Third Week.
Ohm's Law; Electric Power and Energy; Wire; Measurement of Resistance.

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1

QUESTION #1. What is the unit of quantity, current, pressure and resistance?

ANSWER #1. The unit of quantity is the Coulomb. It is the amount of electricity that will flow past any point in a circuit, in one second, when the current strength is one ampere; therefore: to find the total quantity of electricity in coulombs passing through a circuit in a given time, multiply the current strength, in amperes, by the time, in seconds; to find the average current strength in amperes, divide the quantity, in coulombs, by the time, in seconds; to find the time required for a given quantity of electricity to pass a point in a circuit, divide the quantity of electricity, in coulombs, by the rate of flow in amperes

If: I = current (in amperes)
Q = quantity (in coulombs)
t = time (in seconds)

$$Q = I \times t$$

$$I = \frac{Q}{t}$$

$$t = \frac{Q}{I}$$

The unit of current is the Ampere. It is the rate of flow of one coulomb of electricity per second.

The unit of pressure is the Volt. One volt is the pressure require to force one ampere to flow through a resistance of one ohm.

The unit of resistance is the Ohm. A wire offers one ohm resistance when a pressure of one volt is required to force a current of one ampere through it.

QUESTION #2. Write Ohm's Law and give Algebraic symbols and equations.

ANSWER #2. There are three factors which are present in every electrical circuit, in which a current is flowing: The pressure causing the current to flow, the resistance which must be overcome, and the current strength which is maintained. These factors have a definite relation, and this relation has been stated by Georg Simon Ohm, who discovered the relation, and this statement, called Ohm's Law, is the most important equation of the electrical science, as all calculations in electrical engineering are based on it.

Ohm's Law states:

First: The current in any electric circuit is equal to the electromotive force applied to the circuit, divided by the resistance of the circuit.
Second: The current strength in any circuit increases or decreases directly as the E.M.F., or potential

ANSWER #2. Continued.

difference, increases or decreases, when the resistance is constant. With a constant pressure the current increases as the resistance is decreased, and decreases as the resistance is increased. Briefly, the current varies directly as the E.M.F. and inversely as the resistance.

Third: The electromotive force required to maintain a certain current strength in a circuit of known resistance, is numerically equal to the product of the current and the resistance.

The Algebraic symbols for the three factors are:

I = Current (in amperes)
E = Pressure (in volts)
R = Resistance (in ohms)

The Algebraic equations for Ohm's Law are:

$$I = \frac{E}{R}$$

$$E = I \times R$$

$$R = \frac{E}{I}$$

QUESTION #3. Define the Standard Unit of Current, Pressure, and Resistance.

ANSWER #3. The Standard Ohm is the resistance of a column of pure mercury 106.3 centimeters long, of uniform cross-section, and weighing 14.4521 grams at 0° Centigrade.

The Standard Volt is defined as 1/1.0183 of the voltage of a Standard Weston cell under standard conditions.

The Standard Ampere is the rate of flow of a steady current which one standard volt pressure forces through one standard ohm resistance. It is that steady current which, when passed through a solution of nitrate of silver in water, in a silver voltameter, deposits silver at the rate of 0.001118 gram per second.

QUESTION #4. What is meant by the terms, "Difference in Potential", or "Drop in Potential", or merely "Drop"?

ANSWER #4. Before a current can flow in a circuit, there must be a "Difference in Potential," that is, the electrical pressure in one part of the circuit must be greater than in another part. Nature tends to equalize, so, if no more pressure were supplied, or generated, the current would continue to flow until the pressure at these two points was equal, until there was no "Difference in Potential." The E.M.F. is the total pressure generated. The "Difference in Potential" is any part of the E.M.F. It is that portion of the E.M.F. used in causing the current to flow. The E.M.F. is the sum of all the "Drops in Potential" The "Drop in Potential" is the volts lost. Pressure could not be lost unless a current had been transmitted by it. The terms, "Difference in Potential," "Drop in POTENTIAL," and "Drop" are synonomous.

QUESTION #5. How many volts are needed to force 4 amperes through 58 Ohms?

ANSWER #5. Formula: $E = I \times R$

therefore: $E = 4 \times 58 =$ 232 volts. Ans

QUESTION #6. What current is produced through a resistance of 2.5 ohms by an Electromotive Force of 46 volts?

ANSWER #6. Formula: $I = \frac{E}{R}$

therefore: $I = \frac{46}{2.5} =$ 18.4 amperes. Ans.

QUESTION #7. Through what resistance will 900 volts produce 4.5 amperes?

ANSWER #7. Formula: $R = \frac{E}{I}$

therefore: $R = \frac{900}{4.5} =$ 200 ohms. Ans.

QUESTION #8. Define the Ampere-Hour. A current of 3.5 amperes was maintained by a cell for 4 hours. What quantity (Ampere-Hours) of electricity has been used?

ANSWER #8. The Ampere-Hour is a measurement of quantity of electricity used in a circuit. One ampere-hour is the quantity of electricity that would pass any point in a circuit in one hour, when the strength of the current is one ampere. One ampere-hour is equal to 3600 coulombs.

Formula: Quantity (in ampere-hours) = amps. x hours

therefore: Quantity = 3.5 x 4 = 14 Ampere-Hours. Ans.

QUESTION #9. What is meant by Milliampere, Microampere, Megohm, Kilovolt?

ANSWER #9. When computing unknown values of electrical circuits, when the known values are very large or very small, the use of the units, involves too many figures, so in that case we make use of parts of the units, or many of the units.

A milliampere is one thousandth of one ampere.
A microampere is one millionth of one ampere.
A megohm is one million ohms.
A kilovolt is one thousand volts.

QUESTION #10. Express: 1.5 amperes in Milliamperes, Microamperes. 10 Milliamperes in Amperes. 5 ohms in Megohms. 0.5 Megohms in Ohms. 7 Volts in Kilovolts. 0.00035 volts in Kilovolts.

ANSWER #10. Since one milliampere is one thousandth of one ampere, 1.5 amperes must equal 1000 x 1.5 = 1500 milliamperes. Ans

ANSWER #10. Continued.

Since one ampere equals one million microamperes, 1.5 amperes must equal 1.5 times 1,000,000 or 1.5 times $10^6$ which equals $1.5 \cdot 10^6$ or 1,500,000 microamperes. Ans.

Since one milliampere is equal to one thousandth of one ampere, 10 milliamperes must equal 10 divided by 1000 or $10^1$ divided by $10^3$ which equals $10^{-2}$ or .01 amperes. Ans.

Since one ohm is equal to one millionth of a megohm, 5 ohms must equal 5 divided by 1,000,000 or 5 divided by $10^6$ which equals $5 \cdot 10^{-6}$ or .000005 megohms. Ans.

Since one megohm equals one million ohms, .5 megohm must equal .5 times 1,000,000 or $5 \cdot 10^{-1}$ times $10^6$ which equals $5 \cdot 10^5$ or 500,000 ohms. Ans.

Since one volt equals one thousandth of a kilovolt, 7 volts must equal 7 divided by 1000 or 7 divided by $10^3$ which equals $7 \cdot 10^{-3}$ or .007 kilovolts. Ans.

Since one volt equals one thousandth of a kilovolt, 0.00035 volts must equal 0.00035 divided by 1000 or $3.5 \cdot 10^{-4}$ divided by $10^3$ which equals $3.5 \cdot 10^{-7}$ or .00000035 kilovolts. Ans.

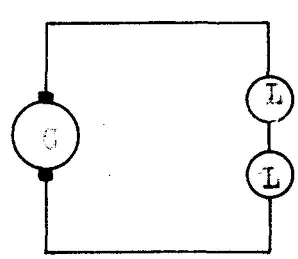
QUESTION #11. What is meant by Series, Parallel, and Series-Parallel circuits? Show by conventional diagram examples of each, using lamps and a Generator supply.

ANSWER #11.

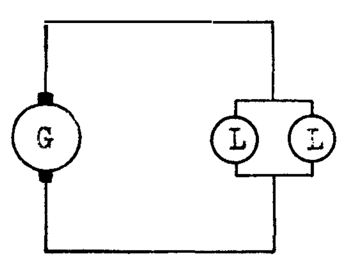
A series circuit is one in which the pieces are connected in tandem. See conventional diagram of a series circuit below.

A parallel circuit is one in which the pieces are connected side by side. See conventional diagram of a parallel circuit below.

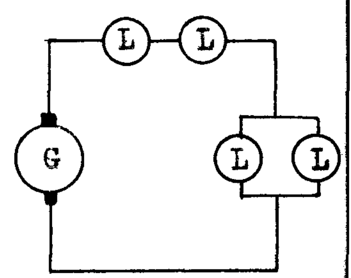
A series-parallel circuit is one in which one or more pieces are connected in series with a parallel combination of pieces. See conventional diagram of a series-parallel circuit below.



Conventional diagram of a Series Circuit.



Conventional diagram of a Parallel Circuit.



Conventional diagram of a Series-Parallel Circuit.

QUESTION #12. What is the Resistance, Voltage and Current relations in Series Combinations? Parallel Combinations?

ANSWER #12. In a series combination, the resistance is the sum of the resistances of the separate parts; the voltage across the series combination is the sum of the voltages across the separate parts; the current through the combination is the same as the current through the separate parts.

In a parallel combination, the resistance is less than the resistance of the smallest resistance; the voltage across the combination is the same as the voltage across each branch; the current through the combination is the sum of the currents through all the branches.

QUESTION #13. Three resistances of 8 ohms, 3 ohms and 10 ohms respectively, are joined in Series across a 110 volt line. What current flows through the Series Circuit? What is the voltage across each Resistor?

ANSWER #13. The total resistance of the circuit is the sum of the resistances of the separate parts: 8 plus 3 plus 10 equals 21 ohms, total resistance of the circuit.

To find the current in the series circuit, we divide the line voltage by the total resistance:

Formula: $$I = \frac{E}{R}$$

therefore: $$I = \frac{110}{21} = \underline{5.238 \text{ amperes. Ans.}}$$

To find the voltage across each resistor, we multiply the resistance of that part by the current flowing through that part, and, as the current through a series combination is the same as that through each part, we multiply 5.238 amperes by each resistance:

Formulae: $E_1=I_1R_1$, $E_2=I_2R_2$, $E_3=I_3R_3$.

| | | |
|---|---|---|
| 5.238 | 5.238 | 5.238 |
| 8 | 3 | 10 |
| 41.904 Volts | 15.714 Volts | 52.38 Volts |
| Ans. | Ans. | Ans. |

QUESTION #14. What is the Rule for finding the resistance of a Parallel circuit with more than one resistor in the circuit? When Resistors are equal in value? Unequal in value?

ANSWER #14. It must be clearly understood that the total resistance of a parallel is always less than the resistance of the smallest resistor, therefore, to find the total resistance, find the reciprocal of the sums of the reciprocals of the separate resistors.

To find the total resistance of a parallel circuit in which all of the resistors have the same resistance, divide the resistance of one of the resistors by the total number of resistors.

To find the total resistance when the parts are unequal, follow the rule given in part one of this question.

QUESTION #15. Resistors of 2 ohms, 5 ohms and 10 ohms are hooked in Parallel. What is the Resistance of the combination?

ANSWER #15. Rule: To find the total resistance of a parallel combination, find the reciprocal of the sums of the reciprocals of the separate resistances. therefore:

$$\frac{1}{\frac{1}{2} + \frac{1}{5} + \frac{1}{10}} = \text{total resistance.}$$

L.C.D. by inspection is 10.

$$\frac{1}{2} = \frac{5}{10}. \quad \frac{1}{5} = \frac{2}{10}. \quad \frac{1}{10} = \frac{1}{10}. \quad \frac{5+2+1}{10} = \frac{8}{10}.$$

$$\frac{1}{\frac{8}{10}} = \frac{10}{8} =$$ 1.25 ohms. Resistance of combination.Ans.

QUESTION #16. A circuit has four branches of 6, 9, 8 and 12 ohms. If 6 amperes flow in the circuit containing 9 ohms, what current will flow in each of the others?

ANSWER #16. To find the voltage across the 9 ohm resistor, we multiply the current by the resistance: 6 x 9 equals 54 volts.

As the voltage, in a parallel combination, is the same across each branch of the circuit, to find the current across each of the other branches, we divide the voltage of the branch by the resistance of the branch:

Formulae: $I_1 = \frac{E_1}{R_1}$. $I_2 = \frac{E_2}{R_2}$. $I_3 = \frac{E_3}{R_3}$. $I_4 = \frac{E_4}{R_4}$.

$I_1 = \frac{54}{6} =$ 9 amperes. Ans.

$I_2 = \frac{54}{9} =$ 6 amperes. Ans.

$I_3 = \frac{54}{8} =$ 6.75 amperes. Ans.

$I_4 = \frac{54}{12} =$ 4.5 amperes. Ans.

QUESTION #17. What are the uses of Voltmeters, Ammeters? How are they hooked in a circuit?

ANSWER #17. A voltmeter is used in a circuit to measure the electrical pressure in that circuit. Since a voltmeter is to register the pressure, and not the current flowing through the circuit, it is tapped on to the line. The circuit is not disturbed by the voltmeter.

An ammeter is used in a circuit to measure the actual current flowing through the circuit, and to to this the circuit must be opened and the ammeter inserted into the circuit. Extreme care must be taken

ANSWER #17. Continued.

to avoid tapping an ammeter on to a line, as the great rush of current, in this case, would ruin the instrument.

An ammeter and a voltmeter may be used in conjunction with each other to measure the resistance of the circuit, by inserting the ammeter in series with the circuit, and by placing the voltmeter in parallel with the circuit, that is, by tapping it around the circuit. The reading on the voltmeter is divided by the reading on the ammeter to find the resistance of the circuit in ohms.

QUESTION #18. What is the Unit of Power? What is the common Units of electrical Work or Energy?

ANSWER #18. The Unit of Power is the watt. It is the power used when one volt causes one ampere of current to flow. It can readily be found by multiplying the current in amperes by the pressure in volts.

The unit of Work is the joule. It is a watt-second.

These units are too small for use with the output of most electrical machinery, so we use a larger unit.

The kilowatt is equal to one thousand watts. The kilowatt-hour is equal to 3,600,000 watt-seconds or joules.

QUESTION #19. Give Algebraic Symbols and Equations for finding Power consumed in a circuit.

ANSWER #19. When:

P is power (in watts)
I is current (in amperes)
E is pressure (in volts)

An Algebraic Equation may be stated:

$$P = IE$$

Variations of this equation may be expressed by substituting in Ohm's Law, making it possible to compute the power when only two of the three factors are known:

Since: $P = IE$ and $E = IR$, P must also equal $I(IR)$ or $I^2R$.

Since: $P = IE$ and $I = \frac{E}{R}$, P must also equal $(\frac{E}{R})E$ or $\frac{E^2}{R}$.

Therefore: $P = IE = I^2R = \frac{E^2}{R}$. Of course the same result may be obtained by computing the unknown factor in the power equation by Ohm's Law and then finding the power consumed by the first equation, but the use of the equations set forth above will save much mathematical work.

QUESTION #20. What power is consumed by a Motor on a 110 volt circuit if it requires 7 amperes to operate?

ANSWER #20. Formula: P = IE

therefore: P = 7 x 110 = 770 watts. Ans.

QUESTION #21. What is meant by Kilowatt, Electrical Horsepower? Why are these terms used to express Output of Electrical Machinery?

ANSWER #21. A kilowatt is equal to 1000 watts. 1 watt would be 1/1000 of a kilowatt, or .001 kilowatt.
An electrical horsepower is equal to 746 watts or .746 kilowatt.
These terms are used to express the Output of Electrical Machinery because the watt is usually too small to be of value when computing the power consumed in an electrical circuit.

QUESTION #22. The Power of a 15 Horsepower Motor could be rated as how many Kilowatts? Watts?

ANSWER #22. Since: 1 Horsepower = .746 Kilowatt,

15 Horsepower = .746 x 15 = 11.19 Kilowatts.Ans

Since: 1 Horsepower = 746 watts.

15 Horsepower = 746 x 15 = 11,190 watts. Ans.

QUESTION #23. What is the Horsepower, Kilowatt and Watt output of a Generator which must deliver 9 amperes at 140 volts?

ANSWER #23. Formula: P = IE

therefore: P = 9 x 140 = 1260 watts.Ans.

746 watts = 1 Horsepower,

therefore: 1260 watts = $\frac{1260}{746}$ = 1.689 Horsepower.Ans

1000 watts = 1 Kilowatt,

therefore: 1260 watts = $\frac{1260}{1000}$ = 1.260 Kilowatts.Ans.

QUESTION #24. What instrument is used to measure the Power consumed in a circuit? What does it consist of and how hooked in a circuit?

ANSWER #24. The instrument that measures the power consumed in a circuit is called the wattmeter. It is a combination of a voltmeter and an ammeter, as the power in watts is the product of the current times the pressure. The ammeter part is of low resistance to measure the current flowing through the circuit, and the voltmeter part is of high resistance to measure the

ANSWER #24. Continued.

pressure in the circuit. Most wattmeters have four terminals, two for the ammeter side, and two for the voltmeter side. The ammeter side is hooked in series with the part of the circuit being measured, and the voltmeter part of the wattmeter is hooked in parallel across the part being measured. The same care must be taken in connecting a wattmeter in a circuit, that is taken in connecting an ammeter in a circuit. If the ammeter side is connected in parallel with the circuit, there will be a great rush of current and the meter will be burned up. The indicator on the wattmeter is regulated to read the product of the current times the pressure, which is the power in watts.

QUESTION #25. How is the Efficiency of Electrical Appliances found? What terms is Efficiency expressed in?

ANSWER #25. The efficiency of an electrical appliance is the ratio of the output of the appliance to the input of the appliance. Therefore, to find the efficiency of the appliance, compute the value of the ratio, that is divide the output by the input to find the per cent efficiency. There is heat generated in any electrical circuit and this heat, in most cases is lost energy. This lost heat is the cause of loss of efficiency in an electrical appliance. The only appliance that may be termed one hundred per cent efficient is one which makes use of the heat generated by the flow of current, such as an electrical heater, or an electric iron.

The output of an appliance is less than the input so the value of the ratio would be less than unity, therefore the fraction is stated in terms of percentage.

The input and the output must be stated in like terms. If the input in watts, and the output in horsepower or kilowatts, is known before proceeding to find the value of the ratio, the watts must be changed to horsepower or kilowatts, or vice versa.

QUESTION #26. What Efficiency has a 15 Horsepower Motor which requires 74 amperes at 240 volts?

ANSWER #26. The input is the power consumed from the line:

Formula: $P = IE$

therefore: $P = 74 \times 240 = 17{,}760$ watts input.

The output is 15 Horsepower. Before we can find the efficiency, we must change the Horsepower to watts, so that we compare like terms:

1 Horsepower = 746 watts,

15 Horsepower = 15 x 746 = 11,190 watts output.

ANSWER #26. Continued.

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}.$$

$$\text{Efficiency} = \frac{11,190}{17,760} = .63006$$

Therefore, the Motor is 63% efficient. Ans.

QUESTION #27. What Efficiency of transmission for a circuit which receives 13 Kilowatts from a Generator at one end and delivers 11.5 Kilowatts to a Motor at the other end?

ANSWER #27. The input is 13 Kilowatt and the output is 11.5 Kilowatts. They are like terms, so:

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}.$$

$$\text{Efficiency} = \frac{11.5}{13} = .8846$$

Therefore, the efficiency of transmission is 88%.Ans.

QUESTION #28. What measure is used for Wire? Why? What is the Unit of this measure?

ANSWER #28. The circular measure is used for wire. It is used because most wire is round, and to measure the cross-sectional area in square inches would be very inconvenient. The unit of the circular measure is the circular unit of area, which is the circular mil. One circular mil is the area of a circle whose diameter is 1 mil in length. The mil is one thousandth of of one square inch. The term "mil" is used because "mil" always means 1/1000. Just as in the coinage of the United States: One mill is equal to 1/10 of 1 cent. One cent is equal to 1/100 of 1 dollar, so 1 mill is equal to 1/10 x 1/100 or 1/1000 of one dollar.

QUESTION #29. How is the Circular Mil Area of a wire obtained? How is the Area in square inches obtained from a wire or circle?

ANSWER #29. The circular mil area of a wire is obtained by squaring the diameter in mils. If the diameter of the wire is expressed in inches or fractions of an inch it is advisable to change the inches or fractions of an inch to mils before squaring the diameter, because, though there are 1000 mils in one inch (linear measure) there are 1000 x 1000 or 1,000,000 circular mils in one square inch.

The area of a wire or a circle in square inches may be obtained by the formula for finding the area of a circle: Pi x $r^2$, where Pi equals 3.1416 and r equals the radius of the circle.

QUESTION #30. What is the Circular Mil Area of a wire 0.055 inch in diameter? What is the diameter of a wire containing 1450 circular mils?

ANSWER #30. One inch is equal to 1000 mils, therefore 0.055 inch is equal to 1000 times 0.055 or 55 mils.

Squaring the diameter in mils:

55 x 55 = 3,025 circular mils. Ans.

When the circular mil area is known, finding the diameter in mils, is the reverse process of finding the circular mil area when the diameter in mils is known; therefore, to find the diameter in mils of a wire containing 1450 circular mils, we find the square root of 1450:

```
             3  8. 0  7  8
          √14'50.00'00'00
         :  9
         :  5 50
      68:   5 44
         :     6 00 00
    7607:      5 32 49
         :       67 51 00
   76148:        60 91 84
         :        6 59 16
         :
```

Therefore, the diameter is 38.078 mils, which is equal to 38.078 divided by 1000, or .038078 inches. Ans

QUESTION #31. What is the Unit of wire? Define the Unit.

ANSWER #31. The unit of wire is the mil-foot. It is a wire having a cross section area of one circular mil and a length of one foot. It is used in the calculation of the resistance of a length of wire.

QUESTION #32. The resistance of any wire is equal to the resistance of one mil-foot of the same kind of wire times the length of the wire in feet divided by the square of the diameter in mils. The Algebraic symbols and equation is as follows:

R is the resistance of wire in ohms.
K is the resistance of 1 mil-ft. in ohms.
l is the length in feet.
d is the diameter in mils.

$$R = \frac{Kl}{d^2}$$

The K varies according to the kind of metal used in the wire. The Kl is divided by $d^2$ because the resistance of a wire is inversely proportional to the cross section area.

QUESTION #33. What is the resistance of 3 miles of copper wire three sixteenths of an inch in diameter?

ANSWER #33. Formula: $R = \frac{Kl}{d^2}$

There are 5280 feet in 1 mile, so there are 3 x 5280 feet, or 15,840 feet in 3 miles.

The resistance of 1 mil-foot of copper at 20°C. is 10.4 ohms.

K = 10.4 ohms.
l = 15,840 feet.

Kl =

```
   15840   (multiplying)
    10.4
   63360
 158400
 164736.0
```

$\frac{3}{16}$ of an inch equals .1875 inches. There are 1000 mils in one inch, therefore, in .1875 inch, there are 1000 times .1875 or 187.5 mils.

$d^2$ =

```
    187.5
    187.5
     9375   (multiplying)
   13125
  15000
  1875
  35156.25 circular mils.
```

$\frac{Kl}{d^2}$ =

```
                    4.685
35156.25./164736.00.000
          140625 00
           24111000
           21093750
            3017250 0
            2812500 0
             204750 00
             175781 25
              28968 75
```

Therefore, there are 4.685 ohms resistance in 3 miles of copper wire three sixteenths of an inch in diameter. Ans.

QUESTION #34. What is the resistance of 1000 feet of 4000 circular mil wire? 9000 circular mil wire? What size single conductor wire (using B & S Tables) would have the same resistance as the 4000 circular mil wire of the same length?

ANSWER #34. Following the formula: Kl would equal 10.4 times the length in feet, or 10.4 times 1000 which equals 10,400. Dividing Kl by the $d^2$, which we already have:

10,400 divided by 4000 is equal to 104 by 40:

```
        2.6 ohms.Ans.
   40/104.0
       80
       24 0
       24 0
       ====
```

Proceeding with the second part the same way:

10,400 divided by 9000 is equal to 104 by 90:

```
        1.1555 ohms.Ans.
   90/104.0000
       90
       14 0
        9 0
        5 00
        4 50
           500
           450
            500
            450
             50
```

There is no wire shown in the B & S Tables with a circular mil area of 4000 circular mils and a resisance of 2.6 ohms for 1000 feet, the closest one to it being #14 with a circular mil area of 4,106.8 circular mils and a resistance of 2.525 ohms per 1000 ft. Ans.

QUESTION #35. It is desired to install a conductor to carry 60 amperes. What size copper wire should be used?

ANSWER #35. It is seen from the Table of "Allowable Carrying Capacities of Wires" that a #4 with rubber insulation, #6 with varnished cloth insulation, or #6 with other insulation, would carry a current of 60 amperes safely within the limits prescribed by the National Electrical Code of 1923.

QUESTION #36. Draw "TP" Transmitter.

ANSWER #36. See diagram on separate sheet.

QUESTION #36. Explain the "Ammeter-Voltmeter Method" of measuring resistances. Show by sketch two methods of connecting a voltmeter and an ammeter in a circuit to determine the resistance of a lamp. Which is the best method of measuring a high resistance? A low resistance? Why?

ANSWER #36. One of the simplest methods of determining the resistance of an appliance is by the "Ammeter-Voltmeter" method. A current is sent through the resistor and measured by an ammeter and the voltage drop across the resistor is measured. To find the resistance it is only necessary to apply Ohm's Law: R equals E divided by I. But care must be taken to connect the meters properly so that there will be no appreciable error. There are two methods. One is to insert an ammeter in series with the resistor and tap a voltmeter around the resistor. The fault with this method is that the ammeter will read high by as much current as will flow through the voltmeter.

The other method is to connect an ammeter in series with the resistor and tap a voltmeter around both the resistor and the ammeter. In this case the ammeter reads only the current flowing through the resistor but the fault is that the voltmeter will read high by as much as the voltage drop across the ammeter.

The second method is best for measuring a high resistance providing a high voltage is used, because the voltage across the ammeter would be too small to affect appreciably the reading of the high reading voltmeter. Most ammeters have a low resistance.

The first method is best for measuring a low resistance because the error in this method is in the ammeter reading, which reads too high, by the amount of current flowing through the voltmeter. Since most voltmeters have a high resistance, the amount of current flowing through it would be too small to affect appreciably the reading of the ammeter.

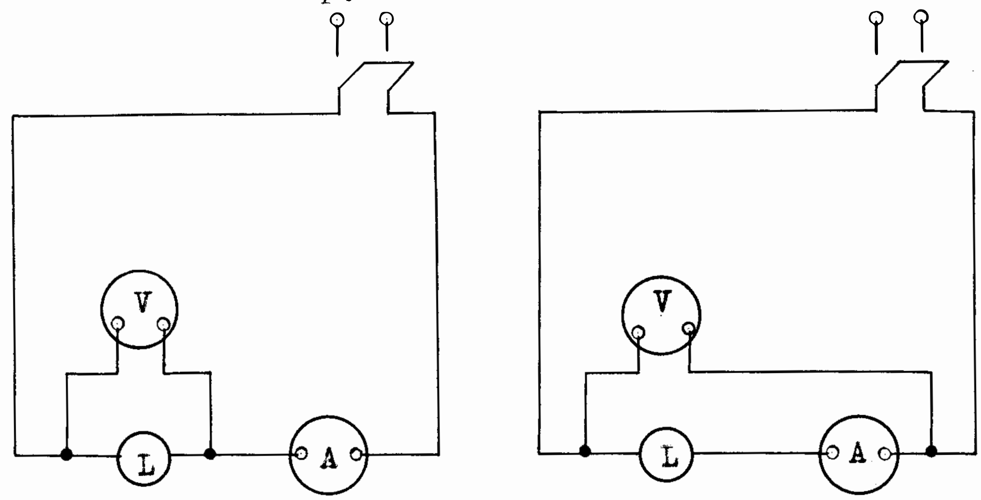
To find the error in the first method: Find the current flowing through the voltmeter by dividing the reading of the voltmeter by the resistance of the voltmeter. Next, subtract the current through the voltmeter, from the reading of the ammeter, to find the current through the resistor. The error is the ratio of the current through the voltmeter to the current through the resistor, stated in per cent.

To find the error in the second method: Find the voltage drop across the ammeter by multiplying the reading of the ammeter by the resistance of the ammeter. Next, subtract the drop across the ammeter from the reading on the voltmeter, to find the drop across the resistor. The error is the ratio of the drop across the ammeter to the drop across the resistor. It is thus plain to see that the first method is best for measuring a low resistance with a low potential and that the second method is best for measuring a high resistance with a high potential.

One disadvantage of the "Ammeter-Voltmeter" methods is that the voltmeter must be accurately calibrated to read volts and the ammeter must be accurately calibrated to read amperes.

ANSWER #36. Continued.

Sketch of the two methods of connecting a voltmeter and an ammeter in a circuit to determine the resistance of a lamp:




First Method. For measuring low resistances.

Second Method. For measuring high resistances.

QUESTION #37. A resistance is to be measured. A 3 volt Voltmeter of 300 ohms resistance and an ammeter of 0.0009 ohm resistance. (The voltmeter is shunted around the unknown resistance and the ammeter). The voltmeter reads 2.0 volts and the ammeter reads 50.0 amperes. What percent error is made in this measurement?

ANSWER #37. $E_d$ across Resistor and Ammeter = 2 volts.

$E_d$ across Ammeter, by Ohms Law (E = IR) .0009 x 50 = .045 volts.

$E_d$ across resistor equals the difference between total $E_d$ and $E_d$ across ammeter: 2 - .045 = 1.955 volts.

Formula:

$$\text{Percent error} = \frac{E_d \text{ across ammeter}}{E_d \text{ across resistor}} \times 100$$

Therefore:

$$\text{Percent error} = \frac{.045}{1.955} \times 100 = \underline{2.3\%\ \text{error.Ans}}.$$

QUESTION #38. Explain the "Fall of Potential-Method" of measuring resistance. What is needed for this method? Show by sketch how the Meters and Resistors are connected in the circuit.

ANSWER #38. In this method, a known resistance is connected, in series with the unknown resistance. The laws of series circuits state that the current is the same throughout a series circuit. And Ohm's Law tells us that, if the current is constant, the voltage will vary directly with the resistance. Therefore, it is only necessary to connect a voltmeter around the known resistance, take that reading; connect the same voltmeter around

ANSWER #38. Continued.

the unknown resistance, and take that reading. The value of the unknown resistance will have the same ratio to the known resistance as the voltage drop across the unknown resistance will have to the voltage drop across the known resistance. This may be stated in the form of an equation:

$$\frac{R_x}{R} = \frac{V_2}{V_1}$$

Where: $R_x$ = Unknown resistance.
$R$ = Known resistance.
$V_2$ = $E_d$ across unknown resistance.
$V_1$ = $E_d$ across known resistance.

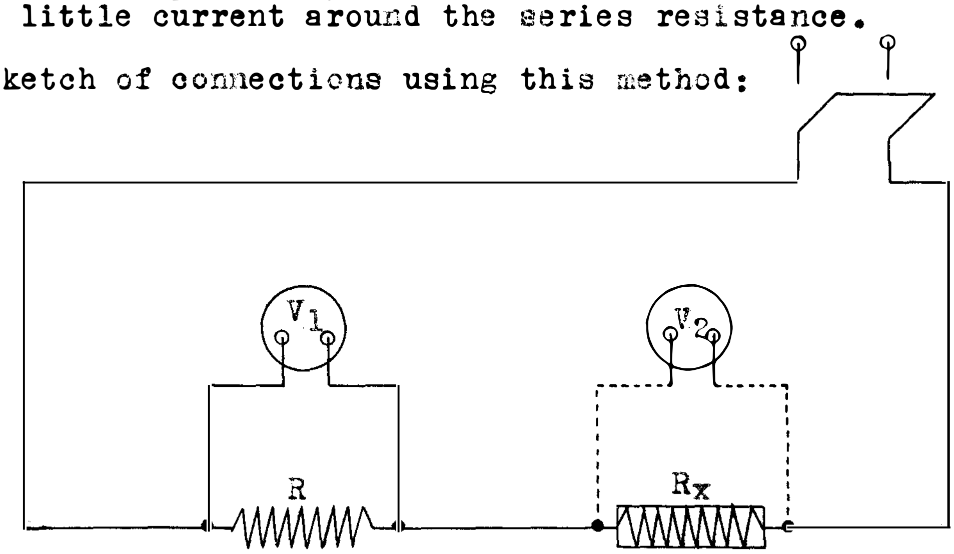
This is the same as a proportion:

$$R_x : R :: V_2 : V_1$$

Since R, $V_2$, and $V_1$ are known, to find $R_x$ we divide the product of the means (R and $V_2$) by the known extreme ($V_1$).

For this method is needed: A known or standard resistance, a source of supply, and a voltmeter. The voltmeter need now be accurately calibrated, provided the deflections are proportional to the voltage and it is an accurate method of measuring low resistances if the voltmeter has a high resistance, or is replaced by a galvanometer. This shunts very little current around the series resistance.

Sketch of connections using this method:




QUESTION #39. What are the advantages and disadvantages of measuring Resistors by the Fall of Potential-Method?

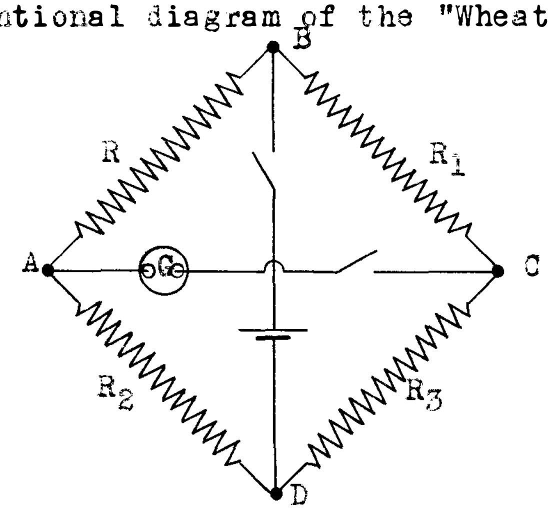
ANSWER #39. The advantages of this system are: That it is not necessary to have an accurately calibrated voltmeter so long as the deflections are proportional to the voltage; low resistances may be accurately measured provided the voltmeter has a high resistance, or is replaced by a galvanometer, which shunts very littl current around the series resistance. Using a potentiometer, no current is shunted around the resistance therefore low resistances may be measured accurately.

The disadvantage of this method is that one of the resistances must be known. Such a resistor, the resistance of which is standard, is very seldom found outside a laboratory, therefore the value of the unknown resistor will be only a close approximate.

QUESTION #40. What does the "Wheatstone Bridge" consist of? Draw conventional diagram and explain how the value of an unknown resistance is determined by this method. Show the fundamental equation of the "Wheatstone Bridge".

ANSWER #40. The "Wheatstone Bridge" consists of a loop of four resistances, one of which is unknown. A battery supplies the current and is connected so that the current is divided into the two branches, returning to the battery from the other side of the loop. A key is inserted in the battery circuit to break the circuit. A galvanometer is connected across the two branches and a key is inserted in series with the galvanometer.

Conventional diagram of the "Wheatstone Bridge":




The current enters at B, divides into two parts, one flowing through the branch of R and $R_2$, the other flowing through the branch of $R_1$ and $R_3$. Both keys are closed and the resistors R, $R_1$ and $R_2$ (which are variable) are varied until the galvanometer shows no reading. This "balances" the bridge. Points A and C then have the same potential, therefore the voltage drop across R and $R_1$ must be equal and the voltage drop across R2 and R3 must be equal, there; fore: The ratio of R to R2 must equal the ratio of R1 to R3. This is the fundamental equation of the "Wheatstone Bridge":

$$R : R^2 :: R1 : R3$$