THEORY MODULE

TEST PREPARATION
STUDY GUIDE

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GETTING TO KNOW THOSE LITTLE ELECTRONS

OHMS LAW
AND OTHER CALCULATIONS

THE THREE BASIC UNITS OF ELECTRICITY

In the science of electricity, three basic units are used to measure just about all electrical activity. They are:

VOLTAGE
CURRENT
RESISTANCE

To best illustrate what each of these does for electricity let's compare them to how liquids behave. Liquid in a pail or tank exerts pressure on the faucet (measured in pounds per square inch). Nothing happens as long as the valve remains closed. However, there is a ***potential*** for doing work, which will be realized as soon as the valve is opened and the liquid is released. Remember, though, *no work is done* unless the valve is opened.

VOLTAGE

A battery is a lot like the tank of water. It has the *potential* for doing work, but no work will be done until a 'valve' is released (electrical circuit is attached). In hydraulics, we speak of pressure when we refer to the *potential energy* that the liquid has. In electricity, we speak of VOLTAGE. Voltage is ***electrical pressure***, and is measured in VOLTS.

You can think of the battery like an electrical storage tank. How much energy it stores is determined by many things, but we know that the "pressure" it produces to do work is called VOLTAGE.

CURRENT

The hydraulic tank also uses another kind of measurement and that the RATE OF FLOW. The rate at which the liquid leaves the tank when the valve is opened is determined by both the pressure within the tank and by the size of the faucet on the tank. For example, when you get gas for your car, you may pump at a rate of 3 gallons per minute. If you squeeze the handle harder, you open the release valve wider and the rate of flow increases. You pump more liquid in a given time, therefore get more work done.

In electricity, the same principle applies. No liquid leaves the battery, but a flow of electrical current does. While we think of the smallest division of liquid as drops, in electricity the smallest unit is the ELECTRON, flowing very rapidly past a given point (the faucet). 1 AMP flowing past a given point sends 6,250,000, 000,000,000,000 electrons past that point every second.

Instead of saying something like "ELECTRONS PER HOUR" we use the term AMPERE. An AMPERE is equal to a tremendous number of electrons running through a circuit each second. In alarm work we don't often deal with that much current, so we break the ampere into 1000 smaller divisions called MILLIAMPS. Remember, like the pressure in the tank, the battery's **voltage** *pushes current* around a circuit.

RESISTANCE

The last of the basic three components is RESISTANCE. In the hydraulic system resistance could be rust or corrosion inside the exit pipe, causing the liquid to flow slower. In electricity, the concept of RESISTANCE also applies. Resistance may be caused by corrosion in the circuit wiring through which the electric current flows; so in practice, resistance appears all over and everything used in electricity has some. RESISTANCE is measured in OHMS. When denoting the amount of resistance we use the Greek letter for omega.

RESISTORS

Resistors come in an infinite variety of sizes and values. Because of this, and the fact that most are small, a color code of banding has been developed to make it easier to identify what the value of a resistor is. The table below lists the color codes for resistors. A resistor will normally have 4 color bands around it. The first three tell what the resistance is and the fourth is the tolerance of that value.

RESISTOR COLOR CODE

Black	=	0
Brown	=	1
Red	=	2
Orange	=	3
Yellow	=	4
Green	=	5
Blue	=	6
Violet	=	7
Gray	=	8
White	=	9
Gold	=	5% tolerance
Silver	=	10% tolerance
no color	=	20% tolerance

OHM'S LAW

This very basic relationship between VOLTAGE, CURRENT, and RESISTANCE is the cornerstone of modern electronics today. Ohm's law states that when a battery rated at 1 VOLT is wired to a resistance of 1 OHM, then a current of 1 AMPERE will flow in the circuit. The relationship governed by OHM'S LAW can be best expressed in this manner:

$$\text{CURRENT} = \frac{\text{VOLTAGE}}{\text{RESISTANCE}}$$

Said another way:

$$\underset{\text{(in amperes)}}{\text{CURRENT}} = \frac{\text{PRESSURE (in volts)}}{\text{RESISTANCE (in ohms)}}$$

When working with electrical quantities in OHM'S LAW, abbreviations have been standardized to make things easier. For CURRENT use the letter I (for intensity). For VOLTAGE use E (for electromotive force) and for RESISTANCE we use R.

By reconfiguring the basic formula we keep the relationships the same but make it easier to calculate for any of these elements.

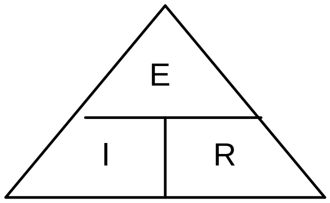
OHM'S LAW

For CURRENT: $I = \frac{E}{R}$

For VOLTAGE: $E = IR$

For RESISTANCE: $R = \frac{E}{I}$

Another way of showing Ohms Law is through the triangle method. In the triangle below you will note the three pieces of Ohms Law. If you cover up the piece you want to find the remaining two pieces show you how to find it. For example if you are looking for (I) amps cover the I and you find that you should divide E by R.



THE BASIC RULES WHEN USING OHM'S LAW

RULE #1. Always solve parallel portions of the circuit first then use those answers to solve the series portion of the problem.

PARALLEL RESISTANCE FORMULAS

2 Resistors in parallel

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

more than 2 resistors

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

SERIES RESISTANCE FORMULA

$$R_T = R_1 + R_2 + R_3 + R_4$$

Let's take an example of a circuit that has a single resister (R_1 = 50 ohms) followed by two resistors in parallel (R_2 = 40 ohms and R_3 = 30 ohms). The first step of the problem is you need to find the total resistance of the parallel part of circuit. First you use the parallel resistance formula to find the resistance of the two parallel resistors (call the answer R_A = 17.14 ohms), then you solve the circuit resistance by adding the first resistor to that answer ($R_A + R_1$ = 67.17 ohms).

RULE #2. In a series circuit **voltages** are added; in a parallel circuit voltage is constant.

PARALLEL VOLTAGE FORMULA

$$E_T = E_1 = E_2 = E_3 = E_4$$

SERIES CURRENT FORMULA

$$E_T = E_1 + E_2 + E_3 + E_4$$

RULE #3. In a series circuit **current** is constant; in a parallel circuit currents are added.

PARALLEL CURRENT FORMULA

$$I_T = I_1 + I_2 + I_3 + I_4$$

SERIES CURRENT FORMULA

$$I_T = I_1 = I_2 = I_3 = I_4$$

CAPACITORS

A capacitor is an apparatus that stores energy, much like a resistors cut down the amount of energy passing through. Sometimes you may need to calculate capacitance (C) of a circuit. This is the opposition to voltage change and is measured in farads (f).

Again there are two formulas for calculating multi-capacitance circuits.

PARALLEL CAPACITANCE CIRCUIT

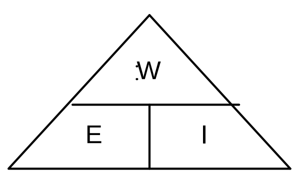
$$C_T = C_1 + C_2 + C_3 + C_4$$

SERIES CAPACITANCE CIRCUIT

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}$$

WATTS IT ALL ABOUT?

What about watts? Watts are found by multiplying current times voltage. In the drawing below you can see that the "Ohm's Law" formula can be changed to find watts in relationship to current and volts.



By covering the item you are looking to find with your finger, you get the formula for how to find it. For example, if you are looking to solve for watts, cover the w and what you have as a formula is E x I. If you cover E, then the formula would be W/I.

VOLTAGE DROP CALCULATIONS

As electrons flow through a circuit, their energy is depleted, (normally in the form of heat caused by resistance in the circuit), or by use of items connected to the circuit. As the electrons return to the source they are replenished by new electrons with new power to make the trip around the circuit. This keeps the voltage constant as the energy is used up.

We are familiar with Samuel Ohm and his law and rules, let's look to Kirchhoff and his voltage law. Kirchhoff says "The sum of the voltage drop is equal to the source voltage."

Kirchhoff's Voltage Law

The sum of the voltage drop is equal to the source voltage

In a series circuit a portion of the source voltage is dropped across each series load.

The sum of these voltage drops would equal the source voltage.

When the loads are connected in parallel, voltage is also dropped across each load Instead of a part of the source voltage being dropped across each load, as with the series circuit, in a parallel circuit all of the source voltage is dropped across each load. The reason is that loads connected in parallel are connected directly across the source voltage.

Up until now we have talked about voltage drops across specific items or loads in a circuit. The problem we face now is that the circuit itself, by virtue of the wiring, is also a cause for voltage drop.

Watts - Revisited

Before we go further lets revisit the term Watts. Watts come in two types, useful work and wasted work(dissipated). Watts = I x I x R Watts = Heat

Useful Work

Useful work would be an appliance such as an electric skillet, the I x I x R heating is needed and is not considered wasted power. Another example is the light bulb. The wattage or power is a measure of, I squared times R, and is the heating of the filament of the bulb, which, depends on the fixed resistance of the filament.

Wasted Work

Wasted work is the heating of the conductors supplying the energy to the load. The conductors have a resistance to the flow of current. Therefore, the voltage at the load can never be the same as the source voltage due to the resistance of the conductors.

Voltage Drop

The resistance of the circuit conductors causes a voltage drop to the source voltage. How much the source voltage will drop depends on two things:

1. the load, and
2. the resistance in the circuit.

The voltage drop in a conductor is a percentage of the source voltage. If conductors had zero resistance, there would be no voltage drop between the load and the source. This is not possible as all matter has resistance.

So, we can define voltage drop as wasted work in the heating of the conductors in a circuit. Since the generation of electricity costs money it is important to us to keep the wasted energy to a minimum.

Because of the way electricity travels through a circuit we find a larger size conductor (in circular-mil area) will have a lower resistance and less voltage drop in the same distance.

Voltage drop in circuits can be designed for, that is by designing a circuit correctly for the smallest voltage drop we can drop the percentage of wasted power in the circuit.

The National Electric Code gives us two guidelines when it comes to voltage drop allowances.

1. The percent of drop shall not exceed 5% from the source through the last overcurrent protection device to the load.
2. The circuit from the last overcurrent device (panel fuse) and back again, exclusive of the load will not be more than 3% of the total source current.

What does this mean to us? If we are dealing with a 12vdc circuit the total voltage drop allowed would be 3% of 12vdc or .36vdc. Likewise in dealing with a 24vdc fire panel the total drop per circuit would be 24vdc times 3% or .72vdc. You can see how this would effect your installation if the circuit is designed without regard to wire (circuit) distance and the associated resistance factors of different wire sizes.

Now that we have set the groundwork for voltage drop lets get our hands dirty and work on the different formulas we need to know to keep us out of trouble.

VOLTAGE DROP FORMULAS

To find the information we need to know to calculate voltage drops we turn to Chapter 9, Table 8 of the NEC. The first column gives us the wire sizes, the second column gives us the area in circular mils. The area in circular mils is the crosscut area of the wire and what the area is in mili-inches. Moving on the third column we find the number of strands in a given conductor. If we are looking for the properties of a solid conductor we use the information listed in the 1 line, for stranded conductors we use the 7 quantity line for information. The seventh column of the chart gives us the resistance of the conductor in ohms per 1000 feet of conductor if the conductor is pure copper, if the conductor is coated (tinned) we use the 8th column, and if the conductor is aluminum we use the last column. In our work 99% of the time we will use the 7th column (uncoated pure copper). For this reason I suggest you highlight the 2nd and 7th columns in your NEC as these are the columns we will be using, unless otherwise specified in a problem.

Remember when calculating length of a circuit that the distance from point A to point B is only half the distance, the circuit still has to return to the source.

VOLTAGE DROP = I x R

Lets look at a problem using this formula.
We have a circuit of #14AWG stranded copper uncoated, from the source to the load is 125 feet. The load is 5 ohms and the amperage is 5 amps.

Solution: Looking in Table 8 we find that #14AWG stranded uncoated copper has a resistance of 3.14 ohms per kft. We know our circuit is 250 feet so we take the value of 3.14 and divide it by 4 to come up with .785 ohms, then we multiply by the 5 amps in the circuit to find a voltage drop of 3.925.

The complete group of voltage drop formulas are listed on the next page.

VOLTAGE DROP FORMULAS

NOTATIONS

I - amps R = resistance VD = voltage drop

VD permitted = 3% of voltage drop on any circuit (12vdc x #5 = .36v)

CM = size of conductor in circular mils *(Table 8)*

D = distance of the circuit one way

PL = power loss (wasted electricity) due to conductor resistance

K = resistance of a circular mil-foot of wire *(Table 8)*

Ⓚ = approximate K; use 12.9 for copper; 21.2 for aluminum

Power Loss = VD x I **Exact K** = $\frac{R \times CM}{1000'}$

Voltage Drop = VD = $\frac{2 \times K \times D \times I}{CM}$ or **Voltage Drop** = VD = I x R

Wire Size = CM = $\frac{2 \times Ⓚ \times D \times I}{\text{VD permitted}}$

Distance = D = $\frac{CM \times \text{VD permitted}}{2 \times K \times I}$

Load = I = $\frac{CM \times \text{VD permitted}}{2 \times K \times D}$

Using the different formulas above we can now solve a myriad of problems dealing with voltage drops. We can calculate for load on a circuit, distance (with voltage drop permitted) to determine if a given size conductor will keep us within the permitted voltage drop percentage, calculate for wire size and even calculate Power Loss problems. Next we will put these formulas to work and solve problems using them.

VOLTAGE DROP PROBLEMS

(Remember the NEC standard for wire notations.)

1. What is the voltage drop in a branch circuit to a siren that has a 50 ohm load? The source voltage is 6 volts, the distance is 40 feet, the conductor is #14AWG.

2. What is the total resistance of two #16AWG conductors? Each is 85 feet in length and they are connected in parallel.

3. What is the maximum load in amps the code allows for a branch circuit using #18AWG coated? The power source is 65 feet away and is 12 volts.

4. What size copper conductor is required for a branch circuit to a horn that has a .25 amp load? The power source is 6 volts and is 50 feet away.

5. Find the approximate distance between the source and the load if a #18AWG stranded conductor is used and the total conductor resistance is 1.05 ohms.