cost of each lamp in this series?

The old style of lamps have carbon filaments and they do not give as much light as the tungsten filaments. The tungsten filament lamps are more expensive at first cost but they give more than two times as much light for the same amount of current used. Let us wrap this 60-watt Mazda lamp in a cloth and crush it with a board in order to examine the tungsten filaments. When a bulb is broken the loud report is caused by the sudden inrush of air as the glass breaks, for the inside is a vacuum. A filament would soon burn up if the air is not taken out of the bulb. Some lamps are now filled with nitrogen gas to prevent the filament from burning. We might perform an experiment to

see how long the tungsten lamp will burn if the tip of the bulb is snapped off and the air allowed to enter. With air inside, the filament breaks almost as soon as it touches the electric wires and the bulb fills with tungsten smoke.

The tungsten filament in this 60-watt lamp is about two feet long. My 11-year-old friend, Jack, dropped in the other day when I was experimenting with some lamps. He measured the thickness of the filament with a micrometer screw and concluded that it was about half as thick as a hair and one-fourth as thick as a No. 50 cotton thread. It looks much thicker than that when it is heated on the line-wires. Tungsten metal is better than other metals for making lamp filaments because it will withstand so much heat without melting. The temperature must be 5,300 degrees before tungsten melts. That explains how it is possible to make these little filaments white-hot without destroying them.

On the table is a series of lamps with carbon filaments for comparison with the tungsten-filament lamps.

3 candle power	.....110 volts x .1 ampere	= 11 watts
6 candle power	.....110 volts x .2 ampere	= 22 watts
12 candle power	.....110 volts x .4 ampere	= 44 watts
16 candle power	.....110 volts x .5 ampere	= 55 watts
32 candle power	.....110 volts x 1. ampere	= 110 watts

The effectiveness of an exercise like the foregoing will depend to a large extent upon what lessons follow this one and upon the educational ingenuity of the teacher. This work should be supplemented by a laboratory exercise in which students are given two dry cells, insulated wire, voltmeters, lamps, bells and motors. The laboratory project is to wire up a small electric lighting and power system and measure the current required to operate lamps, bells and motors.

It will, of course, be advisable and necessary to devote much of the next hour to general discussion and review work. The overhead line-wires will suggest an endless variety of experiments for purposes of review and for widening the students' electrical horizon. A second profitable lesson for purposes of general education may be centered around resistance wires and heating utensils.