



Ohm's Law and DC Circuits Trainer

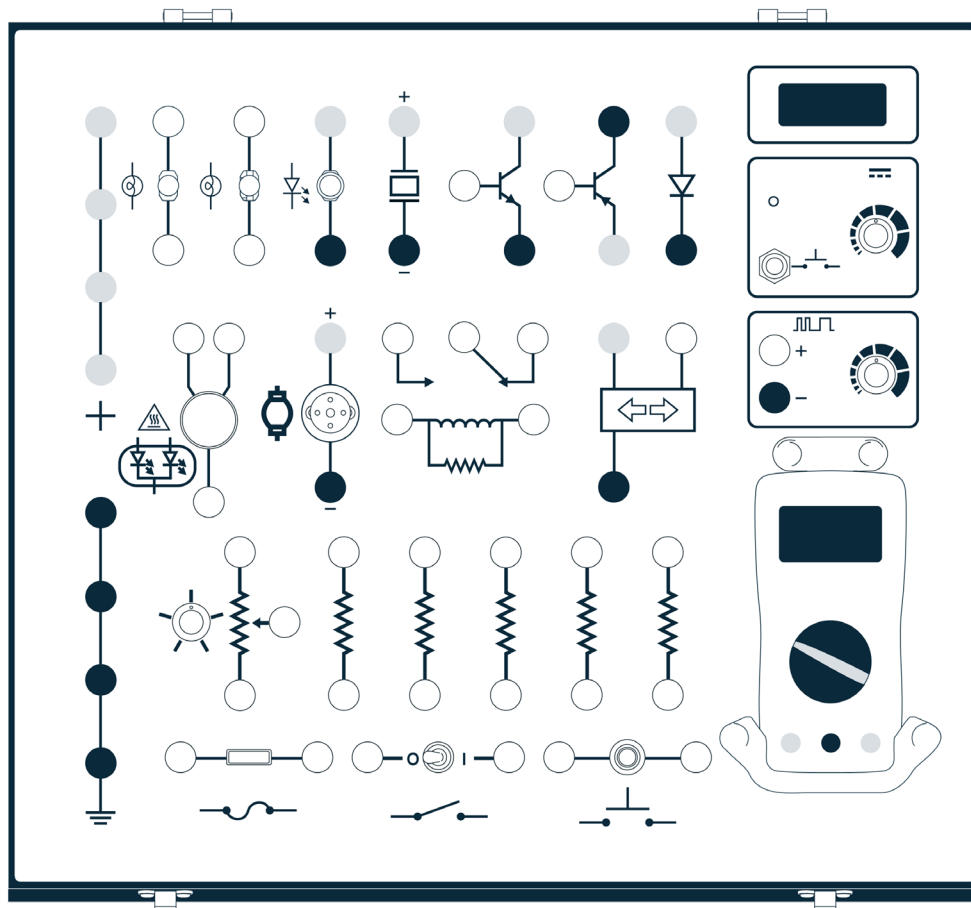


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Trainer Layout and Familiarization

The CL-1919-06_053052 Ohm's Law and DC Circuits Trainer contains electrical and electronic components mounted on a panel containing electrical connection receptacles where students complete the wiring of circuits. The trainer is designed to provide learning assistance in the understanding of basic Ohm's Law concepts and also provides learning activities for student learning of basic circuit components and operation.

A built-in 120VAC to 14VDC (4A max) power supply is internally protected and is adjustable from 2-14VDC. The front panel contains a digital display indicating the DC voltage supply available to the trainer. The CL-1919-06_053052 trainer meets CSA/UL safety requirements.

The CL-1919-06 also contains a surface mounted digital multi-meter (DMM) that is powered with two AAA replaceable batteries.

NOTE: Because the trainer's power supply output is limited to 4 A, the meter's internal 10A ammeter fuse should never need replacement. The meter is used throughout the student activities and circuit construction for electrical measurements and diagnostic training.



CL-1919-06 Ohm's Law and DC Circuits Trainer

Student Learning Modules

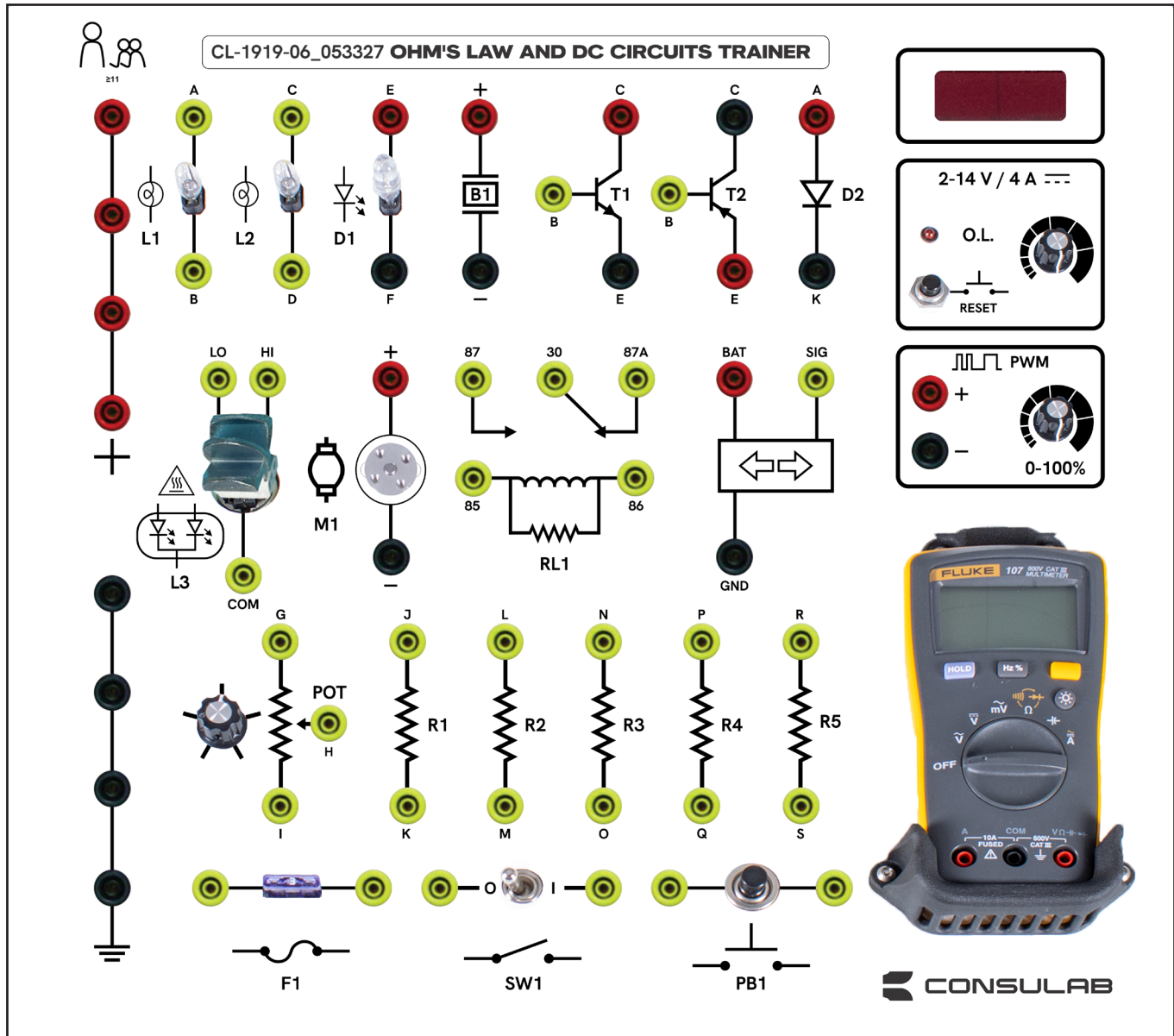
The CL-1919-06 manuals contain Student Learning Modules designed to provide information and resources to assist students in mastering various skills and knowledges covered with this trainer. Each module comes with educational support information, student activity assignments, student answer sheets, instructor keys and assessment tests. Instructors can use them as they see fit for their programs. Student answer sheets, schematics and assignments can be duplicated and distributed within the schools programs only. PDF fillable answer sheets are also available. Duplication of documents used for outside sources is prohibited. Assignment and test answer sheets can be filed in student files for record keeping of progress. It is recommended that instructors follow the chronological order of the assignments. However, each module can be presented on its own if desired.

THE CL-1919-06 LEARNING MODULES:

1. UNDERSTANDING THE DIGITAL MULTIMETER — SETUP, USE & INTERPRETATION
2. BASIC ELECTRICITY
3. OHM'S LAW
4. COMPONENT EXPLANATION
5. STUDENT EXPERIMENTS
6. ADVANCED STUDENT CIRCUIT ASSIGNMENTS

CL-1919-06 wiring blank template

Circuit _____ Name _____ Date _____



Instructor's check: _____ Credit/Grade: _____

Comments: _____

MODULE 1

Understanding the Digital Multimeter

Setup, Use & Interpretation

**Fluke Model 107 Digital Multimeter**

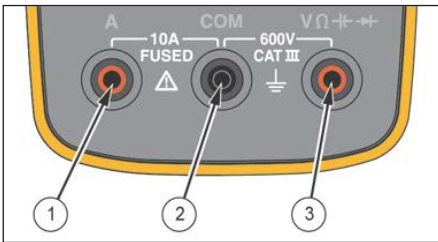
In order to accurately diagnose electrical circuits and components, it is essential that technicians be able to understand how to properly setup, use and interpret digital multimeter readings. Digital multimeters are one of the most commonly used tools by technicians working in the electrical field. This instructional unit is designed to provide students with sufficient basic information that if successfully understood, will allow them to properly set up, make measurements and interpret meter readings. Most technician's today use "digital" multimeters. Digital means that the meter displays the measured values in "digital" form. Most digital meters have 3 ½ or 4 ½ digits of display. This means that the meter has three or four locations on the display that can display from 0-9. The ½ digit means that the display can be only a single digit display (usually 0-9 depending on the meter). Digital meters have some advantages over other types. Digital meters usually are not polarity sensitive when making measurements with the positive and negative test leads. If the test leads are installed "backwards" (reverse polarity) in the circuit being tested, the digital meter will display a minus sign (-) in front of the meter reading. No damage will occur to the meter.

Analog meters can sometimes be used in electrical testing. An "analog" meter has a display face that contains a needle that moves back and forth on the face. Analog meters are polarity sensitive and if the meter test leads are installed "backwards" (reverse polarity), damage to the meter's needle and internal circuitry can occur. There are some applications in electrical testing where analog meters may be used.

A digital multimeter is a very versatile tool with many features that can go beyond basic measurement of volts (electrical pressure), amps (electrical flow), and ohms (electrical resistance). Such things as: Duty Cycle, Frequency, Capacitance, Temperature, Pulse Width, Diode Testing and others can be tested with some digital multimeters. For the purposes of the CL-1919-06, this instruction will be limited to the measurement of volts, amps and resistance.

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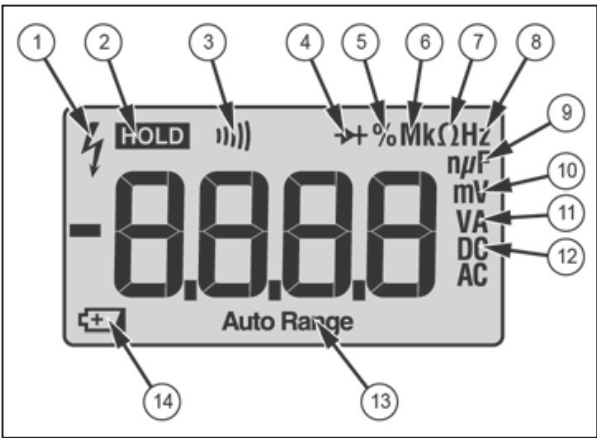
TERMINALS



#	DESCRIPTION
1	Input terminal for AC and DC current measurements to 10 A and current frequency measurements.
2	Common (return) terminal for all measurements.
3	Input terminal for voltage, current, continuity, diode, capacitance and frequency measurements.

NOTE: This meter is able to measure **DUTY CYCLE** and **FREQUENCY** on AC circuits only. Do not attempt to measure these values on DC circuits.

DISPLAY



#	DESCRIPTION	#	DESCRIPTION
1	High Voltage	8	Frequency is selected
2	Display Hold is enabled	9	Farads
3	Continuity selected	10	Millivolts
4	Diode Test is selected	11	Amps or Volts
5	Duty Cycle is selected	12	DC or AC Voltage or Current
6	Decimal prefix	13	Auto Range mode is enabled
7	Ohms is selected	14	Low Battery - Replace Battery

AUTO POWER OFF

The DMM automatically powers off after **20 minutes** of inactivity. A tone will be heard at the end of 20 minutes indicating the meter will soon shut off.

To restart the DMM, turn the rotary switch back to the **OFF** position and then to a necessary position.

To disable the Auto Power Off function, hold down the **YELLOW** button when turning on the DMM until **Poff** shows on the display.

AUTO BACKLIGHT OFF

The DMM backlight automatically turns off after **2 minutes** of inactivity.

To disable the Auto Backlight Off function, hold down ☼ when turning on the DMM until **Loff** shows on the display.

Note: To disable both Auto Power Off and Auto Backlight Off functions, hold down the **YELLOW** button and ☼ at the same time until **Poff** and **Loff** show on the display.

MEASUREMENTS

Data Hold

⚠ WARNING ⚠

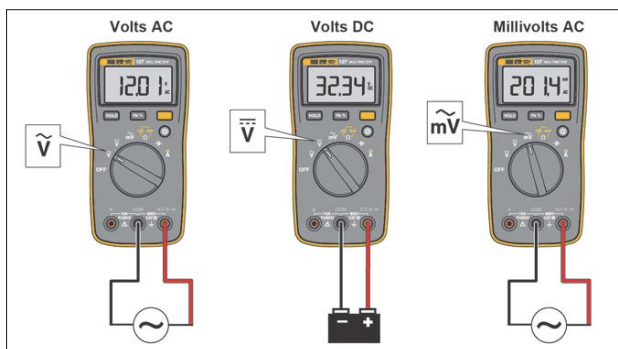
To prevent possible electrical shock, fire or personal injury, do not use the HOLD function to measure unknown potentials. When HOLD is turned on, the display does not change when a different potential is measured. **WARNING - Do not use this meter for any other application other than the CL-1919-06.**

To hold the present reading, push **HOLD**. Push it again to continue normal operation.

Measure AC and DC Voltage

To measure AC and DC voltage:

1. Choose AC or DC by turning the rotary switch to $\tilde{V}$ or $\bar{V}$. NOTE: Select the AC millivolts position ONLY ($\tilde{mV}$) when measuring AC millivolts. Do not use for DC millivolts
2. Connect the **RED** test lead to the $V \Omega \text{---} \text{---} \text{---} \text{---}$ terminal and the **BLACK** test lead to the **COM** terminal.
3. Measure the voltage by touching the probes to the correct test points of the circuit.
4. Read the measured voltage on the display.



MEASUREMENTS

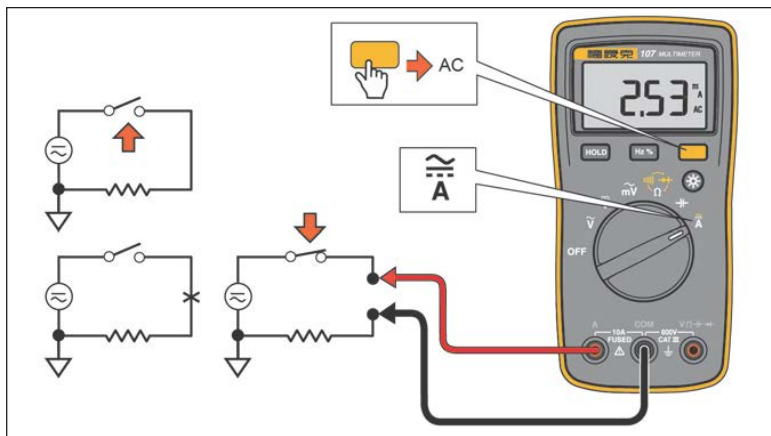
Measure AC and DC Current

⚠ WARNING ⚠

To prevent possible electrical shock, fire or personal injury, remove circuit power before you connect the DMM in the circuit when you measure current. Connect the instrument in series with the circuit.

To measure AC and DC current:

1. Turn the rotary switch to $\overline{\text{A}}$.
2. Push the **YELLOW** button to toggle between AC or DC current measurement.
3. Connect the **RED** test lead to the **A** terminal and the **BLACK** test lead to the **COM** terminal.
4. Break the circuit path to be measured.
5. Connect the test leads across the break and apply power.
6. Read the measured current on the display.

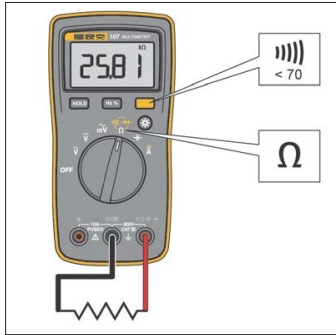


Measure Resistance

1. Turn the rotary switch to Ω . Make sure power is disconnected from the circuit to be measured.
2. Connect the **RED** test lead to the $\text{V} \Omega \text{ } \overline{\text{A}}$ terminal and the **BLACK** test lead to the **COM** terminal.
3. Measure the resistance by touching the probes to the desired test points of the circuit.
4. Read the measured current on the display.

Test for Continuity

With the resistance mode selected, push the **YELLOW** button once to activate the continuity mode. If the resistance is less than 70 Ω , the beeper sounds continuously when you have a connection, designating a short circuit. If the DMM reads OL, the circuit is open.



Test Diodes

1. Turn the rotary switch to Ω .
2. Push the **YELLOW** button to activate the diode test mode.
3. Connect the **RED** test lead to the $V \Omega \rightarrow \rightarrow$ terminal and the **BLACK** test lead to the **COM** terminal.
4. Connect the red probe to the anode and the black test lead to the cathode of the diode being tested.
5. Read the forward bias voltage value on the display.
6. If the polarity of the test leads is reversed with diode polarity, the display reading shows OL. This can be used to distinguish the anode and cathode sides of a diode.

Measure Capacitance

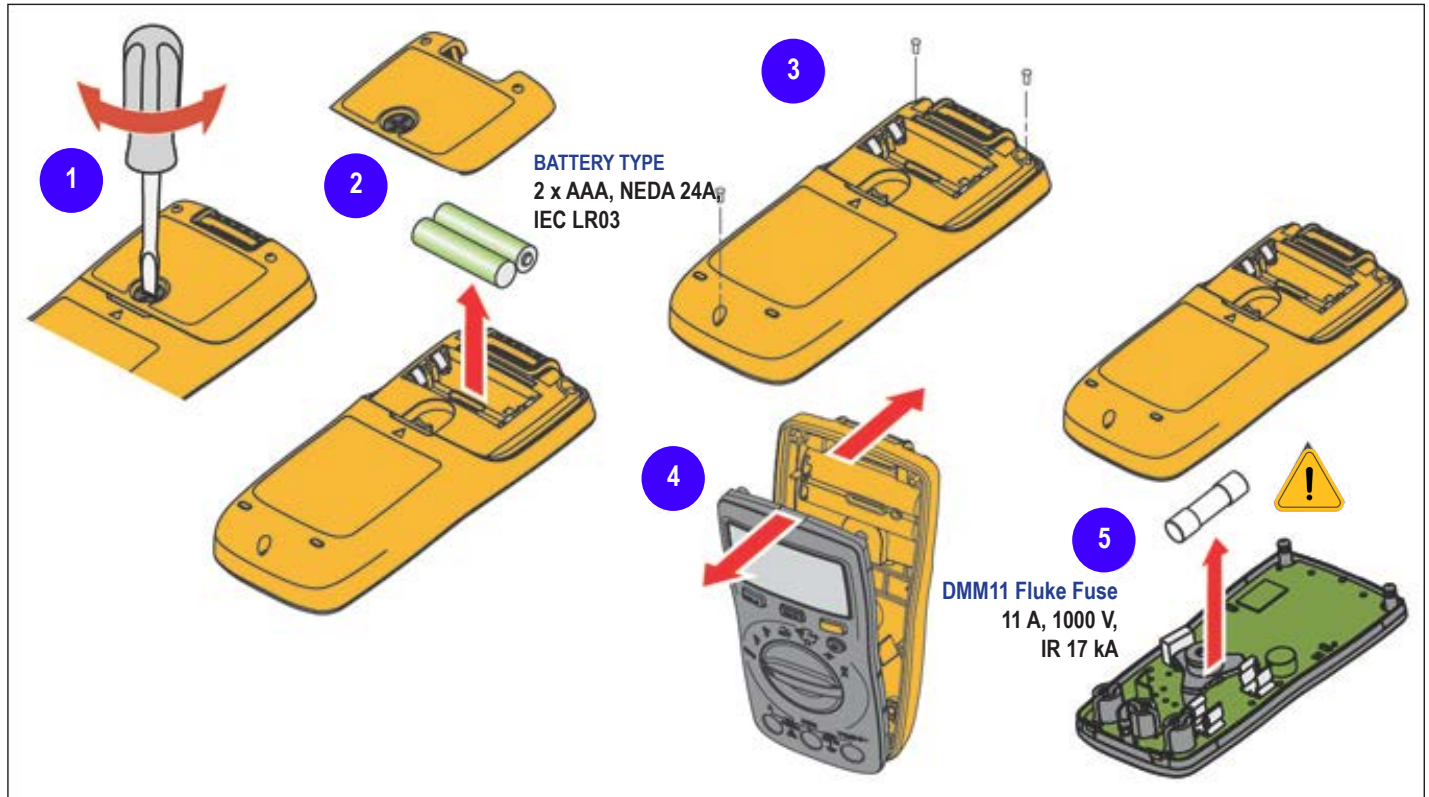
1. Turn the rotary switch to $\rightarrow$.
2. Connect the **RED** test lead to the $V \Omega \rightarrow \rightarrow$ terminal and the **BLACK** test lead to the **COM** terminal.
3. Touch the probes to the capacitor leads.
4. Let the reading stabilize (up to 18 seconds).
5. Read the capacitance value on the display.

Measure Frequency and Duty Cycle

NOTE: This meter is able to measure DUTY CYCLE and FREQUENCY on AC circuits only.

Do not attempt to measure these values on DC circuits.

DMM BATTERIES AND FUSE REPLACEMENT



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SA-1 Measuring Resistance

Ω —The Greek omega symbol represents ohms or the measurement of resistance. Use this function when measuring resistors or the resistance of an electrical component. The abbreviation of “k” indicates that the scale is for “kilo-ohms”. There are 1,000 ohms in one kilo-ohm. This would be written as 1 k Ω . The abbreviation of “M” indicates that the scale is for “mega-ohms”. There are 1,000,000 ohms in one mega-ohm. This would be written as 1 M Ω . The electrical symbol used on analog (needle type) meters that indicates electrical infinity or that there is too much resistance to measure is ∞ . Digital meters cannot display this symbol and instead will display either an OL, O.L or 1. In addition, some meters will cause the display to “flash” on and off. The important factor to remember about measuring resistance is that the circuit or component being measured for resistance **MUST BE ELECTRICALLY DEAD** or turned off. A typical ohmmeter outputs a very small voltage into the component being tested and measures the voltage drop across the component and then converts that reading internally into an ohm equivalent value which is shown on the meters readout display. Therefore, never hook up an ohmmeter to a live circuit or meter damage can occur. To measure resistance with the meter, place the red meter test lead in the **V Ω $\rightarrow$** socket and the black meter lead in the **COM** socket.

RESISTANCE

The Fluke 107 digital meter is an “auto ranging” meter. There are six resistance scales on this meter and the meter will automatically select the correct one based on the value of the resistance being measured. In order to understand what scale the meter has chosen, you must observe the meter’s readout screen to know what scale has been chosen. The six possibilities are: 400 Ω , 4.000k Ω , 40.00k Ω , 400.0k Ω , 4.000M Ω & 40.00M Ω . The scale information will be seen in the upper right corner of the meter display screen. Below is a chart that identifies the different scales and what different resistances measured would display on the meters display screen.

METER CHOSEN SCALE	READING WITH NO RESISTANCE	MAXIMUM RESISTANCE THAT CAN BE MEASURED	SAMPLE RESISTANCE MEASURED	METER READOUT & SCALE DISPLAYED
400 Ω	O.L M Ω	400 Ω	54 ½ ohms	54.5 Ω
400 Ω	O.L M Ω	400 Ω	9.5 ohms	9.5 Ω
4.000k Ω	O.L M Ω	4,000 k Ω	1,492 ohms	1.492 k Ω
4.000k Ω	O.L M Ω	4,000 k Ω	2,200 ohms	2.200 k Ω
40.00k Ω	O.L M Ω	40,000 k Ω	21,640 ohms	21.64 k Ω
40.00k Ω	O.L M Ω	40,000 k Ω	47,000 ohms *	47.0 k Ω
400.0k Ω	O.L M Ω	400,000 k Ω	43,200 ohms	43.2 k Ω
400.0k Ω	O.L M Ω	400,000 k Ω	239,722 ohms	239.7 k Ω
4.000M Ω	O.L M Ω	4,000,000 Ω	472,345 ohms	0.472 M Ω
4.000M Ω	O.L M Ω	4,000,000 Ω	4,340,267 ohms	4.35 M Ω
40.00M Ω	O.L M Ω	40,000,000 Ω	2,190,783 ohms	2.192 M Ω
40.00M Ω	O.L M Ω	40,000,000 Ω	10,520,973 ohms	10.52 M Ω

* NOTE: DELIBERATELY USED AN OVER RANGE RESISTOR

SA-1 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-1 student answer sheet to record all of your measurements and question answers.

1. Properly setup the CL-1919-06 for use. Plug power cord into a 120VAC receptacle and turn on the master power switch. Confirm that the display reads around 14.00 volts.
2. Place the meter test leads into the appropriate sockets. **RED** into the $V \Omega \text{---} \text{---} \text{---}$ socket and the **BLACK** into the COM socket.
3. Obtain and fill out the student answer sheet for SA-1 MEASURING RESISTANCE as you make each measurement.
4. Place the meter function switch to the Ω position.
5. Measure the resistance of R5 on the panel. Record your reading on the student answer sheet.
6. Measure the resistances of R4, R3, R2, and R1 and record your readings on the answer sheet.

In the following steps you will be measuring various components on the trainer. Record all your measurements on the answer sheet.

7. L1.
8. L2.
9. DC Motor
10. Terminals #85 to #86 of relay RL1.
11. Terminals G to I of the POT
NOTE: Potentiometer resistances are very sensitive to measurements due to how they are constructed. Lightly wiggle the knob if necessary to get a consistent reading.
12. Terminals I to H of POT with knob turned fully clockwise (CW).
13. Terminals I to H of POT with knob turned fully counter-clockwise (CCW).
14. Explain why the resistance of the POT terminals changed as you turned the knob.

You are now going to measure the resistance of the two switches available on the CL-1919-06. Ohmmeters can also be used to measure “continuity” (whether the circuit is “continuous”, “open” or have resistance). When normally testing switches, if the component is functioning normally, its resistance when the switch is turned on should be very close to “0” or no resistance. When the switch is turned off, there should be an infinite amount of resistance or is “open”. Follow the below instructions.

15. Measure the resistance of SW1 with the switch positioned in the “O” position.
16. Measure the resistance of SW1 with the switch positioned in the “I” position.
17. Explain the readings of steps #15 and #16 in the space provided on the answer sheet.
18. Measure the resistance of PB1 switch without pushing in the button.
19. Measure the resistance of PB1 switch while pushing the button down.

You will now be instructed to measure various components on the trainer. Be sure to carefully read the instructions and make sure you are properly installing the ohmmeter test leads. Follow the below instructions:

20. **Black** meter lead to terminal B of T2 transistor and **red** meter lead to terminal E of T2 transistor.
21. **Red** meter lead to terminal B of T1 transistor and **black** meter lead to terminal E of T1 transistor.

22. **Black** meter lead to terminal C of T1 transistor and **red** meter lead to terminal E of T1 transistor.
23. **Red** meter lead to **RED** PWM receptacle of the PWM generator and **black** meter lead to **BLACK** receptacle of the PWM generator.
24. Make sure you have filled in ALL of the answer sheet blanks, then turn in your answer sheet to your instructor for grading and credit.

Ask your instructor for Test 1 and answer sheet, before going on to the next assignment.

SA-1 MEASURING RESISTANCE - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

- 5- R5 = _____ Scale displayed: ____ Expressed as: _____
6. R4 = _____ Scale displayed: ____ Expressed as: _____
 R3 = _____ Scale displayed: ____ Expressed as: _____
 R2 = _____ Scale displayed: ____ Expressed as: _____
 R1 = _____ Scale displayed: ____ Expressed as: _____
7. L1 = _____ Scale displayed: ____ Expressed as: _____
8. L2 = _____ Scale displayed: ____ Expressed as: _____
9. DC Motor = _____ Scale displayed: ____ Expressed as: _____
10. Relay terminals #85 & #86 = _____ Scale displayed: ____
 Expressed as: _____
11. Terminal G to I of POT= _____ Scale displayed: ____
 Expressed as: _____
12. Terminals I to H of POT with knob turned fully clockwise = _____ Scale displayed: ____
 Expressed as: _____
13. Terminals I to H of POT with knob turned fully counter-clockwise = _____
 Scale displayed: ____ Expressed as: _____
14. _____

15. SW1 in the "O" position = _____ Scale displayed: ____
 Expressed as: _____
16. SW1 in the "I" position = _____ Scale displayed: ____
 Expressed as: _____
17. _____

18. PB1 in the "O" position = _____ Scale displayed: ____
 Expressed as: _____
19. PB1 in the "I" position = _____ Scale displayed: ____
 Expressed as: _____

20. Term B (BLK lead) to term E (RED lead) of trans T2 = _____ Scale displayed: ____
Expressed as: _____
21. Term B (RED lead) to term E (BLK lead) of trans T2 = _____ Scale displayed: ____
Expressed as: _____
22. Term C (BLK) lead to term E (RED lead) of trans T1 = _____ Scale displayed: ____
Expressed as: _____
23. RED meter lead to RED PWM receptacle and BLK meter lead to BLK PWM receptacle =
_____ Scale displayed: _____ Expressed as: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

Ask your instructor for Test 1 and answer sheet, before going on to the next assignment.

SA-2 Measuring DC Voltage

Technicians are often required to accurately measure DC voltages on various circuits and components. Understanding how to use a voltmeter is an essential skill that must be mastered by students and technicians. Voltmeters are commonly made as part of a digital or analog multimeter. Analog meters are not very common in today's environments, but can still be found in certain applications. This unit will primarily cover the digital voltmeter. As with the digital ohmmeter, a solid understanding of the displayed voltage scales is necessary in order to obtain an accurate reading.

Digital voltmeters use various scales measuring voltages from very small levels up to higher levels. Common vehicle repairs deal with voltages from 0-50 VDC. Most digital voltmeters can measure both AC and DC voltages and it is important that you properly adjust the voltmeter to measure the desired voltages for your application. Digital multimeters use a master function switch that selects the desired function of the meter. There may be positions for VDC and VAC and it is important that the correct position is selected.

Voltages can only be measured when the circuit is "on" or "live". With electric vehicles (EV) becoming more common, it is CRITICAL that technicians understand that there are voltmeters specifically designed to safely measure the higher voltages on EV vehicles. Serious shock hazards and injury can result from improper understanding of service procedures on EV vehicles. Digital multimeters are now classified by the level of voltage it can safely measure. A system of "CATEGORIES" is used. Common categories are CAT-I, CAT-II, CAT-III and CAT-IV. Each category has a MAXIMUM voltage and current the meter AND meter leads can safely measure. The meter and meter leads will have the Category printed or molded on the device. The Fluke 107 multimeter on the CL-1919-06 is a CAT-III meter, but because we do not use the meter leads that originally came with the meter, it should NEVER be used for measuring voltages above 20 V! **Use the this meter ONLY with the CL-1919-06 trainer.**

Most digital and analog voltmeters can accurately read both volts and millivolts. There are 1,000 millivolts in one volt. In digital form, a millivolt is written as 0.001 V. Ten millivolts is written as 0.010 V and one hundred millivolts is written as 0.100 V. One volt expressed in millivolts would be 1.000V. Verbally, 0.100V would be expressed as "one hundred millivolts or one-tenth of a volt". It is extremely important to know how to accurately read, write and express voltage readings.

The Fluke 107 multimeter uses three voltage function choices. They are displayed as $\tilde{V}$ for ACV, $\overline{V}$ for DCV & DCmV and mV for ACmV. The voltmeter has three scales that will be automatically chosen by the meter based on how much voltage is being measured. The DC voltage scales are: 6.000VDC, 60.00VDC and 600.0VDC. See the below table to view how different voltages will be displayed based on what scale has been chosen by the meter.

VOLTAGE MEASURED	VOLTAGE DISPLAYED	SCALE CHOSEN
218 millivolts	0.218 VDC	6.000VDC
48 millivolts	0.048 VDC	6.000VDC
3.249 volts	3.249 VDC	6.000VDC
7.325 volts	7.33 VDC	60.00VDC
10.443 volts	10.44 VDC	60.00VDC
14.527 volts	14.53 VDC	60.00VDC
492.7 volts***	492.4 VDC***	600.0VDC***

*** NOTE: There are no voltages on the CL-1919-06 above 15.00VDC. This reading display is for understanding only.

SA-2 PROCEDURE

Follow the instructions below to practice using the **VOLTMETER** function of the multimeter. Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the SA-2 student answer sheet to record all of your measurements and question answers.

1. Properly set up the CL-1919-06 for use. Plug the power cord into a 120VAC receptacle. Turn on the trainer's power switch and adjust the voltage display to about **14.00VDC $\pm$** .
NOTE: The adjustment knob is VERY sensitive to movement. You may have to very slightly move it to get small changes in voltage.
2. Insert a **red** jumper wire into the **V Ω ** socket of the meter and a **black** jumper wire into the COM socket of the meter.
3. Obtain and fill out the student answer sheet for SA-2 MEASURING DC VOLTAGE as you make each measurement.
4. Place the meter function switch in the **$\overline{V}$** position.
NOTE: Remember that the meter is "auto-ranging" and you must properly determine what scale is being used based on the location of the decimal point.
5. Place the red meter lead into any of the red receptacles on the left side of the trainer.
6. Place the black meter lead into any of the black receptacles on the left side of the trainer.
7. Measure the voltage displayed in the upper right trainer voltage display window and fill in the answer sheet. You will be asked to also "express" what the voltage reading is in your own words for this and most all voltage measurements.
8. Turn the POWER SUPPLY voltage adjustment knob fully "counter-clockwise"  and measure, then record the reading on the answer sheet.
9. Turn the POWER SUPPLY voltage adjustment knob fully "clockwise"  and measure, then record the reading on the answer sheet. Reset the voltage to about 14.00 VDC $\pm$ when finished.
10. Connect a red jumper wire from any of the four red receptacles to the left-hand terminal of fuse F1.
11. Connect a red jumper wire from the right-hand terminal of fuse F1 to the left-hand terminal of switch SW1.
12. Connect a red jumper wire from the right-hand terminal of switch SW1 to terminal A of light bulb L1.
13. Connect a black jumper wire from any of the four black receptacles to terminal B of light bulb L1.
14. Turn switch SW1 on. The L1 light bulb should be on. If not, recheck all your connections, correct the problem and confirm bulb operation.
15. Measure the voltage available at light bulb L1 (red meter lead to terminal A of bulb L1, black meter lead to terminal B of bulb L1). Record your reading on answer sheet.
16. Now, slowly turn the voltage adjustment knob from fully clockwise to fully counter-clockwise and record the highest and lowest voltage displayed. Record your readings on answer sheet. Turn knob fully clockwise when finished.
17. What did bulb L1 do as the voltage was being adjusted? Fill in the answer sheet.

18. Turn switch SW1 off, readjust displayed voltage to 14.00 V $\pm$ and remove voltmeter leads from bulb L1.
19. Remove the black jumper wire from terminal B of bulb L1 and connect it to terminal D of bulb L2.
20. Connect a red jumper wire from terminal B of bulb L1 to terminal C of bulb L2.
21. Turn switch SW1 on and confirm both bulbs L1 and L2 are on.
22. What do you observe about the performance of the light bulbs? Fill in the answer sheet.
23. Measure the voltage available to bulb L1 by placing your voltmeter leads on terminals A & B of bulb L1. Fill in the answer sheet.
24. Measure the voltage available to bulb L2 by placing your voltmeter leads on terminals C & D of bulb L2. Fill in the answer sheet.
25. Measure the voltage between terminal A of bulb L1 and terminal D of bulb L2. Fill in the answer sheet.
26. In your own words, try to explain the two voltage readings and why the bulbs operated dimmer than when just one was connected in the circuit. Fill in the answer sheet.
27. Turn switch SW1 off. Remove voltmeter leads.
28. Using the “piggy back” method, install another black jumper wire from terminal C to terminal D of bulb L2.
29. Place the red meter lead to any of the four red receptacles on the left-hand side of trainer.
30. Place the black meter lead to terminal A of bulb L1.
31. Turn switch SW1 on and record the voltage measured on the answer sheet.
NOTE: You are measuring the total voltage drop of the entire “positive” circuit including all wires, fuse and switch SW1. Voltage drop testing will be explained later on in further assignments.
32. Turn switch SW1 off. Remove voltmeter leads.
33. Remove all jumper wires from bulbs L1 and L2, but leave red jumper wires connected to fuse F1 and switch SW1.
34. Connect a red jumper wire from the right-hand terminal of switch SW1 to the LO terminal of bulb L3.
35. Connect a black jumper wire from any of the black receptacles on left-hand side of trainer to terminal COM of bulb L3.
36. Turn switch SW1 on.
37. Bulb L3 LO side should now be on. If not, recheck your connections, correct and confirm proper operation.
38. Measure the voltage available to bulb L3 LO by installing voltmeter leads to terminals LO and COM. Fill in the answer sheet.
39. Can you explain why bulb L3 LO was brighter than bulbs L1 and L2 yet all three had the same voltage available to them? Put your answer on the answer sheet.
40. Remove all jumper and meter wires from the trainer and turn trainer off.
41. Complete all blanks on the answer sheet, then turn in to instructor for grading and credit.

Ask your instructor for Test 2 and answer sheet, before going on to the next assignment.

SA-2 MEASURING DC VOLTAGE - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

NOTE: The voltage adjustment knob is VERY sensitive to movement. You may have to very slightly move it to get small changes in voltage.

7. _____ VDC Expressed as: _____
8. _____ VDC (fully counter-clockwise) Expressed as: _____
9. _____ VDC (fully clockwise) Expressed as: _____
15. _____ VDC Expressed as: _____
16. _____ VDC (fully clockwise) Expressed as: _____
_____ VDC (fully counter-clockwise) Expressed as: _____
17. _____

22. _____

23. _____ VDC Expressed as: _____
24. _____ VDC Expressed as: _____
25. _____ VDC Expressed as: _____
26. _____

31. _____ VDC Expressed as: _____
38. _____ VDC Expressed as: _____
39. _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

Ask your instructor for Test 2 and answer sheet, before going on to the next assignment.

SA-3 Measuring DC Current

Technicians often measure DC current when diagnosing various circuits and components. Just to confirm, the terms **CURRENT** and **AMPERAGE** are synonymous, just different terms meaning the same thing. CURRENT is defined as the “amount” of electricity flowing in a circuit. Current is what “does the work” in an electrical circuit and the amount of current is determined by the circuit’s resistance and available voltage. The Fluke 107 multimeter used on the CL-1919-06 trainer can measure both DC and AC currents. The maximum current the meter can safely measure is 10 A (both DC and AC currents). There is an internal 10A fuse inside the meter. However, because the CL-1919-06’s internal power supply is limited to 4 A, there should be no scenario which would require the replacement of the Fluke 107’s internal fuse. **USE THE FLUKE 107 METER FOR THE CL-1919-06 EXPERIMENTS ONLY.**

The Fluke 107 multimeter ammeter has two scales that the meter will automatically chose from based on how much current is being measured. The two scales are 4.000A and 10.00A. The proper meter setup for measuring current is to place the **red** meter lead into the **A** socket (left-hand side) and the **black** meter lead in the **COM** socket (middle). The function switch should be adjusted to the $\tilde{A}$ position. Push the yellow button  on the meter to switch between $\overset{A}{DC}$ and $\overset{A}{AC}$. For the purposes of the current measuring assignments, the meter should be set to measure DC amperage.

Measured current will be displayed using the two automatically selected meter scales (4.000A & 10.00A). **Be sure to observe how the decimal point is used in each measurement which will tell you what scale has been chosen by the ammeter.** The following chart gives sample current readings and how they would be displayed on the meter’s display screen.

CURRENT MEASURED	CURRENT DISPLAYED	SCALE CHOSEN
218 milliamps	0.218 ADC	4.000A
48 milliamps	0.048 ADC	4.000A
3.249 amps	3.249 ADC	10.00A
4.044 amps	4.04 ADC	10.00A
7.338 amps	7.34 ADC	10.00A

NOTE: When measuring a value of 3.890A current, the meter will display 3.890A using the 4.000A scale. However, if the measured current was 4.500 A, the display would show 4.50 A using the 10.00A scale. If the current is reduced to just below 4.00 A, the meter display may still use the 10.00A scale. If the current is continued to be lowered, the meter will shift to the 4.000A scale.

It is important to remember that when measuring current, the circuit **MUST** be on or “live”. In addition, the ammeter **MUST** be installed in the circuit so that the circuit current also flows through the ammeter. This means that the circuit must be “broken” either in the positive half or ground half of the circuit. This creates two “ends” of the circuit to which the two ammeter meter test leads are connected to. It doesn’t make any difference regarding meter test lead polarity as to whether the red meter lead is connected to the positive side of the circuit or that the black meter lead is connected to the positive side of the circuit. If the black meter lead is connected to the positive side of the circuit, there will be minus sign (-) in front of the displayed current value.

IT IS VERY IMPORTANT TO REMEMBER TO TURN THE CIRCUIT “OFF” BEFORE INSTALLING OR REMOVING THE AMMETER INTO THE CIRCUIT. NEVER CONNECT OR REMOVE AN AMMETER IN A “LIVE” CIRCUIT. AFTER PROPERLY INSTALLING THE AMMETER, TURN THE CIRCUIT ON.

SA-3 PROCEDURE

Follow the instructions below to practice using the **CURRENT** function of the multimeter. Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the SA-3 student answer sheet to record all of your measurements and question answers.

- Properly set up the CL-1919-06 for use. Plug the power cord into a 120VAC receptacle. Turn on the trainer's power switch and **adjust the voltage display to about 14.00 VDC±**.
NOTE: The adjustment knob is VERY sensitive to movement. You may have to very slightly move it to get small changes in voltage.
- Insert a **red** jumper wire into the left-hand A meter socket and a **black** jumper wire into the **COM** meter socket.
- Obtain and fill out the student answer sheet for SA-3 MEASURING DC CURRENT as you complete each task.
- Place the meter function switch in the $\tilde{A}$ position. Remember that the meter is "auto-ranging" and you must properly determine what scale is being used based on the location of the decimal point.
- Toggle the  button to choose $\frac{A}{DC}$ function. (AMPS DC).
- Construct the following circuit by installing red and black jumper wires as described:
RED:
 - Any of the four red power receptacles on the left side of the trainer to left-hand terminal of fuse F1.
 - Right-hand terminal of fuse F1 to terminal O of switch SW1.
 - Terminal I of switch SW1 to terminal to terminal A of bulb L1.**BLACK:** a) Terminal B of bulb L1 to any of the four black ground receptacles on the trainer.
- Turn switch SW1 to the ON position. Confirm that bulb L1 is on. If not, confirm all your circuit connections, correct the problem and confirm bulb L1 operation.
- Turn switch SW1 to the OFF position.
- Remove the black wire from terminal B of bulb L1 to the ground receptacles.
- Connect the RED ammeter lead of the meter to terminal B of bulb L1.
- Connect the BLACK ammeter lead to any of the four black ground receptacles of the trainer.
NOTE: You have installed the ammeter in the GROUND circuit of bulb L1. **BE SURE THE FLUKE 107 METER IS PROPERLY SETUP TO READ DC AMPS.**
- Turn switch SW1 ON. Bulb L1 should be ON and the ammeter should indicate the amount of current flowing through the bulb. Record the ammeter reading on your answer sheet and describe in your own words how much current is indicated.
- Turn switch SW1 OFF. Reverse the red and black ammeter leads so that the red ammeter lead connects to the four black ground receptacles and black ammeter lead connects to terminal B of bulb L1.
- Turn switch SW1 ON. The ammeter should be reading current. Record the ammeter reading on your answer sheet and describe in your own words how much current is indicated.
- Turn switch SW1 OFF.
- What is different about the two readings from Steps 12 and step 14?

17. Remove both ammeter leads from the trainer.
18. Reinstall a black wire from any of the four black ground receptacles on the trainer to terminal B of bulb L1.
19. Remove the red wire that connects from terminal I of switch SW1 to terminal A of bulb L1.
20. Install the red ammeter lead to terminal I of switch SW1.
21. Install the black ammeter lead to terminal A of bulb L1.
22. Turn switch SW1 ON. Bulb L1 should be on. Record the current shown on the ammeter on your answer sheet. Also described in your own words, how much current is being displayed.
23. Turn switch SW1 OFF.
24. Remove the ammeter test leads from the circuit and replace the red jumper wire from terminal I of switch SW1 to terminal A of bulb L1.
25. Remove the red jumper wire connected from any of the four red positive receptacles to the left hand terminal of fuse F1. Set the wire aside for now.
26. Connect the red ammeter lead to any of the four red positive receptables on the trainer and the black ammeter lead to the left-hand terminal of fuse F1.
27. Turn switch SW1 ON. Bulb L1 should be on and the ammeter should be measuring the current flowing in the circuit. Record the display reading on your answer sheet and describe in your own words the displayed amount.
28. Now evaluate your measured current readings from steps 12, 14, 22 and 27.
What are your conclusions? Record your answer on the answer sheet.
29. Turn switch SW1 OFF. Remove the ammeter test leads and replace the red jumper wire connecting any of the four red positive receptacles to the left-hand terminal of fuse F1.
30. Remove the red jumper wire between the right-hand terminal of fuse F1 and the O terminal of switch SW1.
31. Install the red ammeter lead to right-hand terminal of fuse F1 and the black ammeter lead to terminal O of SW1.
32. Turn switch SW1 ON and confirm that bulb L1 is on and that the meter is measuring current. Record your reading on the answer sheet and describe the value being displayed in your own words.
33. Turn switch SW1 OFF. Connect a red jumper wire from terminal A of bulb L2 to terminal C of bulb L2. Using the “piggy-back” method, connect a black jumper wire from terminal B of bulb L1 to terminal D of bulb L2.
34. Before turning on the circuit, make a prediction of what the measured current will be when the circuit is turned on
35. Turn switch SW1 ON. Now measure the displayed current and also describe the reading in your own words.
36. Turn switch SW1 OFF. Remove the red and black jumper wires connecting bulb L1 to L2.
37. Move the black wire from terminal B of bulb L1 to terminal D of bulb L2.
38. Install a red jumper wire from terminal B of bulb L1 to terminal C of bulb L2.
39. Turn switch SW1 ON and record the displayed current on answer sheet as well as your description.
40. Why do you think that both bulbs L1 and L2 are on but dimmer than before? Put your answer on answer sheet.

41. Turn switch SW1 OFF and disconnect all red and black wires from bulbs L1 and L2. Leave wires from red positive receptacles on left side of trainer, wires to fuse F1, both ammeter leads and red wires to terminal O of switch SW1 still connected.
42. Connect a red jumper wire from terminal I of switch SW1 to the HI terminal of bulb L3.
43. Connect a black jumper wire from terminal COM of bulb L3 to any of the four black ground receptacles.
44. Turn switch SW1 ON and record displayed current read, fill in answer sheet and describe the displayed current.
45. Turn switch SW1 OFF.
46. Remove all wires from bulb L3. Confirm that wires from red positive receptacles, fuse F1, the ammeter and switch SW1 are still connected.
47. Connect a red jumper wire from terminal I of switch SW1 to the red positive terminal of the DC motor M1.
48. Connect a black jumper wire from the black ground terminal of DC motor M1 to any of the four black ground receptacles.
49. Turn switch SW1 ON. Record the measured current and describe the displayed reading in your own words on the answer sheet.
50. While the motor is turning, grab the flywheel of the motor with your thumb and index finger to “slow” the motor down by increasing pressure of your fingers. Notice what affect this has on the current flowing through the motor. Describe what you notice on the answer sheet.
51. With your fingers, completely stop the motor and record the maximum amount of current flowing through the motor. Record this value on the answer sheet. Also describe the displayed reading in your own words.
52. Turn switch SW1 OFF.
53. Remove the black and red wires from the motor M1. Connect a black jumper wire from any of the four black ground receptacles to terminal B of bulb L1. Connect a red jumper wire from terminal I of switch SW1 to terminal A of bulb L1.
54. Turn switch SW1 ON. While watching the ammeter, slowly turn the voltage adjustment knob clockwise  and then counter-clockwise . What does the ammeter display as the knob is adjusted? Put your answer on the answer sheet.
55. What is your opinion on what affect voltage has on the amount of current flowing in a circuit? Put your answer on the answer sheet.
56. Turn switch SW1 OFF.
57. Remove all wires from the trainer and multimeter. Turn multimeter and trainer off. Complete the answer sheet and make sure there are no blanks left. Turn in the answer sheet to your instructor for grading.

Ask your instructor for Test 3 and answer sheet, before going on to the next assignment.

SA-3 MEASURING DC CURRENT - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

Be sure to carefully read and understand each step in the assignment BEFORE you turn on switch SW1.

12. _____ Amps Expressed as: _____
14. _____ Amps Expressed as: _____
16. _____
22. _____ Amps Expressed as: _____
27. _____ Amps Expressed as: _____
28. _____
34. _____
35. _____ Amps Expressed as: _____
39. _____ Amps Expressed as: _____
40. _____
44. _____ Amps Expressed as: _____
49. _____ Amps Expressed as: _____
50. _____
51. _____ Amps Expressed as: _____
54. _____
55. _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

After completion of SA-3, turn in your answer sheet to the instructor and ask for Test 3, then Test 4 before proceeding to the next module.

MODULE 2

Basic Electricity

PREREQUISITES: At this point, it is necessary for all students to have successfully completed the instructional unit on digital multimeter setup and use to be able to correctly obtain accurate readings of voltage, resistance and amperage. If this is not true, STOP and complete the digital multimeter unit first. Obtain instructors permission to proceed to the next section. Understanding how to properly setup and read digital multimeters is required for student activities covered in the following unit of BASIC ELECTRICITY.

Theory and Understanding

WHAT IS ELECTRICITY?

Electricity has always been somewhat of a complicated subject to understand. Electricity wasn't really "discovered" because it occurs naturally. The early Greeks, Phoenicians, Mesopotamians and others were long aware of the presence of electrical properties in some materials. It was known that static electricity occurred in nature. Alessandro Volta (1745-1827) was the first to create a "battery" which was called a "voltaic pile". The modern term of VOLTS is taken from his name. Andre-Marie Ampère (1775-1836) was a French physicist who is credited with a basic understanding of electromagnetism and electrodynamics. The term AMPERES or AMPS was taken from his name.

THE ATOM

In order to understand electricity, it is necessary to have a very basic understanding of the composition of matter. Matter is anything that takes up volume and space on earth and even in space. Matter is made up of molecules made from just over 100 individual components called "elements". The very smallest part that an element can be broken down into is called an **atom**. The atom is made up of two basic parts:

1. The **NUCLEUS** (center of the atom) which is made up of two parts, **neutrons** and **protons**. Neutrons have a neutral electrical charge while protons have a positive charge.
2. Spinning around the nucleus in various orbits are **electrons** which have a negative charge. In a stable atom, there are an equal number of electrons and protons.

THE CONDUCTORS & INSULATORS

All elements are electrically classified as either an electrical **CONDUCTOR** or an **INSULATOR**. The difference between the two is how many electrons there are in the outer most orbit ring (called the **VALENCE RING**). Conductors have four or less electrons in the valence ring, while insulators have four or more electrons. This means that the outer most electrons in conductors are held in orbit with less force than in an insulators outer orbit. It is easier to cause electrons to flow from atom to atom in a conductor than in an insulator. Copper is the most common conductor because of its cost and availability. Other conductors are gold, silver, aluminum and most metals. Common insulator materials are wood, glass, most plastics, rubber, nylon and fiberglass. Based on the results of many years of study and experimentation by many dedicated scientists, it is understood that "electricity" is the flow of electrons (an element of the atom) through a conductor from atom to atom whenever there is an imbalance of electrons established between two different points in a circuit. Imbalance means that at one point in a circuit there is an excess of electrons and at another point, there is a deficiency of electrons.

Certain laws of physics indicate that nature wishes to exist in a "stabilized" state and if a conductive path is connected between the excess and deficiency locations of electrons, the electrons will flow between atoms until they are equal or stabilized. There remains today some disagreement on what direction electrons actually move. The **CONVENTIONAL ELECTRON THEORY** states that they flow from positive to negative in a circuit.

The **ELECTRON THEORY** states that they flow from negative to positive. There are very technical and complex arguments to substantiate each side and we will not get into those issues here. For purposes of this level of understanding, if you carefully follow the proper hookup of both the positive and negative (ground) wires in different circuit design applications, the actual direction of electron flow won't really matter. For the purposes of this manual, any reference to electron or current flow will use the **CONVENTIONAL THEORY** (positive to negative).

THE SEMICONDUCTORS

Materials with exactly four electrons in their outer orbit are neither conductors nor insulators, but are called semiconductors. Semiconductors can be either an insulator or a conductor in different circuit design applications. Examples of semiconductor materials include: **Silicon**, **Germanium** and **Carbon**. Semiconductors are used mostly in transistors, diodes, integrated circuit chips, computers, and other electronic devices.

MAGNETISM

Magnetism is an invisible force of nature present in either natural or man-made magnets. A magnet has a north pole and a south pole. If two magnets are brought together with both north poles facing each other, the magnets will repel or push each other away. If a north pole of one magnet and a south pole of another magnet are brought together, the magnets will “snap” together. Therefore, it is understood that like poles of magnets repel each other and unlike poles attract each other. The electrical charges of both electrons (–) and protons (+) are like poles of a magnet. Like charges (both – or +) will repel each other. The electron is held and pushed away from the proton which allows it to keep spinning around the nucleus. The electrons keep moving in their orbits because being like charges, they repel each other.

TYPES OF ELECTRICITY

There are generally three types of electricity:

1. Static Electricity
2. Alternating Current (AC)
3. Direct Current (DC)

Static Electricity

Static electricity occurs naturally in nature. Lightning during a storm is an extreme example of static electricity. Walking across some rugs and touching metal can result in small electrical shock caused from static. Sometimes, it can cause damage to automotive circuits and components. For the most part, static electricity performs no useful purpose. In the automobile, static electricity can be generated by sliding across the upholstery and touching a metal object resulting in a small spark. Often automotive technicians are required to wear special anti-static safety equipment which is designed to prevent damage to electrical circuits and components.

Alternating Current (AC)

Alternating Current (AC) electricity is used in our homes and industry to power all the electrical devices we depend on for our lives. AC electricity is generated by power plants using coal, water, natural gas, solar, geo-thermal or nuclear power sources. The electricity is sent to homes and factories using overhead and underground wires ending up in electrical panels that branch off into individual circuits. Alternating Current can be very dangerous and even lethal, and only qualified and experienced technicians should work on this type of electricity. There are a few places in the automobile where AC electricity may be used with the alternator and many engine sensors being the most common examples. Newer hybrid and electric vehicles can use both AC and DC electricity. Most electric and hybrid cars operate on very dangerous levels of both AC and DC electricity and all appropriate safety precautions must be followed when working on these vehicles.

EV (Electric Vehicles) are becoming more common with the world embracing cleaner fuels and trying to reduce the carbon footprint of which fossil fuels (gasoline and diesel) are huge contributors. Most EV vehicles can have both AC and DC voltages approaching 500 volts. New service and safety procedures have been developed to allow trained, certified and qualified repair technicians to safely work on these vehicles. **NEVER** attempt to work on or even touch high voltage EV systems without the proper training and supervision.

Direct Current (DC)

Direct Current (DC) electricity is commonly used in the automobile. True or “pure” DC electricity can be generated by a battery using a chemical reaction to create an electron imbalance. However, there are many different electronic circuits and devices that can change AC electricity to DC electricity and be very close to “pure” DC electricity generated from a battery. Also, there are devices that can change DC to AC electricity. Again, the electric and hybrid vehicles use these devices for the operation of the hybrid power train. EV and some hybrid vehicles use components called “inverters” to change AC to DC or DC to AC. Most automotive electrical circuits in today’s vehicles operate in the 12-14 volts DC range. As vehicle technology evolves, many vehicle manufacturers are now using systems with 48 V or higher system voltages. As stated earlier, many EV and hybrids use voltages from 300-500 volts. Direct Current circuits consist of a “positive” side (from the battery to a resistance) and a “negative” or ground side (from the resistance back to the battery). The term “resistance” is any component in the circuit that does “work” for us. Examples could be motors, solenoids, coils, light bulbs, heaters, relays or more. The most common term used today for “resistance” is the circuit “load”

Dangerous electrical shock hazards from 12 volt DC circuits are extremely rare. However, with electric and hybrid vehicles, high voltage batteries generating voltages in excess of 500 volts can be used. These voltages represent a very dangerous shock hazard and there are many safety precautions and safety procedures which must be carefully followed to prevent injuries. There are also specially designed multimeters and test equipment designed to high voltage batteries. Technicians must receive very specialized training and certifications before working on high voltage hybrid electrical systems.

NEVER work on or gain access to any high voltage EV or hybrid electrical system without proper safety training and certification.

SOURCES OF ELECTRICITY

There are several available sources to generate electricity. Let’s look at the most common ones:

Chemical Reaction – Having two dissimilar metals coming in contact with an acid will generate electricity. This is how batteries operate whether they are either wet cell or dry cell. The only difference between the two is whether the acid is in liquid or paste form. The voltage generated by a battery is dependent on the materials used in the battery construction and design. Batteries consist of “cells” each of which must contain “plates” of dissimilar metals and an acid. For example, an automotive lead-acid battery contains Lead (-) and Lead Oxide (+) and diluted sulfuric acid. Each cell of an automotive lead-acid battery generates about 2.1 volts. Cells can be inter-connected in parallel or series. Parallel connections give the battery long operational life without increasing the cell voltage totals and series connections cause the cell voltages to add together to higher voltage. Therefore, a 12V car battery has six cells connected in series resulting in an output voltage of 12.6 when fully charged.

Magnetism – Physicists discovered years ago that if a conductor such as a copper wire is moved through an established magnetic field, a voltage is generated. This law of physics was used to develop generators and alternators which are used throughout countless applications. Additionally, either the magnetic field or the electrical conductor can be moved to generate electricity.

Pressure – In the late 1800’s, it was discovered that when pressure was applied to some crystals (quartz, topaz and some salts), a small voltage is generated. This process is called “piezoelectricity” and is used by some microphones, underwater hydrophones, gas charcoal grill ignitors, some fuel injectors and detonation knock sensors.

Light – Also, in the 1800’s, experiments consisting of shining light over both liquids and metals found that electrons (electricity) were released from the surface of some materials. The electrons can be collected and caused to flow in conductors. The process is called “photoelectricity” and components such as photocells have been developed. Applications of this process are camera exposure meters, automatic headlight dimming systems used in vehicles and in a larger application, solar arrays for the generation of electricity.

Heat – Again in the 1800's, it was discovered that when two dissimilar metals are joined together and then heated, a very small amount of electricity is generated. Components called “thermocouples” were developed using this process and are used for the measurement of temperature. Another process discovered during experiments is called the Peltier Effect and causes the transfer of heat in materials in one direction as electricity is passed through it. It also can cause cooling if the electron flow is reversed. Applications of this concept are portable beverage coolers and heated and cooled seats used in vehicles.

COMMON ELECTRICAL TERMS

What is Voltage?

Voltage or **Volts** — Voltage is the electrical “pressure” pushing electrons through the circuit. Voltage is the difference in pressure between any two points in a circuit. Some sources will use the acronym “E” for electromotive force as a symbol for voltage. Others use “V” for simplicity. Voltage can also be called the “electromotive force” pushing electrons in circuit.

Compare voltage to the pressure in a water hose. If you open the nozzle, water will flow out of the hose as long as there is pressure pushing it. If two different water tanks were connected by a pipe and one was higher than the other, water would flow between them until the water was at the same height.

Many instructors use the water pipe system analogy to help teach electricity. Voltage is more or less equal to the water pressure (psi) in the pipes. As long as there is pressure, water flow is possible if a valve is opened. In the automobile, the battery develops the initial electrical pressure and the alternator also creates “pressure” to cause electrons to flow. The DC battery represents a difference in the number of electrons at one battery post compared to the other. This electron imbalance is “waiting” to stabilize whenever a conductive path is connected between the positive and negative posts of the battery. A “dead” battery has no electron imbalance and thus, no electrons will flow.

What is Amperage?

Amperage or **Current** — Amperage or current is a term used to measure the amount of electricity flowing in a circuit. There CANNOT be any current unless the circuit is operating. Technically, there is an actual measurement of current that states that one ampere is equal to 6.25×10^{18} electrons flowing past a given point in one second. This actual mathematical expression is called a “coulomb”. It would be written as 625,100,000,000,000,000 electrons and is called a “quintillion”. This is a very difficult number to comprehend.

Again, using the water analogy, current is the amount of water flowing inside the hose or the amount of water flowing out of the nozzle in a given amount of time. Water uses the “gallons per minute” specification and electricity uses “amperes” or current. Most sources use the acronym “A” for amperage. Others can use “I” for intensity.

There are two factors in electricity that affect how many amperes flow in a circuit. They are the amount of voltage (pressure) and the amount of resistance (ohms). If we increase the pressure and/or lower the resistance, more amperes will flow. If the source pressure (battery voltage) stays the same and we increase the resistance, less amperes will flow in the circuit. It is common for technicians to abbreviate the term amperes into just “amps”.

In conclusion, amps or current does the “work” in the circuit. The more amps that are flowing, the more electrical “work” is being done. The largest consumer of amps in the vehicle is the electrical starter.

What is Electrical Resistance?

Resistance or **Ohms** — Resistance is the opposition to the flow of electrons and is the means by which useful things are performed by circuits. Most sources use the acronym “R” for resistance. The Greek symbol of Omega or “ Ω ” is normally associated with resistance. The term “ohm” was named after Georg Ohm (1759-1854) in his honor.

Just like in a water system, the diameter of the hose or pipes dramatically affects how much water can flow, the diameter of the wires also affects how many amps that can safely flow in a circuit. Anything that is in the path of water can also reduce the flow and consequently, anything in the circuit that causes resistance will reduce the flow of current. All electrical circuits require some amount of resistance in order to perform useful work.

For example, a light bulb has a calculated amount of resistance that determines how many amps flows in the circuit when the light bulb is turned on. In the water system example, a sprinkler will cause a certain amount of water to flow. If we increase the size of the holes of the sprinkler (less resistance), then more water will flow. If we keep lowering the resistance, the pressure will also be reduced. In electrical circuits, anything that adds resistance to a circuit results in a reduction in the flow of current.

Desired resistance can come from light bulbs, coils, resistors, and motors and are designed into circuits. Unwanted resistances can be in the circuit which can cause unwanted circuit performance. Unwanted resistance results in reduced circuit amperage and voltage drops. Among the most common sources of unwanted resistances are: corrosion, heat, loose or dirty contacts, and rust. If resistance increases in a circuit, the amount of amperage flowing will decrease. All circuits **MUST** have some amount of designed resistance in order to function properly. Therefore, any device that performs any function in the vehicle represents a certain amount of resistance in the circuit. Technicians are often required to find and repair the source of unwanted circuit resistance.

What are Watts?

Watts or **Wattage**: The term **watts** is used to describe an amount of electrical power consumed. The term “watt” was named after James Watt (1736-1819), a Scottish mechanical engineer and inventor who worked with steam engines. We can use the water comparison again to describe watts. In the case of a water wheel turning grinding stones that is powered by water, we could increase the power developed by the system two different ways:

- Increase the amount of water (flow rate) hitting the water wheel, or
- Increase the pressure (voltage) hitting the water wheel.

Wattage is a term used to describe the “amount of work”. Watts are calculated by multiplying the volts times the amperage or current. If a common #3157 dual filament automotive light bulb used for tail and stop lights is turned on and operated with the tail light filament, it will consume 8.26 watts of power and will draw 0.59 amps of current with an operating voltage of 14 VDC. However, the same bulb operating with the stop light filament on will draw 2.10 amps and consume 29.42 watts of power. This means that the stop light filament will be brighter than the tail light filament and uses more “power” or watts. A thousand watts is called a “kilo-watt” and is expressed as “kW”. Many vehicles use kilo-watts to express the developed horsepower of the engine. There are approximately 746 watts in one horsepower (1 hp).

It is important for technicians to understand these basic electrical principles, but it is much more critical that the technician understand the operational relationships between the three operating factors of electricity.

After completion of BASIC ELECTRICITY module, ask your instructor TEST 5.

MODULE 3

Ohm's Law

Definition and Relationships

This section of the CL-1919-06 manual will cover Ohm's Law basics and electrical circuit understanding. Successful technicians in any electrical specialty must understand and be able to apply the concepts of Ohm's Law when performing any electrical circuit diagnosis and repair. A lack of understanding of the relationships between volts, ohms and amps described in this manual often results in misdiagnosis of the original problem and unnecessary replacement of expensive components.

WHAT IS OHM'S LAW?

A German physicist by the name of Georg Ohm (1787-1854) conducted many different experiments with electricity and around 1827, he formulated an explanation of how electricity "behaves". Basically, Ohm's Law describes the direct relationships that occur between voltage, amperage or current and resistance. Mr. Ohm applied mathematics to explain the relationships between the three "elements" (voltage, current and resistance) of electricity. It was previously understood that electricity was the flow of electrons through a conductor, but Mr. Ohm was able to explain how each element affected the other.

The formula of $A = V/R$ was his conclusion of how electricity operates in a circuit. Looking at the formula, "A" is the "intensity" or the amount of current (electrons) flowing in a circuit. "I" is expressed as INTENSITY which is the amount of current or amperage flowing in the circuit. Most sources use "A" instead of "I". "V" is the electrical pressure pushing the electrons through the circuit. "V" is expressed in VOLTAGE or VOLTS. "R" is expressed as resistance opposing the flow of current and is expressed in OHMS or uses the symbol of the Greek Omega sign of " Ω ".

Understanding how to use this information is critical to being able to diagnose electrical circuit problems. Ohm's Law can be taught several different methods with some using extensive mathematical calculations used to "prove out" the system. For purposes of this manual, we are going to keep this section as simple as possible. Your instructor can supply additional information if needed to fully understand how to use Ohm's Law in your learning of electrical fundamentals.

RELATIONSHIPS

A statement that explains Ohm's Law is that: "It's take one volt of electrical pressure to push one ampere of electrons through one ohm of resistance."

Voltage and Resistance are the primary contributory "factors" of amperage. Amperage by itself cannot be "created", but is the result of changes in either voltage or resistance. Thinking of a water hose, if the water pressure was somehow increased, the amount of water flowing out of the hose would also increase. If the water hose became "crimped" or restricted, less water would flow from it. The increase in water flow is equal to an increase in current or amperage when the voltage or pressure is increased. Amperage is the amount of electrical flow caused from the amount of voltage and resistance in the circuit. Many instructors today find that using "voltage drop" to explain Ohm's Law to students provides a clearer understanding than using math formula's. It is a personal choice for each instructor.

Certain "rules" can be created to explain circuit performance:

- If the **voltage** (pressure) is increased, and the **resistance** remains the same, the **amperage** (flow) will also increase. This is because there is a stronger amount of "push" pushing the electrons through the same resistance which results in more electrical flow.
- If the **voltage** (pressure) is decreased, and the **resistance** remains the same, the **amperage** (flow) will also decrease. Less pressure will reduce the flow of electrons because there is less "push" causing the electrons to move.

- If the **resistance** (ohms) increases, and the **voltage** remains the same, the **amperage** (flow) will decrease. If we increase the amount of restriction to flow, the flow will decrease. Think of crimping the water hose a bit. What happens? Less water comes out.
- If the **resistance** (ohms) decreases, and the **voltage** remains the same, the **amperage** (flow) will increase. If we cause the resistance to go down, more flow will result. Increasing the size of the water hose would result in more water flowing from it.
- If both **resistance** (ohms) and **voltage** (pressure) increase, the amperage (flow) will also **increase**.
- If both **resistance** (ohms) and **voltage** (pressure) decrease, the amperage (flow) will also **decrease**.

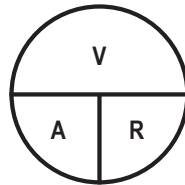
USING OHM'S LAW TO UNDERSTAND "CIRCUIT BEHAVIOR"

Anyone diagnosing electrical circuit problems must understand the concepts of Ohm's Law and be able to apply them to an abnormally behaving circuit in order to determine the source of the fault. For a specific example, suppose that a vehicle headlight operated dimly when turned on. A dim headlight indicates that the amperage flow in the headlight circuit is less than designed amounts. What would cause a reduction of circuit amperage? Remembering Ohm's Law, either an increase in resistance or a reduction of voltage would cause this condition.

If the vehicles operating voltage remains unchanged, then the problem must be an increase in a resistance somewhere in the circuit. This unwanted increase in resistance could be in either supply (positive) side or the ground (negative) side of the circuit. The technician would then test for the unwanted resistance until it was found. Common sources of unwanted increased resistance in headlight circuits could be corrosion, rust, dirty electrical terminals and corroded wires.

With Ohm's Law if any two of the three circuit values (volts, amps or ohms) are known, you can calculate the third unknown value. We can use formulas to assist us when we calculate for the unknown value. For the purposes of this manual, we will use the following abbreviations for: Ohms = R, Amps = A and Voltage = V.

To calculate OHMS: $R = V / A$
 To calculate AMPS: $A = V / R$
 To calculate VOLTS: $V = A \times R$



An easier method to remember the above formulas is to visualize the formulas in a circle as shown. To use this shortcut, simply place your finger over the value you wish to calculate and perform the math that shows in the remaining display. For example, if you wish to calculate for resistance, place your finger over the R. What is left is to divide **VOLTAGE** by **AMPS**. This calculation would result determining the **OHMS** value.

Example:

If the blower motor has a resistance of 2 ohms, how many amps will it "draw" when running on "high" speed with an operating voltage of 14.5 volts?

Answer: 7.25 amps $14.5 \text{ V} / 2 \Omega = 7.25 \text{ A}$

In recent years, many instructors no longer use complicated math formulas to teach Ohm's Law to students, but instead discuss and measure the voltage drop across each resistance. Voltage drop measurements tend to give students more related knowledge of how electrical circuits "behave".

Explanations and activities of **VOLTAGE DROP** will be covered in upcoming sections.

ELECTRICAL CIRCUIT

What is an Electrical Circuit?

A typical automotive electrical circuit contains the following:

- A source of voltage (usually the battery).
- Some type of overcurrent protection (fuse, circuit breaker or fusible link).
- Usually a type of switch (to control when the circuit is on. The switch can be on either the positive or negative side of the circuit).
- Some type of resistance that performs a useful purpose (light bulb, motor, horn, etc.). This resistance is commonly called the **LOAD** in the circuit.
- Positive wires that allow current to flow from the battery to the resistance.
- Ground wires that allow current to flow from the resistance back to the battery.

TYPES OF CIRCUITS IN AUTOMOTIVE ELECTRICAL SYSTEMS

The modern automobile contains three basic types of electrical circuits. They are:

1. Series circuit
2. Parallel circuit
3. Combination series/parallel circuit

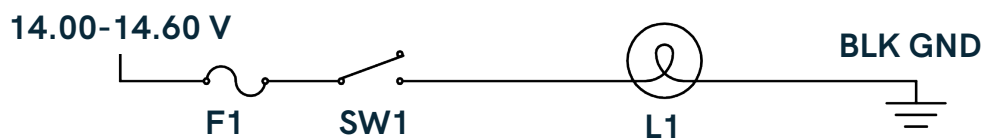
It is important for the technician to understand all three types of circuits and how volts, amps and ohms “behave” in each. This understanding is **CRITICAL** in being able to understand, diagnose and repair electrical circuits on today's complex vehicle systems.

After completion of this section, ask your instructor for Test 6.

SA-4 Series Circuits

SA-4 CIRCUIT EXPLANATION

A series circuit is defined as having just one single path that electricity can flow. The circuit will have positive and negative wires connected from the voltage source to a resistance located between them. The important thing to remember about a series circuit is that a break (open) occurring anywhere in a series circuit will cause the entire circuit to shut off or not operate. A series circuit can have more than one resistance, but normally has only one. Volts, Amps and Ohms and their relationship to each other “behave” or perform in predictable ways in a series circuit. In the following steps, you will construct some series circuits on the trainer to further learn how series circuits operate. Be sure to carefully read, understand and follow the written instructions for the trainer wiring exercises. Use the student answer sheet for SA-4 SERIES CIRCUIT ASSIGNMENTS to record all of your measurements and question answers. This circuit is a SERIES circuit because there is only one path for current to flow. Also, this circuit has only one resistance (bulb L1). The overcurrent device is fuse F1 and the control device is switch SW1. Turning SW1 on and off should cause the bulb to switch on and off. Most of the circuits used in the automobile are series circuits.



SA-4 PROCEDURE:

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-4 student answer sheet to record all of your measurements and question answers.

- A. Make sure the CL-1919-06 trainer is properly set up and is plugged in to a 120V receptacle.
- B. Turn the CL-1919-06 master power switch ON. The voltage display should be on. Adjust the voltage adjustment knob until the voltage displayed is 14.00-14.60 volts.
- C. Connect **RED** jumper wires to the following locations:
 - a. Any of the four red + power terminals of the trainer to left-hand yellow terminal of the F1 fuse.
 - b. The right-hand yellow terminal of fuse F1 to terminal O of switch SW1.
 - c. Terminal I of switch SW1 to terminal A of bulb L1.
- D. Connect **BLACK** jumper wires to the following locations:
 - a. Terminal B of bulb L1 to any of the black ground terminals on the trainer.
 - b. Draw the circuit you have just constructed on a blank trainer schematic sheet and label it:
SA-4 SERIES CIRCUIT WITH ONE RESISTANCE, that will also serve for SA-5 assignment.
- E. Confirm the correct hookup of this circuit your instructor.

SA-4 SERIES CIRCUIT OPERATION

With a series circuit, a break or “open” anywhere in the circuit whether on the “positive” or “negative-ground” side will cause the entire circuit to be inoperative. To confirm this, perform the following steps with the bulb L1 on:

1. Temporarily disconnect either end of any of the red jumper wires (positive). Describe the circuit performance on the answer sheet.
2. Temporarily disconnect either end of the black jumper wire (negative or ground). Describe the circuit performance on the answer sheet.

SA-4 SERIES CIRCUIT - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

1. Describe the circuit performance:

2. Describe the circuit performance:

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-5 Series Circuits with One Resistance

SA-5 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.
Use the SA-5 student answer sheet to record all of your measurements and question answers.

1. Start with the circuit turned OFF.
2. Disconnect any red wire from the circuit and install the red and black ammeter leads at the two connections the red wire was removed from. This puts the ammeter in “series” with the circuit. Make sure meter has been adjusted to read amperage.
3. Turn on the circuit by operating SW1 and read the amperage of the bulb L1. Use the answer sheet.
4. Turn switch SW1 off.
5. Disconnect the DMM test leads
6. Connect the DMM to properly measure amperage in the ground side of the circuit. Connecting the DMM at either end of the black wire is correct.
7. Turn on switch SW1 and measure the ground side amperage. Use the answer sheet.
8. Turn switch SW1 off and disconnect the meter test leads. Reconnect jumper wires for correct circuit operation.

CONCLUSIONS: The amperage in a series circuit is the same in all parts of the circuit. This is because there is only one path for the current to flow.

9. Setup the DMM to measure voltage.
10. Turn switch SW1 to the on position.
11. Measure voltage between any of the four red power receptacles and any of the four black ground receptacles. Use the answer sheet.
12. Measure the voltage at bulb L1 between the positive and ground terminals and record on the student answer sheet.

CONCLUSIONS: In a series circuit with only one resistance, all of the source (battery) voltage is available to the resistance.

SA-5 CALCULATING RESISTANCES USING OHM'S LAW

Light bulb resistances can be measured with the current not flowing in the bulb (static) and the amount of current flowing when the bulb is on (dynamic) can be calculated using Ohm's Law. Light bulb static and dynamic resistances will not be the same because the internal resistance of the light bulb increases with the heat created during illumination. Let's determine the static and dynamic resistance of bulb L1.

13. Turn SW1 off.
14. Set up the DMM to measure resistance.
15. With the circuit off, measure the resistance of bulb L1 and record your measure on the student answer sheet.

NOTE- the resistance of bulb L1 will slowly drop as the bulb cools off. Wait until ohmmeter stabilizes.

16. Using Ohm's Law, calculate the bulb L1's dynamic resistance and record your reading on the student answer sheet. To calculate an incandescent light bulbs "dynamic" resistance and using Ohm's Law, divide the bulbs current into the source voltage. The answer will be the dynamic resistance in ohms.
17. Answer the question, "Why are the static and dynamic bulb resistances different between being OFF and ON?" To complete these next assignments, you will need to have the current flow through bulb L1 and the voltage applied to it that you obtained from previous steps. Put your answer on the answer sheet.

SA-5 SERIES CIRCUIT WITH ONE RESISTANCE - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

3. _____ amps on positive side of circuit. Expressed as: _____

7. _____ amps on negative side circuit. Expressed as: _____

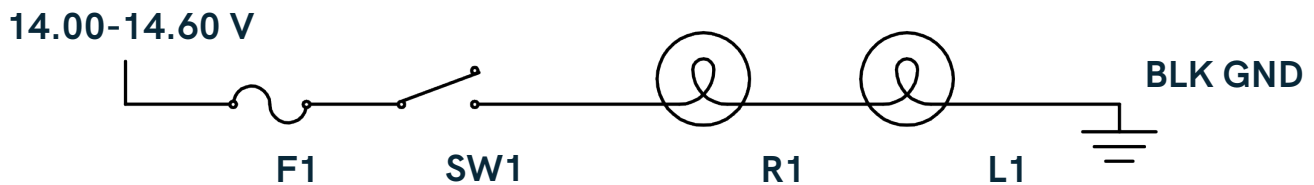
11. _____ volts between positive and ground test receptacles.
Expressed as: _____12. _____ volts between positive and ground terminals of L1.
Expressed as: _____15. _____ ohms of static resistance of L1 (off).
Expressed as: _____16. _____ ohms of dynamic resistance of L1 (on).
Expressed as: _____17. _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-6 Series Circuits with Two Resistances

SA-6 CIRCUIT EXPLANATION

A series circuit has only one path for current to flow, but can have more than one resistance in it. Having two or more resistances will affect the operation of the entire circuit. Many circuit problems are caused by “unwanted” resistances being present in a circuit that is designed to have only one resistance. In the case of light bulbs, having unwanted resistance will cause the bulb to operate with less brilliance than design which results in a “dim bulb” operation.



NOTE- This schematic uses symbols for light bulbs, but each represents a resistance in the series circuit and could also be a resistor instead of a bulb.

SA-6 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-6 student answer sheet to record all of your measurements and question answers.

1. Start with all jumper wires disconnected from the trainer.
2. Connect **RED** jumper wires to the following terminals:
 - a. Any of the four red + receptacles on the trainer to the left-hand yellow terminal of fuse F1.
 - b. The right-hand yellow terminal of fuse F1 to terminal O of switch SW1.
 - c. Terminal I of switch SW1 to terminal K of resistor R1.
 - d. Terminal J of resistor R1 to terminal A of bulb L1.
3. Connect a **BLACK** jumper wire to the following terminals:
 - a. Terminal B of bulb L1 to any of the four black ground receptacles on the trainer.
4. Draw the circuit you have just constructed on a blank trainer schematic sheet and label the schematic: SA-6 SERIES CIRCUIT WITH TWO RESISTANCES.
5. Turn switch SW1 on and observe the operation of bulb L1. Describe circuit operation on the answer sheet.
6. Measure the voltage that is present at terminals A and B of bulb L1. Most technicians describe this voltage as the “voltage drop” across the light bulb. Record your reading on the answer sheet.
7. Measure the voltage that is present at terminals J and K of resistor R1. Most technicians describe this voltage as the “voltage drop” across the resistor. Record your reading on the answer sheet.
8. Measure the voltage that is present between any of the red positive receptacles and any of the four black ground receptacles. Technicians would describe this reading as the “total voltage drop” of the circuit. Record your reading on the answer sheet.
9. Add the readings from steps 6 and 7 together and record your answer on the answer sheet.

CONCLUSIONS: There are two resistances in this series circuit. One is bulb L1 and the other is resistor R1. Because there is only one path for current to flow, the current must flow through resistor R1 and bulb L1 on its way to ground. Because it takes a portion of the total available current to push electrons through the resistor, there will be less available to operate the bulb. That is why the bulb is dim. As voltage is the electrical pressure pushing electrons through resistances, some voltage is used to push electrons through both the resistor and the bulb. How much voltage is used is determined by the value of each resistance. Higher resistances require more voltage to push electrons through them.

10. Measure the current flowing in the circuit by installing your DMM setup to read amperage. You can install the DMM anywhere in the circuit to measure amperage because it is a series circuit. Record your reading on the answer sheet.
11. Using Ohm's Law, calculate the value of the resistor and the bulb in this circuit (Remember the resistance of the bulb is based on its temperature and thus will be different operating dimly than when operating at full brilliance.).
 - A. Value of resistor R1 calculated using Ohm's Law.
 - B. Value of bulb L1's dynamic resistance calculated using Ohm's Law.
12. Turn the circuit off and using the DMM setup to measure resistance, measure the value of R1 and record on answer sheet. Don't forget to change the function switch of the meter from amps to ohms.
13. The calculated value of R1 from step #12 and the measured value of R1 from step #14 should be very close to equal. Are they about equal? Yes or No. Indicate your answer on the answer sheet. If not, go back over your work to determine where you made errors.

SA-6 VARIATION OF RESISTANCE LOCATIONS

In the previous experiment, the resistor was located on the "positive" side of the circuit and caused the bulb to be "dimmer" than normal. Now, we will install the resistor on the ground side of the circuit and evaluate circuit performance.

14. Start with all jumper wires disconnected from the trainer.
15. Connect **RED** jumper wires to the following terminals:
 - a. Any of the four red + power terminals of the trainer to left-hand yellow terminal of the F1 fuse.
 - b. The right-hand yellow terminal of fuse F1 to terminal O of switch SW1.
 - c. Terminal I of switch SW1 to terminal A of bulb L1.
16. Connect **BLACK** jumper wires to the following locations:
 - a. From terminal B of bulb L1 to terminal J of resistor R1.
 - b. From terminal K of resistor R1 to any of the four black ground receptacles on the trainer.
17. Draw the circuit you have just constructed on a blank trainer schematic sheet and label the schematic: SA-6 VARIATION OF RESISTANCE LOCATIONS.
18. Before turning on the trainer, predict what the circuit performance will be with the resistance located in the ground side of the circuit and record your answer on the answer sheet.
19. Turn on the trainer and evaluate circuit performance. Describe on the answer sheet.
20. Using the DMM setup to measure amperage, measure the total circuit amperage anywhere in the circuit and record your reading on the answer sheet.

21. Using the DMM setup to measure voltage, measure the voltage drop across bulb L1 and record on answer sheet.
22. Using the DMM setup to measure voltage, measure the voltage drop across the resistor R1 and record on answer sheet.

CONCLUSION: In a series circuit, adding another resistance affects the performance of the entire circuit. “Unwanted” resistances can be located either on the positive or negative sides of the circuit or both and will have identical effects on circuit performance.

SA-6 SERIES CIRCUITS WITH TWO RESISTANCES - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

5. _____

6. _____ volts available to bulb L1. Expressed as: _____
7. _____ volts available to resistor R1. Expressed as: _____
8. _____ volts available at POS & GND terminals. Expressed as: _____
9. _____ voltage drop of bulb L1 & resistor R1 added together.
Expressed as: _____
10. _____ amps flowing in the circuit. Expressed as: _____
11. A. _____ ohms of R1. Expressed as: _____
B. _____ ohms of L1. Expressed as: _____
12. _____ ohms of R1. Expressed as: _____
13. _____ Yes or No.
18. Your prediction of circuit performance (OFF) _____

19. Description of circuit performance (ON) _____

20. _____ amps of total circuit Expressed as: _____
21. _____ voltage drop across bulb L1. Expressed as: _____
22. _____ voltage drop across resistor R1. Expressed as: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-7 Series Circuits with Two or More Resistances

SA-7 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the SA-7 student answer sheet to record all of your measurements and question answers.

1. Start with all jumper wires disconnected from the trainer.
2. Connect **RED** jumper wires to the following terminals:
 - a. Any of the four red + power terminals of the trainer to left-hand yellow terminal of the F1 fuse.
 - b. The right-hand yellow terminal of fuse F1 to terminal O of switch SW1.
 - c. Terminal I of SW1 to terminal M of resistor R2.
 - d. Terminal L of resistor R2 to terminal A of bulb L1.
3. Connect **BLACK** jumper wires to the following locations:
 - a. Terminal B of bulb L1 to terminal J of resistor R1.
 - b. Terminal K of resistor R1 to any of the four black ground receptacles on the trainer.
4. Draw the circuit you have just constructed on a blank trainer schematic sheet and label the schematic: SA-7 SERIES CIRCUIT WITH TWO OR MORE RESISTANCES.
5. Predict circuit performance before turning on the power. Record your prediction on the answer sheet.
6. Turn on the trainer and evaluate circuit performance. Record the description of the circuit on the answer sheet.
7. Using a DMM setup to measure amperage, measure the total circuit amperage of this circuit and record on the answer sheet.
8. Using a DMM setup to measure voltage, measure the voltage drop across the following components and record your readings on the answer sheet:
 - a. Resistor R2.
 - b. Bulb L1
 - c. Resistor R1
9. Add the voltage drops of all three components together and record on answer sheet. The sum should be almost equal to the source voltage of about 14.6 volts (depending on what the trainers voltage display shows as total voltage)
10. Do not disassemble this circuit yet as it will be needed for further experiments.

CONCLUSIONS: In this circuit, there are three resistances. One of the bulb L1, one is the resistor R2 located on the positive side of the circuit and the last is R1 located in the ground side of the circuit. All three are connected in series. The “behavioral laws” of series circuits are as follows:

- A. Each added resistance will reduce total circuit amperage.
- B. The amperage in a series circuit will be the same throughout all parts of the circuit.
- C. Total circuit resistance is equal to the sum of the individual resistances.
- D. Each resistance will have a voltage drop across it that can be measured.
- E. The sum of all individual voltage drops will equal the source voltage.

SA-7 APPLICATION OF LEARNED CONCEPTS

Because many of the circuits used on automobiles are series circuits, it is important that you understand the operating characteristics in order for you to properly and efficiently be able to diagnose and repair malfunctioning circuits. When evaluating a series circuit with problems, most technicians use voltage drop testing to help them locate the source of the unwanted resistance. Checking voltage drops from one accessible point to another helps in pinpointing the source of the problem. Here are some tips and suggestions for troubleshooting series circuits:

- If possible, measure the available voltage to the component in the circuit. For example, measure the voltage available at the blower motor, the headlight, the power window motor, etc.
- If the voltage is lower than the source voltage and the component is designed to operate on full source voltage, there may be unwanted resistance located in either the positive or ground sides of the circuit.
- The next assignments would be to determine if the unwanted resistance is in the positive or negative portions of the circuit. Assignment SA-8 will conduct an “available voltage test” in the circuit.

SA-7 SERIES CIRCUITS WITH TWO OR MORE RESISTANCES - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

5. Your prediction of circuit: _____

6. Actual circuit performance: _____

7. _____ amps of circuit Expressed as: _____
8. A. _____ voltage drop across R2 Expressed as: _____
B. _____ voltage drop across L1 Expressed as: _____
C. _____ voltage drop across R1 Expressed as: _____
9. _____ total voltage drops Expressed as: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-8 Available Voltage Test

SA-8 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.
Use the SA-8 student answer sheet to record all of your measurements and question answers.

1. Use the SA-7 SERIES CIRCUIT WITH TWO OR MORE RESISTANCES circuit (steps #1-10), (one most recently constructed) conduct an available voltage test to bulb L1.
2. Connect the DMM setup for measuring voltage to terminals A and B of bulb L1. In this test we are measuring “available voltage” to the bulb. In a normally operating circuit, it should equal the source voltage which in this case is approximately 14.6 volts (may vary depending trainer component variations).
3. Turn on the trainer and record available voltage at the bulb. Record your measurement on the answer sheet.
4. A normally operating circuit should have very close to source voltage available to the device (if it is designed to operate at full source voltage). Less than source voltage indicates unwanted resistance somewhere in either the positive side or negative side of the circuit.
5. With the voltmeter still connected at bulb L1 as before, using jumper wires and the piggy-back feature of the connectors, temporarily bypass resistors R1 and R2 by connecting jumper wires from terminals J & K of resistor R1 and terminals L & M of resistor R2.
6. Measure the available voltage with both jumpers installed and record on answer sheet.
7. Remove both jumper wires from resistors R1 and R2.

CONCLUSIONS: With the resistances installed in both the positive and ground sides of the circuit, the available voltage to bulb L1 was much less than source voltage. As soon as the resistors were “bypassed”, the available voltage went up to normal readings. Any available voltage reading less than source voltage indicates unwanted resistance causing a voltage drop somewhere in the circuit. Checking available voltage at the device doing the designed function in the circuit (motor, bulb, etc) is a good way of determining if there is unwanted resistance in the circuit. Available voltage should be very close to source voltage on devices designed to operate at full source voltage.

WARNING: Be sure to measure source voltage first before performing this test as a partially discharged battery could provide a lower than normal source voltage reading. Try to keep the trainers display voltage as close to 14.00 as possible. This is a very sensitive adjustment. Normal source voltages for non-running vehicles is approximately 12.6 volts and between 13.5-14.9 volts on running vehicles.

After completion of SA-8, turn in your answer sheet to the instructor and ask for Test 7 before proceeding to the next assignment.

SA-8 AVAILABLE VOLTAGE TEST - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

3. _____ volts at L1 Expressed as: _____

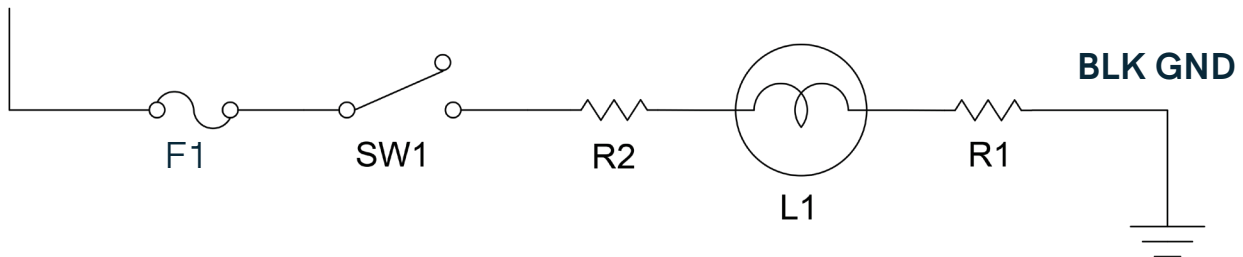
6. _____ volts at L1 with resistors bypassed Expressed as: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

After completion of SA-8, turn in your answer sheet to the instructor and ask for Test 7 before proceeding to the next assignment.

SA-9 Positive Voltage Drop Testing

14.00-14.60 V



SERIES CIRCUIT WITH TWO OR MORE RESISTANCES

SA-9 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.
Use the SA-9 student answer sheet to record all of your measurements and question answers.

1. Using the SA-7 SERIES CIRCUIT WITH TWO OR MORE RESISTANCES circuit from above (steps #1-10), (one most recently constructed) conduct a voltage drop test of the positive side of the circuit.
2. Using a DMM setup to measure voltage, measure the voltage drop from terminal A of bulb L1 to any of the **four red positive** receptacles on the trainer. Record your reading on the answer sheet.
3. What should the voltage drop reading be if the positive side of the circuit is operating normally without faults? Answer on the answer sheet.
4. What does the reading you measured seem to indicate? Answer on answer sheet.
5. Using a red jumper wire and using the piggy-back feature of the connectors, temporarily connect it from terminal L to terminal M of resistor R2. This in effect, bypasses the resistor in the circuit with the jumper wire which removes the resistance from the circuit.
6. With the jumper wire installed, measure the voltage drop of the positive circuit as you did in step #2. Record your reading on the answer sheet.

CONCLUSION: With the jumper wire installed, resistor R2 which is located in the positive half of the circuit is “bypassed” and therefore is not in the circuit. The voltage drop should have dropped to almost zero which indicates a normally operating positive half of the circuit. Any voltage reading more than zero indicates unwanted resistance in the circuit. Checking the available voltage and voltage drops of both the positive and negative sides of the circuit at the controlled device is a very handy way of helping you determine the location of problems from unwanted resistance.

SA-9 POSITIVE VOLTAGE DROP TESTING - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

2. _____ volts to positive of L1 Expressed as: _____

3. _____

4. _____

6. _____ volts to positive of L1 with resistor bypassed Expressed as: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-10 Ground Side Voltage Drop Testing

SA-10 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.
Use the SA-10 student answer sheet to record all of your measurements and question answers.

1. Turn switch SW1 OFF and remove the DMM from the circuit.
2. Remove the red jumper wire from terminal A of bulb L1 and from terminal L of resistor R2.
3. Remove the end of the red jumper wire that was connected to terminal M of resistor R2 and connect it to terminal A of bulb L1. There should now be NO resistances in the positive side of this circuit.
4. Turn switch SW1 to ON and describe the circuit performance in your own words on answer sheet.
5. Perform a voltage drop test of the ground circuit by connecting the red voltmeter lead to terminal B of bulb L1 and black voltmeter lead to the same black receptacle used for this circuit. Record your reading on answer sheet.
6. Turn switch SW1 to OFF.
7. Evaluate the voltage drop reading you measured from Step 11. What does it mean to you? Record your answer on the answer sheet.

SA-10 IDENTIFYING THE EXACT LOCATION OF THE UNWANTED RESISTANCE

8. Connect the red lead of the voltmeter to terminal B of bulb L1 and the black lead of the voltmeter to terminal J of resistor R1. You are measuring the voltage drop of the black ground wire from the bulb to the resistor. Put your voltage reading on your answer sheet
9. Now, connect the black lead of the voltmeter to the ground receptacle that the circuit black wire coming from resistor R1 is connected to and the red lead of the voltmeter to terminal K of resistor R1. You are measuring the voltage drop of the black ground wire from the resistor to system ground. Put your voltage reading on your answer sheet. Remove the DMM.
10. Evaluate both readings from Steps 13 and 14 and list your conclusions on the answer sheet. Remove the voltmeter.
11. Measure the voltage drop across resistor R1 (Red voltmeter lead to terminal J of resistor R1 and red voltmeter lead to terminal K of resistor R1) and record your answer on the answer sheet. Remove the DMM.
12. You have completed a three point voltage drop test of the ground circuit. Your readings when correctly understood will exactly pinpoint the location of the unwanted resistance.
13. What was the location of the unwanted resistance in the ground circuit? Record your answer on the answer sheet.
14. Remove the end of the black wire connected to terminal K of resistor R1 and connect it (piggy back) to terminal J of resistor R1.

15. Connect red voltage meter lead to terminal B of bulb L1 and black voltmeter lead to the ground receptacle used for the circuit. Measure the total ground circuit voltage drop and record your reading on the answer sheet.
16. You should now be able to use voltage drop testing to locate unwanted resistance in both positive and ground circuits.
17. Turn switch SW1 OFF and remove all wires and DMM wires from the trainer. Turn in your answer sheet to instructor.

CONCLUSIONS: With the jumper wire installed, resistor R1 which is located in the ground half of the circuit is “bypassed” and therefore is not in the circuit. The voltage drop should have dropped to almost zero which indicates a normally operating ground half of the circuit. Any voltage reading more than zero indicates unwanted resistance in the ground circuit.

After completion of SA-10, turn in your answer sheet to the instructor and ask for Test 8 before proceeding to the next assignment.

SA-10 GROUND SIDE VOLTAGE DROP TESTING - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

4. _____

5. _____ voltage drop of the ground circuit Expressed as: _____
7. _____

8. _____ voltage drop of one black wire Expressed as: _____
9. _____ voltage drop of one black wire Expressed as: _____
10. _____

11. _____ voltage drop of resistor R1 Expressed as: _____
13. _____

15. _____ voltage drop of ground circuit Expressed as: _____

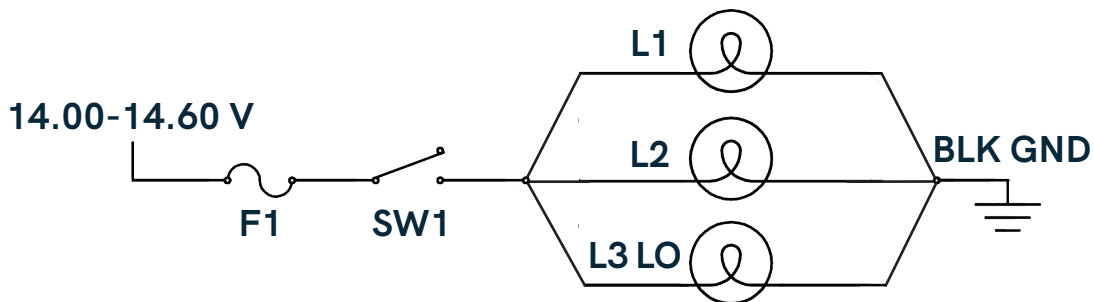
INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

After completion of SA-10, turn in your answer sheet to the instructor and ask for Test 8 before proceeding to the next assignment.

SA-11 Parallel Circuits with Two or More Resistances

SA-11 PARALLEL CIRCUITS EXPLANATION

A parallel circuit is defined as two or more resistances connected to a voltage source in such a way that each one receives full source voltage and a ground. In a parallel circuit with two resistances, there are two paths for current to flow and a break in one of the paths still allows the other resistance to operate. In a parallel circuit, the current is “branched” or split into each of the resistances. The individual resistances can share a common ground and/or voltage feed circuit. A common example of a parallel circuit is a headlight circuit that has a left and right headlight. The circuit is fed with a single power wire from the switch, but the circuit then “splits” to feed each light with a full 12 volts. Both headlight ground circuits are individual at the headlight, but often combine to a single ground point. With a parallel circuit, the left headlight can be removed or become defective and the right headlight will still work. A break in one branch of a parallel circuit will have no effect on the other branches



PARALLEL CIRCUITS WITH TWO OR MORE RESISTANCES

Volts, Amps and Ohms and their relationship to each other “behave” or perform in predictable ways in a parallel circuit. In the following assignments, you will construct some parallel circuits on the trainer to further learn how parallel circuits operate.

SA-11 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.
Use the SA-11 student answer sheet to record all of your measurements and question answers.

1. Make sure the CL-1919-06 trainer is properly set up and is plugged in to a 120V receptacle.
2. Turn the CL-1919-06 master power switch ON. The voltage display should be on. Adjust the voltage adjustment knob until the voltage displayed is 14.00-14.60 volts.
3. Connect **RED** jumper wires to the following locations:
 - a. Any of the four red + power terminals of the trainer to left-hand yellow terminal of the F1 fuse.
 - b. The right-hand yellow terminal of fuse F1 to terminal O of switch SW1.
 - c. Terminal I of switch SW1 to terminal A of bulb L1.
 - d. Terminal I of switch SW1 (piggy-back) to terminal C of bulb L2.

4. Connect **BLACK** jumper wires to the following locations:
 - a. Terminal B of bulb L1 to any of the black ground terminals on the trainer.
 - b. Terminal B of bulb L1 (piggy-back) to terminal D of bulb L2. NOTE: This is a “shared” or common ground path for both bulbs and is a very common method of circuit construction in automobiles.
5. Draw the circuit you have just constructed on a blank trainer schematic sheet and label the schematic: SA-11 PARALLEL CIRCUIT WITH TWO OR MORE RESISTANCES.
6. Confirm the correct hookup of this circuit with your instructor.
7. Turn SW1 to the on position. Both bulbs L1 and L2 should be on at full brilliance. Confirm proper circuit operation.

NOTE: in the previous assignments on series circuits, specific instructions were given regarding making measurements of voltage, resistance and current. For these assignments, less detail will be given. If needed, refer to previous assignments for more detail on meter setup and use.
8. Measure the current flow of bulb L1 at the positive side of the bulb. Record your reading on the answer sheet.
9. Measure the current flow of bulb L2 at the positive side of the bulb. Record your reading on the answer sheet.
10. Now measure the current in the ground path of both L1 and L2 bulbs. Record your reading on the answer sheet.
11. What conclusions can you make about the ground circuit of this circuit? Put your answer on the answer sheet.
12. With the circuit turned on, temporarily remove one end of each red jumper wire one at a time connecting to terminals A and C of bulbs L1 and L2. Describes what happens on the answer sheet. Turn switch SW1 OFF
13. Using the current and voltage measurements from the previous measurements, calculate the “dynamic” bulb resistances of L1 and L2. Put your answers on the answer sheet.
14. What is your prediction of total circuit amperage and total circuit resistance if another bulb is added in parallel to this circuit? Put your answer on the answer sheet.
15. Add L3 LO bulb in parallel to this circuit by connecting another red wire from terminal I of switch SW1 to the LO terminal of bulb L3.
16. Connect a black wire from the COM terminal of bulb L3 to any of the black ground receptacle on the trainer.
17. Turn switch SW1 to ON and confirm that all three bulbs are on at full brilliance. If not, go back over your work and correct the problem.
18. Measure the current flowing through bulb L3 LO and record on the answer sheet.
19. Using the L3 LO current and system voltage, calculate the dynamic resistance of bulb L3 LO. Fill in answer sheet.
20. Measure the total circuit current and record your measurement on the answer sheet.
21. Using your previous measurements, calculate the total dynamic resistance of the total circuit. Fill in answer sheet.

22. Describe what happens to a parallel circuit current and resistance as more resistance is added to the circuit. Fill in your answer sheet with your prediction.
23. Turn circuit OFF and trainer OFF, remove DMM and all red and black wires from trainer. Turn in your answer sheet to your instructor.

CONCLUSIONS: Step #11 confirms that in a parallel circuit, each branch is individually connected to source voltage and is “independent” of other branches. In parallel circuits, as more branches are added, the “total” current flow increases, but the current flow in each branch is determined by the amount of the resistance in that branch. So, as more resistances are added to parallel circuits, the “total” circuit resistance of all branches must be reduced. This is because more current is flowing as branches are added. Considering Ohm’s Law, the only way to get more current is to either decrease resistance or increase voltage. In this assignment, the voltage is constant, so the resistance is lowered as more parallel branches are added.

SA-11 PARALLEL CIRCUITS w/TWO OR MORE RESISTANCES - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

8. _____ amps of L1 on positive half Expressed as: _____

9. _____ amps of L2 on positive half Expressed as: _____

10. _____ amps of L1 & L2 on ground half Expressed as: _____

11. _____

12. _____

13. A. _____ ohms of dynamic resistance of L1 Expressed as: _____

B. _____ ohms of dynamic resistance of L2 Expressed as: _____

14. _____

18. _____ amps of L3 LO Expressed as: _____

19. _____ ohms of dynamic resistance of L3 LO Expressed as: _____

20. _____ amps of total circuit (L1, L2 & L3 LO) Expressed as: _____

21. _____ ohms of dynamic resistance of L1, L2 & L3 LO Expressed as: _____

22. _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-12 Parallel Circuits Behavior

SA-12 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.
Use the SA-12 student answer sheet to record all of your measurements and question answers.

1. Start with all red and black wires removed from the trainer.
2. Connect **red** jumper wires to the following locations:
 - A- Any of the four red positive receptacles to the left-hand terminal of fuse F1.
 - B- Right-hand terminal of fuse F1 to terminal O of switch SW1
 - C- Terminal I of switch SW1 to the left-hand terminal of push button switch PB1
 - D- Right-hand terminal of push button switch PB1 to the + terminal of motor M1
 - E- Terminal I of switch SW1 (piggy-back) to terminal A of bulb L1
 - F- Terminal I of switch SW1 (piggy-back) to terminal C of bulb L2
3. Connect **black** jumper wires to the following locations:
 - A- Terminal B of bulb L1 to any of the four black ground receptacles
 - B- Terminal D of bulb L2 to any of the four black ground receptacles
 - C- Terminal – of motor M1 to any of the black ground receptacles
4. Draw the circuit you have just constructed on a blank trainer schematic sheet and label the schematic:
SA-12 PARALLEL CIRCUITS BEHAVIOR.

SA-12 CIRCUIT EXPLANATION

Light bulbs L1 and L2 as well as the motor M1 are all connected in parallel. Each one is powered by the positive circuit through fuse F1. However, switch SW1 controls lights L1 and L2, but not motor M1. Motor M1 is controlled by push button switch PB1. However, in order for motor M1 to operate, switch SW1 must be in the on position. This is a good example of common parallel circuits used in vehicles. Many devices may be protected by a single fuse, but can be switched in many different ways. So, in this circuit, bulb L1, L2 and motor M1 and all connected in parallel even though they use individual ground circuits. If fuse F1 were to blow open, all three devices would no longer work. However, if there was a problem in just one of the three ground circuits, then only that device would malfunction, but the other two devices would operate normally. It is important that you fully understand this circuit before proceeding.

5. Turn SW1 ON and confirm that bulb L1 and L2 operate at full brilliance.
6. With SW1 still ON, push down the PB1 switch button and confirm that motor M1 starts rotating.
7. If any of the three parallel branches didn't operate properly, go over your wiring and correct the problem.
8. Carefully measure the total circuit current and record your measurement on the answer sheet.
Turn switch SW1 OFF.
9. Measure the resistance of resistor R1 and record your measurement on the answer sheet.

10. Study the circuit and make a prediction about circuit behavior IF resistor R1 were to be installed in the positive feed circuit. Put your prediction on the answer sheet.
11. Remove the red wire from terminal O of switch SW1 and connect it to terminal J of resistor R1.
12. Install a red wire from terminal K of resistor R1 and to terminal O of switch SW1.

NOTE- You have installed resistor R1 in series with the positive feed circuit to bulbs L1, L2 and motor M1.

13. Turn switch SW1 ON and push switch PB1 down, then describe circuit performance on the answer sheet.
14. Measure the total circuit current and record your measurement on the answer sheet.
15. Based on your current measurements in steps 7 and 13, describe why the circuit is behaving the way it is on the answer sheet.
16. Turn switch SW1 OFF.
17. Measure the resistance of resistor R2 and record your measurement on the answer sheet.
18. Move red wire from terminal J of resistor R1 to terminal L of resistor R2.
19. Move red wire from terminal K of resistor R1 to terminal M of resistor R2.
20. Predict what the circuit behavior will be with resistor R2 connected in series with the positive feed circuit. Put your prediction on the answer sheet.
21. Turn switch SW1 ON and describe the circuit behavior on the answer sheet.
22. Measure total circuit current and put your measurement on the answer sheet.
23. Turn switch SW1 OFF.
24. Measure the resistance of resistor R4 and record your measurement on the answer sheet.
25. Predict circuit behavior will be with resistor R4 connected in series with the positive feed circuit. Put your prediction on the answer sheet.
26. Turn switch SW1 ON and describe circuit behavior on the answer sheet.
27. Measure total circuit current and record your measurement on the answer sheet.
28. Turn switch SW1 OFF.
29. Measure the resistance of resistor R5 and record your measurement on the answer sheet.
30. Predict what the circuit behavior will be with resistor R5 connected in series with the positive feed circuit. Put your prediction on the answer sheet.
31. Turn switch SW1 ON and describe circuit behavior on the answer sheet.
32. Measure total circuit current and record your measurement on the answer sheet.
33. Turn switch SW1 OFF
34. Write total circuit currents for each resistor in the blanks provided on the answer sheet.
35. What conclusions can you make regarding the amount of resistance in this circuit. Put your answer on the answer sheet.

36. Remove all resistors from the positive side of the circuit and restore the positive side to original circuit construction as in Step 2. Confirm normal circuit operation. Turn switch SW1 OFF.
37. Insert resistor R1 into the ground circuit of bulb L2 by removing the end of black wire connected to the ground receptacles and connecting it to terminal J of resistor R1. Connect another black wire from terminal K of resistor R1 to the ground receptacles. Predict what will happen when switch SW1 is turned ON. Put your prediction in the answer sheet.
38. Turn switch SW1 ON and describe circuit behavior on the answer sheet.
39. Measure the current flow in bulb L2 circuit. Put your measurement on answer sheet.
40. Temporarily bypass resistor R1 by connecting a black jumper wire from terminal J to terminal K of resistor R1.
41. Measure the current flow in bulb L2 circuit with resistor R1 bypassed. Remove bypass black jumper wire. Record your measurement on answer sheet.
NOTE: This assignment demonstrates that in parallel circuits, unwanted resistances can be in a location that affects all parts of the circuit OR can be located in just one branch of the parallel circuit which will affect only that branch.
42. Measure the voltage drop across bulb L2.
43. Measure the voltage drop of bulb L2 ground circuit.
NOTE: This assignment demonstrates how to locate unwanted resistances in both series or parallel circuits. The voltage drop test of each connection should be close to zero if testing anywhere in either the positive or ground circuits. Total voltage drop across bulb L2 without any resistances should be close to source voltage. It is important that you completely understand how to use voltage drop testing to locate unwanted resistances.
44. Repeat steps 36 through 40 with resistor R5 and record your current measurements on answer sheet. It is not necessary to record your predictions, but should be discussed among yourselves.
45. Turn switch SW1 OFF, remove all jumper wires from trainer and digital multimeter and turn in your completed answer sheet to your instructor.

SA-12 PARALLEL CIRCUIT BEHAVIOR - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

8. _____ amps of total parallel circuit current. Expressed as: _____

9. _____ ohms of resistor R1. Expressed as: _____

10. Prediction: _____

13. Circuit Description: _____

14. _____ amps of circuit total with R1. Expressed as: _____

15. Prediction: _____

17. _____ ohms of resistor R2. Expressed as: _____

20. Prediction: _____

21. Circuit Description: _____

22. _____ amps of circuit total with R2. Expressed as: _____

24. _____ ohms of resistor R4. Expressed as: _____

25. Prediction: _____

26. Circuit Description: _____

27. _____ amps of circuit total with R4 Expressed as: _____
29. _____ ohms of resistor R5 Expressed as: _____
30. Prediction: _____

31. Circuit Description: _____

32. _____ amps of circuit total with R5 Expressed as: _____
34. A. _____ amps without any resistor Expressed as: _____
B. _____ amps with resistor R1 Expressed as: _____
C. _____ amps with resistor R2 Expressed as: _____
D. _____ amps with resistor R4 Expressed as: _____
E. _____ amps with resistor R5 Expressed as: _____
35. Conclusions: _____

37. Prediction: _____

38. Circuit Description: _____

39. _____ amps of bulb L2 ground with resistor R1 Expressed as: _____
41. _____ amps of bulb L2 ground with resistor bypassed. Expressed as: _____
44. A. _____ amps of bulb L2 ground with resistor R5. Expressed as: _____
B. _____ amps of bulb L2 ground with resistor R5 bypassed Expressed as: _____

INSTRUCTOR GRADE: _____ **DATE:** _____ **COMMENTS:** _____

SA-13 Circuit Behavior in Series and Parallel Circuits

LAW: In a **SERIES CIRCUIT**, the total circuit resistance is the sum of each individual resistances. As more resistances are added, the total circuit resistance will also increase and the total circuit current will decrease.

LAW: In a **PARALLEL CIRCUIT**, the total circuit resistance is **LESS** than the lowest value resistance. As more resistances are added, the total circuit resistance will decrease and the total circuit current will increase

SA-13 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the SA-13 student answer sheet to record all of your measurements and question answers.

1. There should be no jumper wires connected to the trainer at this point.
2. Using the DMM, measure the resistances of R1, R2, R3, R4 and R5 and record your readings on the answer sheet for assignment SA-13.
3. In the next steps, you will be working with resistors R3 and R4 which have equal values. Remembering the “laws of circuit behavior” for series and parallel circuits, let’s conduct a few experiments to prove these “laws”.
4. The trainers power switch should be turned OFF and the digital multimeter should be turned ON and adjusted for measuring resistance.
5. Connect a jumper wire from terminal O of resistor R3 to terminal Q of resistor R4. This leaves terminals N & P open. Resistors R3 and R4 are connected in “series”.
6. Connect the leads of the ohmmeter (piggy-back) to terminals N of resistor R3 and terminal P of resistor R4. Record your reading on the answer sheet.

CONCLUSIONS: When any two resistors connected in a series circuit, the total circuit resistance is the sum of the two resistors added together.

7. Remove previously used jumper wires and the DMM.
8. Connect a jumper wire from terminal O of resistor R3 to terminal Q of resistor R4.
9. Connect a jumper wire from terminal N of resistor R3 to terminal P of resistor R4.
10. Connect the leads of the ohmmeter to terminals P and Q of resistor R4 or terminals N and O of resistor R3. Record your reading on the answer sheet.

CONCLUSIONS: Resistors R3 and R4 are connected in parallel. Because resistors R3 and R4 are identical in value ($20\ \Omega$), the total circuit resistance is equal to one-half of either resistor or ($10\ \Omega$). If the resistors were not of equal value, the total circuit resistance will still be less than the lowest value resistor.

11. Connect resistors R1, R2, R3, R4 and R5 in the following sequences, then measure the total circuit resistances for each combination and record your measurements on the answer sheet. Be sure to carefully follow each step carefully to avoid errors.

12. R1, R2, and R3 in parallel. Measure total circuit resistance and record on answer sheet.
13. R1, R2 and R3 in series. Measure total circuit resistance and record on answer sheet.
14. R3, R4 and R5 in parallel. Measure total circuit resistance and record on answer sheet.
15. R1, R2, R3, R4 and R5 in series. Measure the total circuit resistance and record on answer sheet.
16. R1, R2, R3 and R4 in parallel. Measure the total circuit resistance and record on answer sheet.
17. R1, R2, R3, R4 and R5 in parallel. Measure the total circuit resistance and record on answer sheet.

CONCLUSIONS: Adding resistances in a parallel circuit will decrease the total circuit resistance which in turn will cause an increase of total circuit current flow. Adding more resistances in a series circuit will increase the total circuit resistance and thus, will cause a reduction of total circuit current. These relationships are extremely important to learn and remember.

18. Remove all jumper wires from the trainer and turn off the ohmmeter. Hand in your answer sheet to your instructor.

After completion of SA-13, turn in your answer sheet to the instructor and ask for Test 9 before proceeding to the next assignment.

SA-13 CIRCUIT BEHAVIOR IN SERIES & PARALLEL CIRCUITS - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

2. R1: _____ ohms. Expressed as: _____
R2: _____ ohms. Expressed as: _____
R3: _____ ohms. Expressed as: _____
R4: _____ ohms. Expressed as: _____
R5: _____ ohms. Expressed as: _____
6. _____ ohms of this series circuit. Expressed as: _____
10. _____ ohms of this parallel circuit. Expressed as: _____
12. _____ ohms of this parallel circuit. Expressed as: _____
13. _____ ohms of this series circuit. Expressed as: _____
14. _____ ohms of this parallel circuit. Expressed as: _____
15. _____ ohms of this series circuit. Expressed as: _____
16. _____ ohms of this parallel circuit. Expressed as: _____
17. _____ ohms of this series circuit. Expressed as: _____

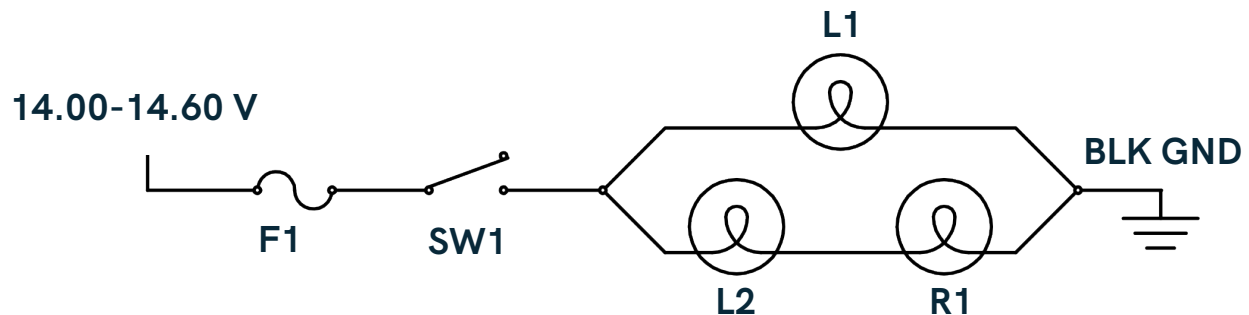
INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

After completion of SA-13, turn in your answer sheet to the instructor and ask for Test 9 before proceeding to the next assignment.

SA-14 Combination Series/Parallel Circuits

SA-14 COMBINATION SERIES/PARALLEL CIRCUITS EXPLANATION

A combination series/parallel circuit is a circuit that is connected with both series and parallel connected resistances. There are branches of the circuit with resistances connected in series, while other branches have resistances connected in parallel. It is not possible to apply a fixed set up rules for circuit behavior in combination series/parallel circuits. The circuit must be “organized” into portions and each analyzed separately. In the automobile, many parallel circuits are used, but certain branches of the parallel circuit can become a combination series/parallel circuit if unwanted resistance becomes present in the circuit. The following assignments will demonstrate this concept. Be sure to carefully read each step to avoid confusion.



SA-14 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.
Use the SA-14 student answer sheet to record all of your measurements and question answers.

1. Make sure the CL-1919-06 trainer is properly set up and is plugged in to a 120V receptacle.
2. Turn the CL-1919-06 master power switch ON. The voltage display should be on. Adjust the voltage adjustment knob until the voltage displayed is 14.00-14.60 volts.
3. Connect **RED** jumper wires to the following locations:
 - a. Any of the four red + power terminals of the trainer to left-hand yellow terminal of the F1 fuse.
 - b. The right-hand yellow terminal of fuse F1 to terminal O of switch SW1.
 - c. Terminal I of switch SW1 to terminal A of bulb L1.
 - d. Terminal I of switch SW1 (piggy-back) to terminal C of bulb L2.
4. Connect **BLACK** jumper wires to the following locations:
 - a. Terminal B of bulb L1 to any of the black ground terminals on the trainer.
 - b. Terminal B of bulb L1 (piggy-back) to terminal D of bulb L2 (NOTE-This is a “shared” or common ground path for both bulbs and is a very common method of circuit construction in automobiles.).
5. Turn switch SW1 to the on position. Both L1 and L2 bulbs should now be on a full brilliance. This circuit is a parallel circuit with the two bulbs sharing a common ground circuit and a common power circuit. Confirm proper circuit operation.
6. Turn switch SW1 off.
7. Disconnect the red jumper wire from terminal C of bulb L2.

8. Connect the disconnected end from step #7 to terminal M of resistor R2.
9. Connect a red jumper wire from terminal L of resistor R2 to terminal C of bulb L2. This step inserts resistor R2 in series with bulb L2. Bulb L1 still is connected to switch SW1 without any resistance.
10. Draw the circuit you have just constructed on a blank trainer schematic sheet and label the schematic: SA-14 COMBINATION SERIES/PARALLEL CIRCUIT.
11. Predict what the circuit performance will be and record your answer on the answer sheet.
12. Turn switch SW1 to the on position and observe the performance of bulbs L1 and L2. Were you correct in your prediction? Put your answer on the answer sheet.

EXPLANATION: The circuit with the resistor inserted is a combination series/parallel circuit. Bulb L1 shares full source voltage with only the resistance of the bulb L1 and illuminates at full brightness. Bulb L2 has the resistance of R2 in series with it and thus current flowing through R2 reduces the current available to L2 because there is only one path in that branch for current to flow. This is the series portion of the circuit. Bulbs L1 and L2 are in parallel with each other but L2 has an additional resistance of R2 in that branch.

13. Measure the available voltage at L1 and L2 and record your measurements on the answer sheet.
14. Measure the voltage drop across resistor R2 and record on the answer sheet.
15. Add the available voltage at L2 with the voltage drop of resistor R2 and record the answer on the answer sheet.

CONCLUSIONS: With resistor R2 inserted in the L2 bulb branch and becoming a series circuit in that branch, there is only one path for current to flow. Therefore, resistor R2 reduced the source voltage to L2 by 7.07 volts and thus bulb L2 only has about 7.0 volts to operate. This results in bulb L2 operating much dimmer than it is designed to. This circuit is a good example of common problems in automotive circuits where unwanted resistance is present in one of the parallel branches. In this case, the problem could not be in the ground circuit because both bulbs share the same ground. NOTE- The only exception to this would be a corroded or loose electrical ground connection at bulb L2 which would insert additional resistance for that branch of the circuit.

SA-14 COMBINATION SERIES/PARALLEL CIRCUITS - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

11. _____

12. _____ Yes or No.

13. A _____ L1 available volts. Expressed as: _____

B _____ L2 available volts. Expressed as: _____

14. _____ voltage drop across R2. Expressed as: _____

15. _____ L2 available + _____ R2 voltage drop = _____ volts.

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-15 Series/Parallel Circuit w/Resistance in One Ground Path Branch

SA-15 EXPLANATION

In this assignment, you will first construct a parallel lighting circuit consisting of bulbs L1 and L2, and bulb LED L3. After confirmation of correct operation, you will insert a resistance into the ground circuit of LED L3 making that branch a series circuit. Be sure to carefully read the instructions to avoid errors.

SA-15 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the SA-15 student answer sheet to record all of your measurements and question answers.

1. Make sure the CL-1919-06 trainer is properly set up and is plugged in to a 120V receptacle.
2. Turn the CL-1919-06 master power switch ON. The voltage display should be on. Adjust the voltage adjustment knob until the voltage displayed is 14.00-14.60 volts.
3. Connect **RED** jumper wires to the following locations:
 - a. Any of the four red + power terminals of the trainer to left-hand yellow terminal of the F1 fuse.
 - b. The right-hand yellow terminal of fuse F1 to terminal O of switch SW1.
 - c. Terminal I of switch SW1 to terminal A of bulb L1.
 - d. Terminal A of bulb L1 (piggy-back) to terminal C of bulb L2.
 - e. Terminal C of bulb L2 (piggy-back) to terminal LO of bulb LED L3.
4. Connect **BLACK** jumper wires to the following locations:
 - a. Terminal B of bulb L1 to any of the black ground terminals on the trainer.
 - b. Terminal B of bulb L1 (piggy-back) to terminal D of bulb L2 (NOTE - This is a “shared” or common ground path for both bulbs and is a very common method of circuit construction in automobiles.).
 - c. Terminal COM of LED L3 to any of the four black ground receptacles on the trainer
NOTE- This is a dedicated ground circuit for bulb LED L3.
5. Draw the circuit you have just constructed on a blank trainer schematic sheet and label the schematic: SA-15 SERIES/PARALLEL CIRCUIT w/RESISTANCE IN ONE GROUND PATH BRANCH.
6. Turn switch SW1 to the on position and confirm proper circuit operation. All three bulbs should be ON at full brilliance.
7. Using the DMM setup to measure voltage, measure the available voltage to each bulb and record on the answer sheet.
8. Make the following modifications to the circuit. Identify the black jumper wire connected from LED L3 LO to any of the four black ground receptacles. Remove the end of that black jumper wire connected to any of the four ground terminals and connect it to terminal N of resistor R3 (do not disconnect the end of that black jumper wire connected to LED L3 LO).
9. Connect a black jumper wire from terminal O of resistor R3 to any of the four black ground receptacles of the trainer. A resistance (R3) has been inserted into the ground circuit of bulb LED L3 LO which makes that branch a series circuit. Current must flow through the resistor before it can get to ground.

10. Predict what the circuit performance will be when you turn the switch on. Record your answer on the answer sheet.
11. Turn on switch SW1 and observe circuit performance.
12. Using the DMM set up for voltage, measure available voltage at L1, L2 and LED L3 LO and record your readings on the answer sheet.

NOTE: Be sure to have the negative lead of your voltmeter at the ground terminal of each bulb you are checking. Failure to do so will result in wrong readings. In order to check “available voltage”, the voltmeter leads **MUST** be attached at the device’s positive and ground circuit connections.

13. Conduct a voltage drop test across resistor R3 and record your reading on the answer sheet.

EXPLANATION: The inserted resistance of R3 in the ground circuit of bulb LED L3 LO causes a voltage drop on the ground side. Resistance in either the positive or ground side of a circuit will cause a reduction in available voltage to the device. The technician’s job is to locate the source of the unwanted resistance and make the necessary repairs. Without the inserted resistor, this circuit was a parallel circuit with three branches. After the resistor was inserted, it became a combination series/parallel circuit with the branch of bulb LED L3 LO becoming a series circuit. However, if the technician placed the black lead of the voltmeter to a “common” ground connection, the voltmeter would read full source voltage and the resistance in the ground circuit would not have been discovered.

CONCLUSIONS: This exercise reinforces the fact that unwanted resistances can be either in the positive side or the negative side of a circuit or even both sides at the same time. Unwanted resistances reduce the available voltage delivered to the device and often results in improper performance of the device. Examples are:

1. Dim bulbs.
2. Slow motor operation.
3. No operation of device at all.

It is important to remember that when checking “source voltage”, the voltmeter leads should be attached to the battery or source of the supply voltage. When checking “available voltage”, the voltmeter leads should be attached to the positive and ground terminals of the device being checked. This is a **VERY IMPORTANT** diagnostic fact to remember when checking circuit performance.

After completion of SA-15, turn in your answer sheet to the instructor and ask for Test 10 before proceeding to the next module.

SA-15 SERIES/PARALLEL CIRCUIT w/RESISTANCE IN ONE GROUND PATH BRANCH - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

7. A. _____ volts L1. Expressed as: _____
B. _____ volts L2. Expressed as: _____
C. _____ volts LED L3 LO. Expressed as: _____
10. _____

12. A _____ volts L1. Expressed as: _____
B. _____ volts L2. Expressed as: _____
C. _____ volts LED L3 LO. Expressed as: _____
13. _____ R3 voltage drop. Expressed as: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

After completion of SA-15, turn in your answer sheet to the instructor and ask for Test 10 before proceeding to the next module.

MODULE 4

Component Explanation

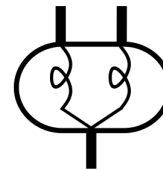
Component Explanation

The CL-1919-06 utilizes common electrical and electronic components for student use in constructing and understanding circuits. This unit is designed to explain each one individually, then in the next unit, students will connect the components into useful circuits. The component explanations follow the chronological order that the components are organized on the trainer.

LIGHT BULBS (INCANDESCENT)



**SINGLE FILAMENT INCANDESCENT
BULB SCHEMATIC SYMBOL**



**DUAL FILAMENT INCANDESCENT
BULB SCHEMATIC SYMBOL**

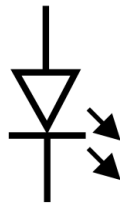
The CL-1919-06 trainer uses two incandescent light bulbs (L1 and L2). The term incandescent refers to any light bulb that operates by passing electrical current through a small wire (filament) which in turn causes the wire to heat up and glow giving off light (incandescence). Incandescent light bulbs at one time were very popular and were used for countless applications. Although incandescent light bulbs are very reliable, they have a few disadvantages in that they generate considerable amounts of heat and require relatively large amounts of electrical current compared to newer technology light bulbs.

Some incandescent light bulbs contain two separate filaments inside a single glass enclosure. These bulbs are called “dual-filament” bulbs and are commonly used in vehicle applications such as a combination tail/stop light bulb. The filaments have different amounts of resistance which in turn causes the bulb to operate at a different brightness. The tail light filament will have a higher resistance than the stop light. This results in the tail light being “dimmer” than the stop light. With a filament having less resistance, more current will pass through it and the brighter the bulb will be.

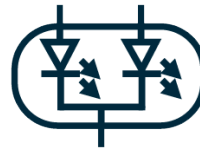
Incandescent light bulbs can be tested using an ohmmeter (if the bulb is removed from the circuit) or common testers such as continuity testers, 12V test lights and voltmeters. Testing also can involve measuring available voltage and voltage drop testing of both positive and ground circuits. The common electrical schematic for an incandescent single and dual-filament light bulb is shown above.

Ohmmeter testing of incandescent bulbs should be used only for determining if the bulb filament has continuity or is open. Ohmmeter testing should not be used in calculating the bulbs resistance. Incandescent bulbs need to have “dynamic resistance” determined by measuring the bulbs current flow and using Ohm’s Law with available voltage to determine actual “live” resistance. Dynamic resistance testing was covered earlier in this manual.

LED (LIGHT EMITTING DIODE)



LED
SCHEMATIC SYMBOL

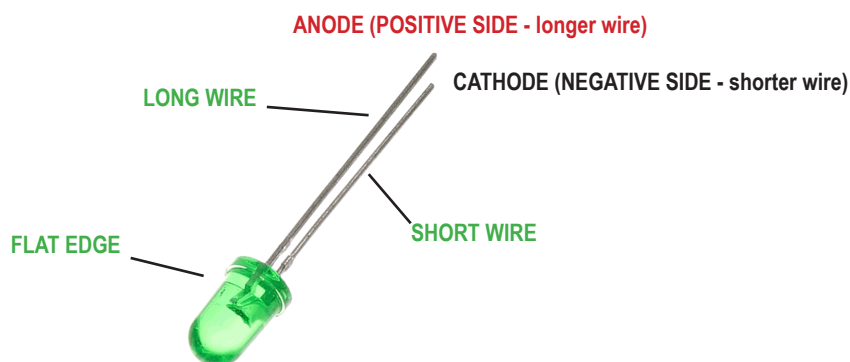


DUAL LED BULB
SCHEMATIC SYMBOL

The LED (light emitting diode) is fast becoming one of the most popular lighting sources used today. LEDs are found around the home, in industry and in most all vehicles today. They are used in appliances, digital readout devices, signs and countless other applications. It has some very useful advantages over incandescent bulbs in that they use extremely small amounts of electricity, are extremely bright, operate with relatively cool temperatures, have a long life span and are easily adaptable to many colors and sizes. LEDs used in vehicles are often grouped together to form different shapes that match styling differences in the vehicle. LEDs can also be “sequenced” to come on in different patterns for specific design effects.

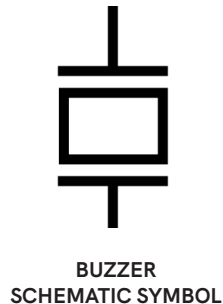
LEDs create light by passing electrical current through a special semiconductor material. Although the exact definition of how a LED works is a very complex technology, for the purposes of this section, we will state that a LED creates light from the movement of photons which are part of an atom when electrons are passed through a semiconductor. Photons are a source of energy which in this case, is used for light.

LEDs have definite polarity concerns when being installed in a circuit. They must be installed properly in the positive and negative sides of a DC circuit. LEDs can have normal operating voltages of about 2.1 volts but are also available in 12VDC designs. LEDs with voltage ranges of 2.1 V must be installed with a voltage dropping resistor in series with the LED. Some LED packages have built in dropping resistances and can be safely connected to 12 volts. If a non-protected 2.1V LED is connected to a 12V circuit, it will be instantly ruined. The LEDs used in the CL-1919-06 is designed to operate properly on full source voltage (14.6 volts) and is internally protected from reverse polarity hookup. If the trainer's L3 LED is installed backwards, nothing will happen and the LED bulb will operation normally. This is because the 3157 LED bulb does have specific polarity. Like all 3157 bulbs, it can be correctly installed two different ways. Other LED bulbs require proper polarity hookup (See drawing below).



LEDs are most commonly tested in the circuit. Checks for proper supply voltage and a good ground circuits are made and if present, the most common method is to replace the LED with another one.

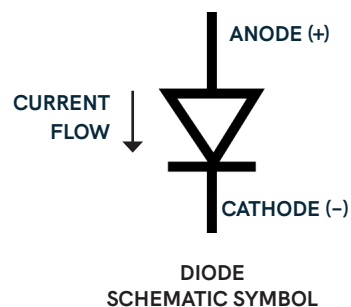
BUZZER



The CL-1919-06 buzzer is an audible device that primarily is used for constructing vehicle horn circuits. Electrical audible devices are available in countless styles, shapes and can generate numerous tones, sounds and volume levels. The most common audible devices operate from 12 VDC but there are variations. Audible devices are also often polarity sensitive requiring the proper connections of positive and negative circuits. The CL-1919-06 12VDC buzzer is protected from reversed polarity and if connected improperly, no damage will occur. A common example of an audible warning device used in an automobile is the horn, seat belt and lights left on indicators.

Audible devices are often tested by performing an available voltage and ground circuit test at the device, and if present, the device is usually replaced.

DIODE



Diodes are used in electrical circuits for numerous purposes and applications. A diode acts like an electrical one-way check valve in that it allows electron flow in one direction, but blocks it in the opposite direction. Most simple diodes have two leads or terminals. One is called the ANODE and is a positive (+) polarity. The other is called the CATHODE and is a negative (-) polarity. Diodes conduct current flow from the ANODE to the CATHODE.

If a diode is connected in a circuit with the positive side of the circuit connected to the ANODE, the diode will conduct current. If the negative side of the circuit is connected to the ANODE, the diode will block current. Typical diodes have very low internal resistances causing a voltage drop in the circuit of about 750 mV or 0.750 V.

Testing of Diodes

NOTE: Diodes must be electrically disconnected from the circuit prior to testing to obtain accurate results.

A. Diodes can be tested with an ohmmeter:

1. Using an ohmmeter, set the ohmmeter to read “AUTO RANGING”.
2. Connect the positive test lead to the diode CATHODE and the negative test lead to the diode ANODE.
3. With this hookup, the ohmmeter should show a reading of approximately 5.5 MΩ.
4. Reverse the ohmmeter test leads to the diode. The ohmmeter should read “infinity” or “OL” or “1.” depending on the DMM style.
5. If the ohmmeter shows continuity in both directions ,or infinity in both directions, the diode is either “shorted” (shows continuity) or “open” (shows infinity).

NOTE- Ohmmeters can often have different internal circuit polarities and thus the readings of steps 3 & 4 may be reversed.

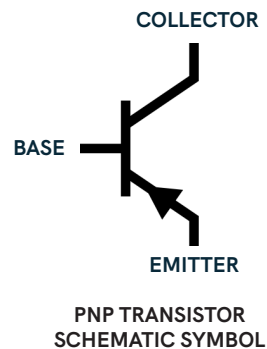
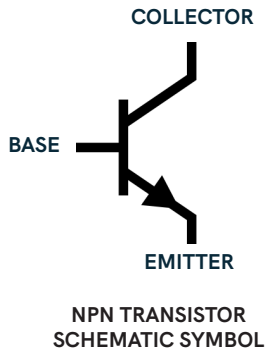
B. Diodes can also be tested with the DIODE TEST function of a DMM if equipped with this feature:

1. Set the DMM to the DIODE TEST function.
2. Hookup of the meter test leads to the diode as when using the ohmmeter.
3. With the red test lead on the ANODE (+) terminal of the diode, the meter should show a voltage drop of approximately 500 mV or 0.500 V (±).
4. With the black test lead on the ANODE (+), the meter should show “infinity”, “OL” or “1.” depending on meter style.

C. Diodes can also be tested with a 12 volt test light:

1. Install a small black jumper wire to the CATHODE (-) terminal of the diode.
2. Connect the other end of this black jumper to the negative terminal of a 12 volt battery.
3. Connect a 12 volt test light to the positive terminal of a 12 volt battery.
4. Connect the probe of the test light to the ANODE (+) terminal of the diode.
5. The test light should illuminate. If the test light does not come on, the diode is open.
6. Reverse the connections of the black jumper wire and the 12 volt test light to the battery. (black jumper connects to the diode ANODE (+) terminal and the test light probe connects to the diode CATHODE (-) terminal).
7. The test light should remain OFF. If the test light comes on, the diode is shorted.

TRANSISTORS



The electronic transistor has literally changed the world and electrical and electronic devices we use every day. Before transistors, all electrical devices including TV's and radios operated with a device called a "vacuum tube". Vacuum tubes were bulky and generated high amounts of heat. There were also more expensive and difficult to manufacture than transistors. The invention of the transistor is considered by many to be one of the biggest events in the history of mankind. Transistors allowed the development of "portable" electronic devices. The high majority of circuits used in devices today utilize many different types of transistors and other semi-conductor devices.

A transistor is a semi-conductor device that is used to amplify and/or switch electronic circuits. It consists of semi-conductor material with at least three electrical terminals consisting of BASE, COLLECTOR and EMITTER. It can both amplify power and switch circuits. There are two basic types of simple transistors. One is called N-P-N and the other is P-N-P.

For switching circuits, a transistor can be thought of as a type of relay. A relay has both a LOAD circuit and a CONTROL circuit. Transistors have the same. For both transistors, current flows into the transistor at the BASE and COLLECTOR and out of the EMITTER. The COLLECTOR TO EMITTER is the LOAD circuit (higher current) and the BASE to EMITTER is the CONTROL circuit (lower current).

For a NPN transistor, the BASE circuit is positively switched to turn the transistor on. For a PNP transistor, the BASE circuit is negatively switched to turn the transistor on. The LOAD is on the positive side of an NPN and on the ground side of a PNP transistor.

NPN Transistor Circuit Hookup:

1. Connect NPN Collector to one side of the load.
2. Connect other side of the load to supply voltage positive.
3. Connect NPN Base to one side of the switch.
4. Connect other side of switch to supply voltage.
5. Connect NPN Emitter to ground.

The LOAD would be connected from source voltage through the load to the COLLECTOR of the transistor. The CONTROL circuit would be connected from source voltage through a switch to the BASE of the transistor. The EMITTER circuit is grounded.

PNP Transistor Circuit Hookup:

1. Connect PNP Base to the switch and the other side of the switch to ground
2. Connect PNP Emitter to positive power supply
3. Connect PNP Collector to positive side of controlled device
4. Connect the ground side of the controlled device to ground

Supply voltage is connected to the EMITTER and the LOAD would be connected from COLLECTOR to ground. The CONTROL voltage would be connected from the BASE through a switch to ground.

Transistors can be tested in many ways, but for the purposes of this manual, an ohmmeter will be used.

Some technicians use a mental “trick” when identifying whether a transistor is a PNP or NPN. They look at the schematic symbol for the transistor in the circuit and observe the EMITTER arrow. If the arrow is pointing away from the center they say: “Not Pointing In” or NPN. If the arrow is pointing to center they say: “Pointing In” or PNP.

Because a transistor is made up of basically two-diode type circuits, the DIODE TEST function of a DMM can also be used. Follow the below chart to test transistors using an ohmmeter:

Testing Transistors with a DMM Ohmmeter

NOTE: Transistors can be tested with an ohmmeter and/or the “DIODE TEST” function of a DMM if equipped. Some technicians prefer the DIODE CHECK method over the ohmmeter because it “loads” the two solid state connections inside the transistor which can give more accurate testing of the transistor under a load.

N	P	N	TEST LEAD POLARITY	P	N	P
-	+	→		+	-	←
E	B	C		E	B	C
M	A	O		M	A	O
I	S	L		I	S	L
T	E	E		T	E	E
T		C		T		C
E		T		E		T
R		O		R		O
		R				R

SHOULD CONDUCT WITH OHMMETER
LEADS CONNECTED BETWEEN POINTS.
SHOULD NOT IF LEADS ARE REVERSED.

SHOULD CONDUCT WITH OHMMETER
LEADS CONNECTED BETWEEN POINTS.
SHOULD NOT IF LEADS ARE REVERSED.

COLLECTOR TO EMITTER testing should ALWAYS show “open circuit” or infinity. If it doesn’t, the transistor is shorted.

MOTOR



MOTOR
SCHEMATIC SYMBOL

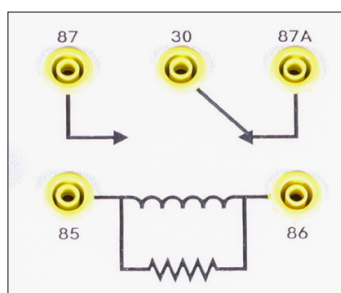
Motors are used in many different applications in electrical circuits. There are DC motors of many different designs and styles. The CL-1919-06 trainer uses a simple DC motor that is designed to draw between 10 mA or 40 mA of current at 14.00 volts depending on the motor installed on your specific trainer. Some DC motors rotational direction can be reversed by reversing the electrical polarity of the positive and ground circuits feeding the motors.

Motors are designed to perform useful work such as moving a window, operate a door lock, raise/lower an antenna, operate windshield wipers, move a seat or rotate a blower cage to move air. Each motor will have a design amperage for the motor to operate within. Motors can have single or multiple speeds. They are mechanically coupled to device they are designed to move or rotate. DC motors can be use brushes or can be brushless types. Brushless DC motors are becoming very common on today's vehicles especially on EV and hybrids.

Testing Motors

Motors are tested by measuring the available voltage, the motor current draw and the voltage drops of both the positive and ground portions of the circuit. Some motors also mechanically fail due to defective or worn bearings.

RELAY

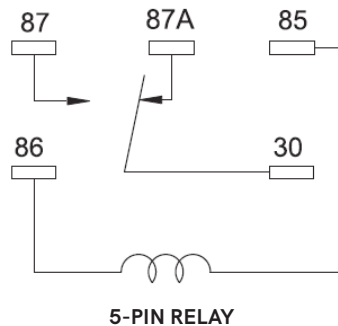


RELAY
SCHEMATIC SYMBOL

Relays are commonly used throughout the electrical industry. A relay performs the function of controlling a high amperage circuit with a very small amperage control circuit. Prior to the use of relays, very large wires had to be connected to switches that were capable of handling the high current of the devices being controlled.

A relay has two “parts” or is divided into two distinct portions. One is called the “CONTROLLED LOAD” (HIGH CURRENT) side and often controls the turning on or off devices such as motors. The other is called “CONTROL” (LOW CURRENT) side and usually contains some type of switch or switching circuit to turn the relay on and off.

The CONTROL side (COIL CIRCUIT) contains a coil of wire which, when supplied with a positive and negative source, creates a magnetic field that in turn moves a mechanical switch inside the relay which either connects or disconnects high current contacts. Either the positive or negative (ground) side of the coil can be switched to control the relay. A very common relay used in automotive circuits is the ISO 5-pin relay. ISO stands for International Standards Organization and indicates that the terminal placement, configuration and identification of this relay will be identical regardless of manufacturer. The CL-1919-06 uses a standard 5-pin ISO mini relay.



PIN	DESCRIPTION
85	NORMALLY COIL GROUND
86	NORMALLY COIL 12V FEED
30	12V FEED IN FOR CONTROLLED CIRCUIT or 12V OUT TO CONTROLLED COMPONENT
87A	NORMALLY CLOSED CONTACT — CAN BE 12V FEED IN or 12V OUT TO CONTROLLED COMPONENT
87	NORMALLY OPEN CONTACT — CAN BE 12V FEED IN or 12V OUT TO CONTROLLED COMPONENT
30 to 87A	NORMALLY CLOSED WHEN RELAY IS OFF
30 to 87	NORMALLY OPEN WHEN RELAY IS OFF

Control Side (coil circuit)

Relay terminals #85 and #86 are the two ends of the relay coil. Terminal #85 normally is connected to a ground circuit. As previously stated, when a positive voltage is connected to terminal #86 and a ground circuit is supplied to terminal #85, the coil is energized and a magnetic field will be established with the coil. This will cause a movement of a switch lever inside the relay which also results in an audible “click” sound when the coil is energized. The coil current of this ISO relay will be approximately 160 mA @ 14.00 volts. The resistance of the relay coil will be about 80 Ω . Relay circuits can switch either the positive side of the coil or the ground side. Check with the circuit wiring schematic to determine which is used. NOTE: Some newer relays can have a higher coil resistance than 80 ohms. Always check service information to confirm.

NOTE: Relay coils generate an induced voltage when they are de-energized which can exceed 200-400 volts. If this induced voltage is allowed to escape the relay, it can damage sensitive electronic components like PCM's and modules. The induced voltage is controlled by two methods. One uses a “shunt” resistor connected in parallel to the relay coil. The other method uses a diode connected across the relay coil. If the coil is protected by a resistor, it doesn't matter which coil terminal (85 or 86) is ground and which is B+. However, if the coil is protected by a diode, the hookup of the 85 & 86 terminals MUST be properly connected based on how the diode is installed in the coil. Hooking up the relay coil circuit “backwards” will instantly destroy the protection diode, but the relay will still operate although without spike protection. ALWAYS follow specific circuit schematics when hooking up and testing relays. NOTE: The CL-1919-06 relay is shunt resistor protected and therefore, terminals 85 & 86 can be either ground or B+.

Controlled Side (load circuit)

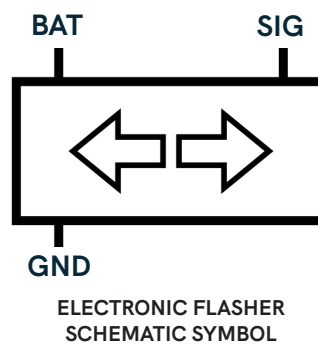
The three remaining terminals of the ISO relay are labeled #30, #87 and #87a. The relay has two sets of contacts. One set are normally closed (NC) when the relay is off. These are labeled #30 and #87a. The other set of contacts are normally open (NO) when the relay is off. These are labeled #30 and #87. When the relay is turned off, there is a connection between #30 and #87a. When the relay is turned on, the connection between #30 and #87a is broken (open) and terminals #30 and #87 are connected.

Most relay coils are protected from induced voltage spikes when the coil circuit is interrupted. The most common method uses a “shunt resistor” connected in parallel with both ends of the coil. Another option is to use a diode in parallel with the coil. If either 85 or 86 can be either positive or ground, the relay is resistor protected. If a diode is used, then 86 must be used as the positive coil feed. The relay in the CL-1919-06 is resistor protected.

ISO Relay Testing

ISO relays can be tested using several different techniques. Testing the relay in the circuit can involve checking for the presence of a voltage supply (usually to terminal # 30) and also testing for a voltage connection (#30 & #87) when the relay is turned on. Checking for a power source and a ground source to the relay coil is also a valuable test. Relay coil resistance can be measured with an ohmmeter and coil current flow can be measured with an ammeter. Always check a relay while it is under load to check for voltage drop across the load terminals. Some technicians mistakenly believe that if the relay “clicks”, it is OK. This is not true. Always check for voltage drop across relay terminals 30 to 87 and 30 to 87a with the relay under the same load as in the circuit.

ELECTRONIC FLASHER

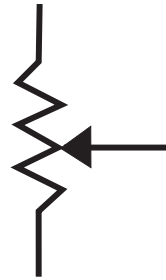


Electronic flashers are most commonly used in vehicles to operate the turning signals and hazard warning lights. There are also other specific uses for them in specialized circuits. The electronic flasher differs from the older style “thermal” flasher in that electronic flashers can handle larger amounts of current. Most vehicles today use electronic flashers.

Flasher Testing

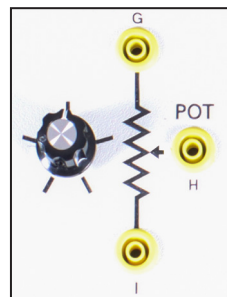
Electronic flashers are commonly tested by confirming the presence of a positive and ground circuits available to the flasher and that the load or signal side of the flasher is connected to a known good bulb (or other load) and ground. Checking for available voltage and voltage drop testing of both positive and ground circuits is also done.

POTENTIOMETER



POTENTIOMETER
SCHEMATIC SYMBOL

A potentiometer is best described as a “variable resistance” that can be controlled by turning a knob or by sliding a control knob back and forth. Common applications of a potentiometer are the volume, tone and balance controls on a typical audio system. A potentiometer usually has three terminals. Looking at the above schematic symbol of a potentiometer, notice that there is a resistance with two ends each having a terminal. The third terminal is represented by an arrow and as the potentiometer is adjusted, the arrow moves back and forth along the resistance. This results in a varying resistance between terminals #I and #H as well as between terminals #G and #H. As the resistance between #I and #H decreases, the resistance between #G and #H will increase. This will be reversed as the potentiometer is adjusted in the opposite direction.



Potentiometers are used in many circuits in industry as well as in vehicles. A common application of a potentiometer in a vehicle is a TP (Throttle Position Sensor). In a typical TP circuit, terminals #G and #I would be connected to a positive power supply (usually 5 volts) and a ground. Terminal #H would be connected to a movable arm that would move as the driver steps on the accelerator pedal. This results in a varying voltage between terminal #H and ground which is used to “inform” the computer of the position of the accelerator pedal. As stated previously, potentiometers are also used as volume, bass, treble, fade and balance controls in audio systems.

Testing Potentiometers

Accurate testing of a potentiometer can be performed using an oscilloscope or graphing multi-meter. As a potentiometer is used over time, it can develop a “bad spot” on the sliding resistance which will affect the signal when the movable arm slides across this area. This condition can cause unwanted circuit performance. Testing a potentiometer with ohmmeter will not reveal these “glitches”. Ohmmeter testing will measure the resistance of the potentiometer and show changes in resistance as the potentiometer is moved. Voltage testing of the supply voltage and ground circuits as well as the varying signal voltage can also be done. Oscilloscope or some type of signal display method is the only way to accurately test potentiometers.

RESISTORS



**RESISTOR
SCHEMATIC SYMBOL**

Resistors are commonly used in electrical circuits for many purposes. Among the most common examples are to reduce voltage in specific parts of a circuit or to serve as current limiting devices. Most common resistors are manufactured from carbon and can be designed to contain resistance values from less than one ohm to over millions of ohms depending on the intended application. In expressing the amount of resistance in a resistor, terms of “kilo” for 1,000 and “mega” for 1,000,000 ohms are used. Abbreviations are used for these terms: “kilo = $k\Omega$ = Kilohm” and “mega = $M\Omega$ = Megohm”.

Some resistors have a color-coded system using colored rings around the resistor that are used to identify the resistors ohm value and $\pm$ accuracy tolerance range. Resistors are also classified by “wattage” which is how much current the resistor can safely conduct without overheating and burning up. Variable resistors are also used in electrical and electronic circuits and are called potentiometers (3-wire) or rheostats (2-wire). Resistors introduce a specific and desired amount of resistance in a circuit to provide intended results, whereas unwanted resistance caused from corrosion, loose or dirty connections is undesirable and needs to be identified and repaired. Voltage drop testing is the most accurate method of determining the location of unwanted resistance in a circuit (See voltage drop testing section).

Testing Resistors

Resistors can be tested using an ohmmeter (out of the circuit) or conducting a voltage drop test across the resistor using a voltmeter. Variable resistors can be testing using an oscilloscope or graphing multimeter. Unwanted resistances in a circuit are tested by conducting voltage drop tests from one point in a circuit to another while the circuit is operating. Common voltage drop specifications for low current circuits range from 0.1-0.2 volts (100-200 mV). Exceptions can be mechanical switches, solenoids and relays.

FUSES



**FUSE
SCHEMATIC SYMBOL**

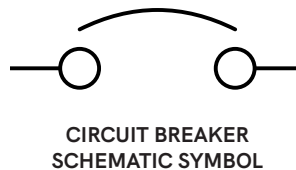
Circuits are commonly protected from excessive current by “over-current” devices. Among the most common are fuses, circuit breakers and fusible links. The CL-1919-06 uses a common replaceable ATC type plastic fuse rated at 2 or 3 amps. Other types of fuses include ATC, MAXI ATC, MINI ATC, MICRO ATC, glass, cartridge and ceramic fuses. The purpose of a fuse is to protect the circuit from excessive current which could cause damage and/or fires. Most fuses are designed for a “one-time” protection event and will “open” if current exceeds it’s designed value.

Fuses are designed with amperage values of less than one amp to many hundreds of amps depending on the circuit it protects. Automotive fuses commonly range from 2-100 amps. A fuse contains a particular size and diameter of wire that is designed to melt and break the circuit if the current flowing through the fuse exceeds its amperage value. NEVER replace a blown fuse with a larger amperage fuse! This can cause wiring to overheat and cause fires and circuit damage.

Testing Fuses

Most fuses have two terminals and are identified as “feed” and “load”. Fuses are tested using a 12-volt test light, voltmeter or ohmmeter (out of circuit). A good fuse should have zero resistance, should have no voltage drop across it and should have full circuit voltage on both sides of the fuse. If it is “blown” or open, one terminal will have circuit voltage and one will measure zero. NOTE: If a fuse is installed in a circuit, anytime current is flowing in that circuit, there will be a voltage drop across the two terminals of the fuse. This fact allows technicians to determine how much current is flowing through the circuit by using specific charts that convert the voltage drop to current.

CIRCUIT BREAKERS



A circuit breaker is also an over-current protection device but often can be either automatically or manually reset after it protects the circuit by opening. Circuit breakers are used in homes, industry and the automobile. They are rated by the maximum current they can conduct without “tripping” or opening the circuit.

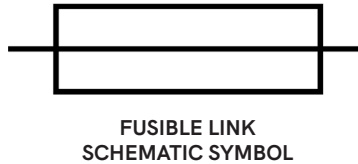
The CL-1919-06 uses a manually reset circuit breaker (located near the voltage adjustment knob). If wiring errors are made on the trainer that result in excessive current flow, the circuit breaker will open and the O.L. indicator light will illuminate. After the circuit error is identified and corrected, the circuit breaker can be reset by pushing and holding in on the RESET button until the O.L indicator flashes, then release the RESET button.

Testing Circuit Breakers

Automotive circuit breakers can be testing using 12-volt test lights, voltmeters, voltage drop testing across the circuit breaker or ohmmeter (out of the circuit). Most circuit breakers have two electrical terminals and operate similar to fuse with the exception that circuit breakers can be reset after the protection event.

The CL-1919-06 uses a circuit breaker device in the overload circuit protection circuit. When an overload occurs, the circuit breaker trips, thus interrupting the circuit until the error is corrected. Circuit breakers are commonly used in some vehicle circuits.

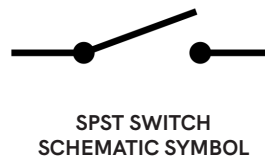
FUSIBLE LINKS



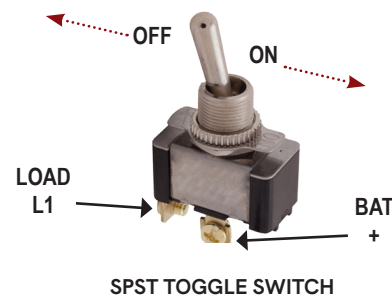
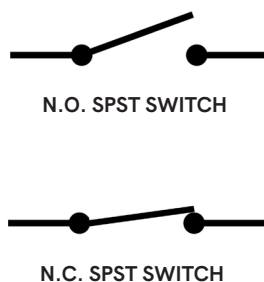
A fusible link is also a type of over-current protection device commonly used on vehicles. A fusible link is a short length of special designed wire and insulation that is smaller in diameter than the other circuit wiring. If a short-circuit condition occurs or the circuit has more current flowing in it than it was designed to handle, the fusible link will melt and open the circuit providing protection.

The insulation covering the fusible link is designed to swell up during the melting and can be inspected and identified as the source of the problem. Fusible links are often used at the battery, power distribution center and starter solenoid on many vehicles. Fusible links are serviced by replacing the melted section with a replacement of the same size. Some repair sources offer specific amperage bulk fusible link wire for repair purposes. Although the CL-1919-06 doesn't use fusible links, it is important that students understand the operation of them.

SWITCHES

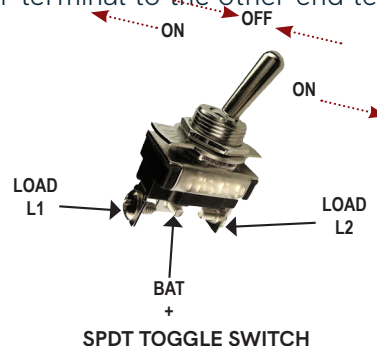
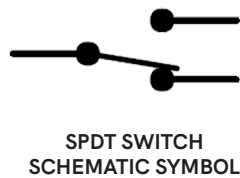


Switches are control devices designed to turn a circuit on or off. There are many different switch designs ranging from simple to very complex. Switches can operate mechanically or electronically. The CL-1919-06 uses a SPST switch. The term SPST means that it can control 1 “pole” or “single pole”. Therefore the switch would have two electrical terminals and would be installed in a single wire of a circuit. The acronym of “ST” means “single throw”. Single throw means the switch has only two positions, **open (N.O.)** or **closed (N.C.)**. So in the case of a SPST switch it would have two terminals and can be switched either on or off. “ON” electrically connects the two terminals together and “OFF” disconnects them.

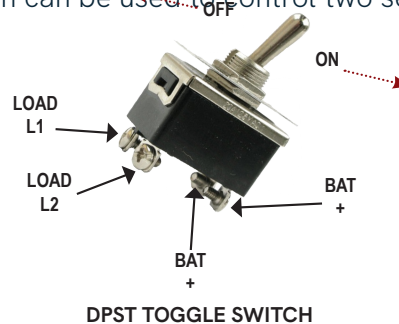
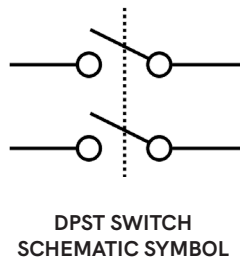


Other types of switches

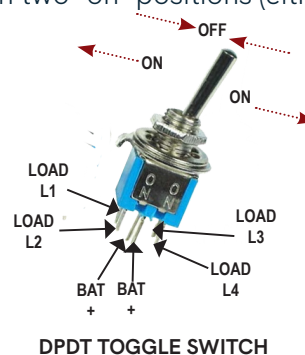
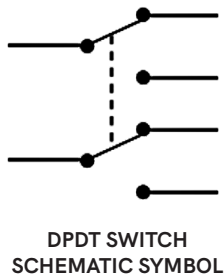
SPDT- (Single Pole Double Throw) (not used on the CL-1919-06) – A SPDT switch has three terminals and three positions. The toggle switch has a center off position during which there is no connection to the other terminals. Moving the toggle to one side connects the center terminal with one of the end terminals. Moving the toggle from center to the opposite side connects the center terminal to the other end terminal.



DPST – (Double Pole Single Throw) (not used on the CL-1919-06) – A DPST switch is really two single pole switches connected together. The switch will have four terminals and has either an “on” or “off” position. The two sets of terminals are not internally connected and the switch can be used to control two separate circuits.



DPDT- (Double Pole Double Throw) (not used on the CL-1919-06) – A DPDT switch is also two switches connected together. It can be configured either as a “center off” with two “on” positions (either side) (ON-OFF-ON) or a two position switch which controls two circuits (ON-ON).



NOTE- WEB LINK THAT THESE CAME FROM: http://www.colehersee.com/home/spst_spdt_dpst_dpdt

PULSE WIDTH MODULATION (PWM)



PULSE WIDTH MODULATION
SCHEMATIC SYMBOL

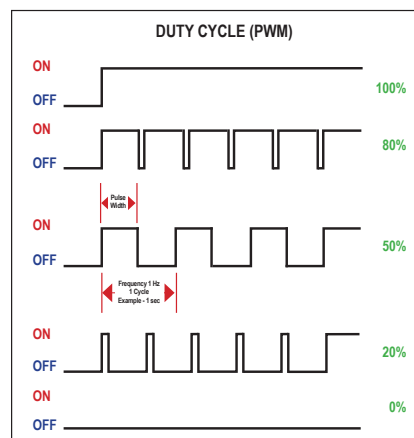
Pulse Width Modulation is an electrical term that describes the control of DC voltage in a circuit by changing the amount of time (pulse) that the circuit is on compared to the time it is off. The term “modulation” means that the circuit is constantly modulating or switching on and off. PWM is commonly used in many electrical components including washers, stoves, dishwashers, most electronic devices. In the automobile, PWM control of circuits, such as fuel pumps, HVAC blower motors, wiper motors and others, is used. PWM control of circuits allows the operation of a DC motor at various speeds without the requirement of voltage dropping resistors. It also allows a more precise control of motor efficiency and current draw due to the faster switching speeds of the circuit. Fuel injection supply pumps are commonly controlled with PWM to provide a more efficient response to pressure and volume requirements. Computers or microprocessors are typically responsible for control of PWM circuits. It is important to understand the terms below when working with PWM.

Pulse Width

The term PULSE WIDTH is the amount of time that the circuit is turned on and is usually measured in milliseconds.

Duty Cycle

The term DUTY CYCLE which is often used when discussing PWM, refers to the amount of time the circuit is ON and is expressed as a percentage. A 10% duty cycle means that the circuit is turned on 10% of the time and off 90% of the time. For example, a 50% duty cycle means that the circuit is on as much as it is off. As the ON time increases, the OFF time decreases. Just to be clear, the device is NOT operating on 6V, but the multimeter “averages” the voltages seen and thus displays 6V. In reality, the device is operating on 12V for only for 50% of the total time. A graphing voltmeter or oscilloscope are the only tools where PWM signals can be accurately displayed. For example, on a 12-volt circuit operating on and off with a 50% duty cycle, the “output” voltage would be measured at 6 volts. Many digital multimeters are equipped to measure DUTY CYCLE.



Ground or Positive Switched PWM

PWM circuits can be either POSITIVE or GROUND switched. This is important to know because the pattern displayed could be easily misunderstood. For example, a pattern showing a short duration at the top of the pattern could be a short duty cycle for a positive switched circuit or a long duty cycle for a ground switched circuit. Properly reading and understanding a wiring schematic is required to fully understand PWM circuits.

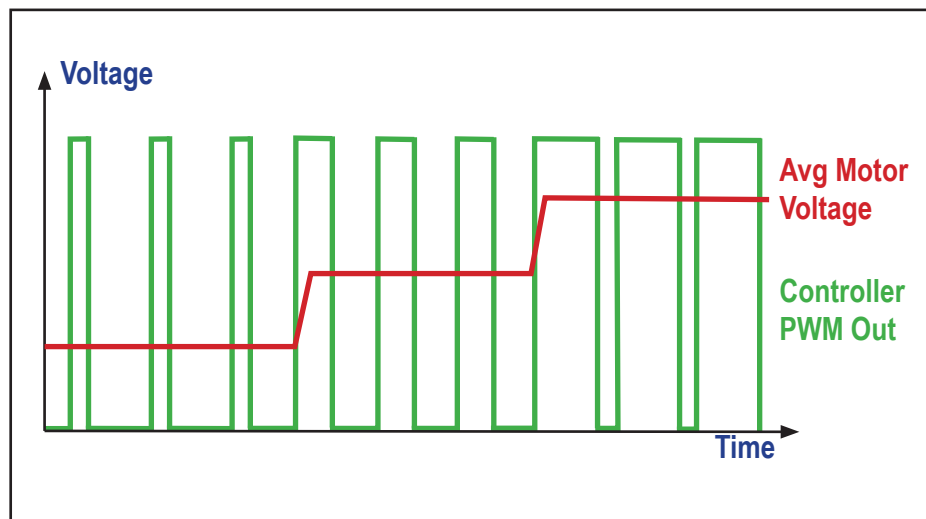
Frequency

FREQUENCY is a term used to define how many “on/off” cycles there are in a given amount of time. Frequency is measured in hertz (Hz). A very simple example of frequency is a circuit that is on for 2 seconds during a total time of 4 seconds. The entire “cycle” includes the time that the circuit is on and also the time it is off. If the circuit is on once for 2 seconds during a total time of 4 seconds, the frequency will be 1 Hz. If the circuit was turned on twice for 1 second each and off for 1 second each during the same time, the frequency would now be 2 Hz, but the time base of 4 seconds remains the same. Actual circuits operate much faster than this example.

Another example of frequency would be the engine RPM's. The frequency of the RPM's would be lower at idle speeds than it would be a cruising speeds.

The CL-1919-06 contains a PWM generator circuit that is adjustable throughout a 0-100% range. The voltage available at the positive (red) and negative (black) terminals will be close to zero at 0% Duty Cycle and about 13.00 volts at 100% duty cycle. The black terminal is connected to a ground source and the red terminal output is controlled by the adjustment knob.

Some digital multimeters and scan tools are able to display and measure frequency..



After completion of COMPONENT EXPLANATION module, ask your instructor TEST 11.

MODULE 5

Student Experiments

Student Assignment Guidelines

Each of the following student assignments are designed to reinforce and apply the concepts, theories and explanations previously discussed in this manual. Be sure to carefully read and understand the directions for each assignment. Assignments also require the careful completion of a Student Answer Sheet for each assignment. Be sure to obtain the correct Student Answer Sheet for the assignment you are working on.

NOTE: For the purposes of this manual and student use of the CL-1919-06 trainer, all manual references to the direction of electron flow will use the CONVENTIONAL ELECTRON THEORY which is from positive to negative in the circuit.

PREREQUISITES

Before starting the student assignments the following instructional modules should have been completed and the assessment tests and/or quizzes successfully taken and evaluated by your instructor:

- Meter setup, use and reading interpretation unit
- Basic electricity
- Ohm's Law
- Component operation explanation

Most assignments will be organized using the following format:

- Students will be given wiring instructions for the correct hookup of the red and black jumper wires to complete the circuit.
- Students will be asked to draw the circuit they are building on a blank template and label it with the name of the circuit being constructed.
- If students are asked to make voltage, resistance or amperage measurements, specific instructions on how to accomplish the readings will not be given as this information was covered in the Meter Unit.
- Students are asked to fill out a student answer sheet for each assignment and turn in to their instructor when completed.

TRAINER SET UP

Unless otherwise noted, it is expected that the trainer is properly plugged into a 120V receptacle and the power supply is turned on. The displayed voltage should be approximately 14.0 - 14.6 volts.

SA-16 Light Bulb with Diode

SA-16 CIRCUIT EXPLANATION

This assignment demonstrates the operation of a diode in circuits. The diode performs the function of an electrical “one-way” check valve and can be used to block electrical flow in one direction.

SA-16 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-16 student answer sheet to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below:

CONNECT **RED** JUMPER WIRES BETWEEN:

- A. Any of the red positive receptacles to terminal O of SW1.
- B. Terminal I of SW1 to terminal A (anode) of diode D2.
- C. Terminal K (cathode) of diode D2 to terminal C of bulb L2.

CONNECT **BLACK** JUMPER WIRES BETWEEN:

- A. Terminal D of bulb L2 to any of the black ground receptacles.

2. Draw the circuit you have just constructed on a blank template and label it:
SA-16 LIGHT BULB WITH DIODE.
3. Turn switch SW1 to the “ON” position. Bulb L2 should be illuminated with full brilliance. Double check the operation of your circuit. If the circuit does not operate as described, go over your connections and make necessary corrections.
4. Measure the voltage drop across diode D2 and record your measurement on the answer sheet.
5. Measure the voltage drop across bulb L2 and record your measurement on the answer sheet.
6. Measure the amperage draw of the circuit and record your measurement on the answer sheet.
7. Using Ohm’s Law, calculate the resistance of bulb L2 and record your answer on the answer sheet.
8. Using Ohm’s Law, calculate the resistance of diode D2 and record your answer on the answer sheet.
9. Add the resistances of bulb L2 and diode D2 together.
10. Fill in the below calculated or measured values on the answer sheet:
 - A. TOTAL CIRCUIT RESISTANCE.
 - B. TOTAL CIRCUIT AMPERAGE.
 - C. SUPPLY VOLTAGE.
11. Using Ohm’s Law, prove out that the total circuit resistance, supply voltage and circuit amperage all mathematically “fit together”. Fill in the below calculated values on the answer sheet.
 - A. Voltage divided by amperage equals ? ohms of total circuit resistance.
 - B. Voltage divided by resistance equals ? amps of total circuit amperage.
 - C. Amperage times resistance equals ? volts of circuit supply.

12. Do your calculations match the measured values above? Yes or No. Put your answer on the answer sheet).
13. Turn switch SW1 to the “OFF” position.

CIRCUIT EXPLANATION: The diode D2 is conducting current flow in a “forward bias” direction. Diode schematic symbols indicate the direction of current flow. Notice that the power “feed” enters the diode at terminal A and exits the diode at terminal K as it flows into bulb L2 and then through the bulb to ground. The arrow on the schematic symbol indicates that the diode “flows” in the direction of the arrow. The diode D2 in the circuit draws a very small amount of current because it’s low resistance is connected in series with the light bulb and total resistance of the circuit is accumulative. The diodes low resistance compared to the light bulb’s resistance is very low, but because it is a series circuit, adding additional low resistances will have very little effect on total circuit amperage.

14. Reverse the red jumper wires at terminals A and K of diode D2.
15. Turn switch SW1 to the “ON” position.
16. What describes the operation of the circuit now? Put your answer on the answer sheet.
17. Measure the voltage drop across diode D2 and record your reading on the answer sheet.
18. What conclusions can you make from the reading taken in Step 17 (describe it on the answer sheet).
19. Install a jumper wire from terminals A to K of diode D2 and describe the circuit performance on answer sheet.
20. Turn switch SW1 to the “OFF” position.

CIRCUIT EXPLANATION: Reversing the positive wires at the diode causes the current to attempt to flow “backwards” through the diode. This is called “reverse bias” and unless the diode is defective, it will block electron flow. There are very technical explanations that describe the internal operation of a diode, but for the purposes of this basic assignment, it will suffice to say that a diode conducts in a forward bias condition and blocks electron flow in a negative bias condition. Installing the jumper wire takes the diode out of the circuit and allows current flow to the light bulb.

SA-16 LIGHT BULB WITH DIODE - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

4. Voltage drop of diode D2 _____ volts. Expressed as: _____
5. Voltage drop of bulb L2 _____ volts. Expressed as: _____
6. Amperage draw of circuit _____ amps. Expressed as: _____
7. Bulb L2 resistance _____ ohms. Expressed as: _____
8. Diode D2 resistance _____ ohms. Expressed as: _____
9. Total circuit resistance _____ ohms. Expressed as: _____
10. A. _____ total circuit resistance. Expressed as: _____
B. _____ total circuit amperage. Expressed as: _____
C. _____ supply voltage. Expressed as: _____
11. A. Voltage divided by amperage equals _____ ohms of total circuit resistance.
Expressed as: _____
B. Voltage divided by resistance equals _____ amps of total circuit amperage.
Expressed as: _____
C. Amperage multiplied by resistance equals _____ supply voltage.
Expressed as: _____
12. _____ Yes/No.
16. _____

17. _____ voltage drop across diode D2. Expressed as: _____
18. _____

19. _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-17 Light Bulb Circuits

SA-17 CIRCUIT EXPLANATION

This assignment is designed to demonstrate the relationship between bulb resistance and illumination brightness. How bright a light bulb is depends on the amount of designed internal resistance.

SA-17 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-17 student answer sheet to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below:

CONNECT **RED** JUMPER WIRES BETWEEN:

- A. Any of the four red power receptacles to terminal O of switch SW1.
- B. Terminal I of switch SW1 to the LO terminal of bulb LED L3 LO.
- C. Using the piggy back feature, terminal I of switch SW1 to terminal A of bulb L1.
- D. Using the piggy back feature, terminal I of switch SW1 to terminal C of bulb L2.
- E. Using the piggy back feature, terminal I of switch SW1 to terminal E of LED D1.
- F. Any of the four red power terminals to left-hand terminal of switch PB1.
- G. Right-hand terminal of switch PB1 to the HI terminal of bulb LED L3 HI.

CONNECT **BLACK** JUMPER WIRES BETWEEN:

- A. Any of the four black ground receptacles to the COM terminal of bulb LED L3.
- B. Terminal B of bulb L1 to any of the four ground receptacles.
- C. Terminal D of bulb L2 to any of the four ground receptacles.
- D. Terminal F of LED D1 to any of the four ground receptacles.

2. Draw the circuit you have just constructed on a blank circuit schematic template and label it: SA-17 LIGHT BULB CIRCUITS.
3. Turn switch SW1 to the ON position. Bulbs L1 & L2, LED L3 LO and the LED D1 should all be on. Confirm proper circuit operation and correct any errors.
4. Push the PB1 switch pushbutton down and the HI side of bulb LED L3 should come on. Confirm proper circuit operation and correct any errors.
5. Using the ammeter feature of the DMM measure the individual current flow of bulbs L1, L2, LED L3 LO, LED L3 HI and the LED D1. Record your measurements on the student answer sheet:
 - A. ? amps for L1.
 - B. ? amps for L2.
 - C. ? amps for LED L3 LO.
 - D. ? amps for LED D1.
 - E. ? amps for LED L3 HI.

6. Using the voltmeter function of the DMM, measure the voltage drop across each bulb and record on the student answer sheet:
 - A. ? voltage drop across L1.
 - B. ? voltage drop across L2.
 - C. ? voltage drop across LED L3 LO.
 - D. ? voltage drop across LED D1.
 - E. ? voltage drop across LED L3 HI.
7. Turn switch SW1 to the OFF position.
8. Based on your readings, is the circuit you have constructed a “series” or a “parallel” circuit. Put your answer on the answer sheet.
9. Using Ohm’s Law, calculate and record the bulb resistances for L1, L2, LED L3 LO, LED L3 HI and LED D1. Record your answers on the answer sheet.
10. Evaluate your calculations of individual bulb resistances. What bulb has the highest resistance? (Answer sheet).
11. What bulb has the lowest resistance? Put your answer on the answer sheet.
12. What bulb was the brightest? Put your answer on the answer sheet.
13. Compare the amount of amperage use and amount of light that the LED D1 produces compared to bulb LED L3 HI? Put your answer on the answer sheet.
14. What is the advantage LED’s have over incandescent bulbs?

CONCLUSIONS: The brightness of an incandescent bulb is controlled by its internal resistance. LEDs have much higher internal resistance and also lower current draw than incandescent bulbs, but can give off much brighter light. This is the main advantage of today’s vehicles using LED bulbs. They operate with much less current, lower temperatures and last much longer than incandescent bulbs. The higher the resistance, the “dimmer” the bulb will be when compared to another bulb with less resistance. Any light bulb is designed to operate with a designed amount of supply voltage and a good ground circuit. Any unwanted resistance in either side of the circuit will result in improper performance and the bulb being “dimmer” than designed. The next assignment demonstrates the effect of having unwanted resistance in lighting circuits.

SA-17 LIGHT BULB CIRCUITS - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

2. Draw the constructed circuit on a blank template and label the circuit "LIGHT BULBS". Use RED for positive wires and BLACK for negative wires.
5. A. _____ amps for L1. Expressed as: _____
B. _____ amps for L2. Expressed as: _____
C. _____ amps for LED L3 LO. Expressed as: _____
D. _____ amps for LED D1. Expressed as: _____
E. _____ amps for LED L3 HI. Expressed as: _____
6. A. _____ voltage drop across L1. Expressed as: _____
B. _____ voltage drop across L2. Expressed as: _____
C. _____ voltage drop across LED L3 LO. Expressed as: _____
D. _____ voltage drop across LED D1. Expressed as: _____
E. _____ voltage drop across LED L3 HI. Expressed as: _____
7. _____ SERIES or PARALLEL.
8. A. _____ ohms of resistance for L1. Expressed as: _____
B. _____ ohms of resistance for L2. Expressed as: _____
C. _____ ohms of resistance for LED L3 LO. Expressed as: _____
D. _____ ohms of resistance for LED D1. Expressed as: _____
E. _____ ohms of resistance for LED L3 HI. Expressed as: _____
9. _____ What bulb has the highest resistance?
10. _____ What bulb has the lowest resistance?
11. _____ What bulb was the brightest?
12. _____

13. _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-18 Light Bulb Circuits with Resistances

SA-18 CIRCUIT EXPLANATION

This assignment is designed to demonstrate the effect of resistance in lighting circuits. Poor lighting circuit performance and dim light bulbs is often the cause of unwanted resistance somewhere in the circuit. It is the technician's job to accurately locate and repair the resistance problem.

SA-18 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the SA-18 student answer sheet to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below:
CONNECT **RED** JUMPER WIRES BETWEEN:
 - A. Any of the four red power receptacles to terminal O of switch SW1.
 - B. Terminal I of switch SW1 to terminal Q of resistor R4.
 - C. Terminal P of resistor R4 to terminal LO of bulb LED L3.
 - D. Using the piggy back feature, terminal I of switch SW1 to terminal C of bulb L2.
 - E. Using the piggy back feature, terminal I of switch SW1 to terminal O of resistor R3.
 - F. Terminal N of resistor R3 to terminal A of bulb L1.CONNECT **BLACK** JUMPER WIRES BETWEEN:
 - A. Any of the four black ground receptacles to the COM terminal of bulb LED L3.
 - B. Terminal B of bulb L1 to any of the four ground receptacles.
 - C. Terminal D of bulb L2 to any of the four ground receptacles.
2. Draw the circuit you have just constructed on a blank circuit schematic template and label it: SA-18 LIGHT BULB CIRCUITS WITH RESISTANCES.
3. Turn switch SW1 to the ON position and observe circuit performance. Describe the circuit performance on your answer sheet:
 - A. Describe bulb L1's operating condition?
 - B. Describe bulb L2's operating condition?
 - C. Describe bulb LED L3 LO operating condition?
4. Using the voltmeter function of the DMM, conduct voltage drop testing of the following bulbs or circuits. Record your measurements on the answer sheet:
 - A. Voltage drop across bulb L1.
 - B. Voltage drop across bulb L2.
 - C. Voltage drop across bulb LED L3 LO.
 - D. Voltage drop of the ground circuit of bulb LED L3 LO.
 - E. Voltage drop of the ground circuit of bulb L1.
 - F. Voltage drop of the ground circuit of bulb L2.
5. Evaluate your measurements. Each bulb is designed to operate on full source voltage (12.6 – 14.5 V). If unwanted resistance is present, it reduces the available voltage to the light bulb and thus, causes dimmer performance.

CONCLUSION: The voltage drop testing performed can be interpreted as follows:

- a) There is unwanted resistance in bulb L1 circuit and it is NOT in the ground circuit because the voltage drop is within accepted parameters.
- b) There is no unwanted resistance in bulb L2 circuit and it is operating normally.
- c) Even though there is unwanted resistance in the LED L3 LO positive circuit (R4), it has NO EFFECT on the operation of the LED bulb. This is because the internal dynamic resistance of the LED bulb is $427\pm$ ohms and adding R4 (20Ω) to the circuit will have a very insignificant affect on the L3's performance. The resistance is there, but does not affect the circuit. The resistance is there, but does not affect the circuit. This is another advantage of LED bulb.

SA-18 LOCATING THE UNWANTED RESISTANCE

When attempting to locate unwanted resistance in a circuit, many technicians utilize a testing procedure called "point to point" testing which if conducted properly, will identify the problem. In the following steps, you will practice the process of identifying the unwanted resistance in bulb L1 circuit. Obviously, you can observe that the unwanted resistance (R3) is installed in the positive side between the switch SW1 and terminal A of bulb L1, but in a vehicle, this would not be the case. Remember that we know the problem isn't in the ground circuit because the voltage drop measured from terminal B of bulb L1 to the ground receptacles was acceptable.

6. Leave one lead of the voltmeter attached to the red positive receptacles and connect the other voltmeter lead to the following test points and record each voltage drop on the answer sheet:
 - A. Terminal O of switch SW1.
 - B. Terminal I of switch SW1.
 - C. Terminal O of resistor R3.
 - D. Terminal N of resistor R3.
 - E. Terminal A of bulb L1.
7. There are several different methods of voltage drop testing. Some technicians measure the voltage drop across the ends of each connection of the circuit. While accurate, this method is often a very time consuming process due to lack of accessibility of the different components in the circuit. For explanation purposes only, if the circuit were to be tested using this approach, the test points are listed below.
8. If you wish to make these measurements, you may do so:
 - A. Red positive receptacle to terminal O of switch SW1 (will result in normal readings).
 - B. Terminal O to terminal I of switch SW1 (will result in normal readings).
 - C. Terminal I of switch SW1 to terminal O of resistor R3 (will result in normal readings).
 - D. Terminal O to terminal N of resistor R3.
NOTE: This is where the unwanted resistance would first show up.
 - E. Terminal N of resistor R3 to terminal A of bulb L1 (will result in normal readings).

CONCLUSIONS: Checking voltage drops in the positive side of the circuit revealed that everything from the red positive receptacles to terminal O of resistor R3 was within normal ranges. As soon as the voltmeter lead was moved to terminal N of resistor R3, the voltage drop increased significantly. Therefore, the problem (unwanted resistance) must be located between terminals O and N of resistor R3.

CONFIRMATION:

9. With the circuit operating, install a jumper wire to connect terminals O and N of resistor R3.
10. Measure the positive circuit voltage drop from the red positive receptacles to terminal A of bulb L1. (answer sheet)
11. Describe the operational condition of bulb L1 with the jumper installed (Answer sheet).

SA-18 VOLTAGE DROP TESTING OF BULB LED L3 LO CIRCUIT

These steps will demonstrate another method of voltage drop testing to locate the source of unwanted resistance.

12. Measure the available voltage at bulb LED L3 LO and record your measurement on answer sheet.

EVALUATION: Anything less than full source voltage indicates an unwanted resistance in the circuit. You will use voltage drop testing to locate the source of the resistance. Obviously, there is a problem here in this circuit.

13. Conduct voltage drop test of the ground circuit and record your measurement on the answer sheet.
NOTE: Your readings should indicate that there is no voltage drop in the ground circuit.
14. Leave one lead of the voltmeter attached to any of the four red positive receptacle and make voltage drop tests to the following locations. Record your measurements on the answer sheet:
 - A. Terminal P of resistor R4.
 - B. Terminal Q of resistor R4.
 - C. Terminal I of switch SW1.
 - D. Terminal O of switch SW1.
 - E. Red positive receptacles of trainer.

CONCLUSIONS: The voltage drop testing of the LED L3 LO positive circuit (with one lead of voltmeter attached to any of the four red power receptacles, the first testing point was Terminal P of resistor R4. The reading showed a drop of about 0.750 volts. That indicates an unwanted resistance is somewhere in the circuit. The next testing point was terminal Q of resistor R4 indicated a “normal” reading. That confirms that the unwanted resistance was located between terminals P and Q of resistor R4. All of the remaining voltage drop test points reveals a very low drop.

Voltage drop testing is a very valuable method of locating unwanted resistances in either the positive or ground side of any circuit. Many technicians use the “jumper method” of testing with a fused jumper to temporarily bypass a wire or connection during diagnosis. This process saves time where accessibility problems block access to circuit components and connections. NEVER bypass a component with a fused jumper wire as this can remove all resistance in the circuit and create a short. The next assignment involves unwanted resistances in the ground circuit.

SA-18 LIGHT BULB CIRCUITS WITH RESISTANCES - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

3. What is the description of each bulb's performance?
- A. _____ Bulb L1's condition.
- B. _____ Bulb L2's condition.
- C. _____ Bulb LED L3 LO's condition.
4. Voltage drop testing of circuit:
- A. _____ Voltage drop across bulb L1. Expressed as: _____
- B. _____ Voltage drop across bulb L2. Expressed as: _____
- C. _____ Voltage drop across bulb LED L3 LO. Expressed as: _____
- D. _____ Voltage drop of the ground circuit of bulb LED L3 LO.
Expressed as: _____
- E. _____ Voltage drop of the ground circuit of bulb L1. Expressed as: _____
- F. _____ Voltage drop of the ground circuit of bulb L2. Expressed as: _____
6. Voltage drop testing for the positive side of bulb L1 circuit with one voltmeter lead on red positive receptacles.
- A. _____ Terminal O of switch SW1. Expressed as: _____
- B. _____ Terminal I of switch SW1. Expressed as: _____
- C. _____ Terminal N of resistor R3. Expressed as: _____
- D. _____ Terminal O of resistor R3. Expressed as: _____
- E. _____ Terminal A of bulb L1. Expressed as: _____
10. _____ Voltage drop of positive side of bulb L1 circuit. Expressed as: _____
11. Condition of bulb L1: _____
12. _____ Available voltage at bulb LED L3 LO. Expressed as: _____
13. _____ Voltage drop of bulb LED L3 LO ground circuit. Expressed as: _____
14. Voltage drop testing of bulb LED L3 LO positive circuit.
- A. _____ Terminal P of resistor R4. Expressed as: _____
- B. _____ Terminal Q of resistor R4. Expressed as: _____
- C. _____ Terminal I of switch SW1. Expressed as: _____
- D. _____ Terminal O of switch SW1. Expressed as: _____
- E. _____ Red positive receptacles of trainer. Expressed as: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-19 Light Bulb Circuits with Problems

SA-19 CIRCUIT EXPLANATION

This assignment will demonstrate the negative effects of resistances in both the positive and ground paths in lighting circuits and how to best identify and locate the problems.

SA-19 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-19 student answer sheet to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below:
CONNECT **RED** JUMPER WIRES BETWEEN:
 - A. Any of the four red power receptacles to terminal O of switch SW1.
 - B. Terminal I of switch SW1 to terminal O of resistor R3.
 - C. Terminal N of resistor R3 to terminal A of bulb L1.
 - D. Using the piggy back feature, terminal I of switch SW1 to terminal C of bulb L2.CONNECT **BLACK** JUMPER WIRES BETWEEN:
 - A. Any of the four black ground receptacles to terminal B of bulb L1.
 - B. Terminal D of bulb L2 to terminal P of resistor R4.
 - C. Terminal Q of resistor R4 to any of the four black ground receptacles.
2. Draw the circuit you have just constructed on a blank circuit schematic template and label it: SA-19 LIGHT BULB CIRCUITS WITH PROBLEMS.
3. Turn switch SW1 to the ON position and observe circuit performance. Describe the circuit performance on your answer sheet:
 - A. Describe bulb L1's operating condition?
 - B. Describe bulb L2's operating condition?
4. Measure the available voltage to both bulbs and record your measurements on the answer sheet:
 - A. Available voltage at bulb L1.
 - B. Available voltage at bulb L2.
5. Conduct a voltage drop tests of bulbs L1 & and L2 positive and ground circuits and record your measurements on the answer sheet:
 - A. Voltage drop of bulb L1 positive circuit from terminal A to red positive receptacles.
 - B. Voltage drop of bulb L1 ground circuit from terminal B to black ground receptacles.
 - C. Voltage drop of bulb L2 positive circuit from terminal C to red positive receptacles.
 - D. Voltage drop of bulb L2 ground circuit from terminal D to black ground receptacles.
6. Evaluate the results of the voltage drop tests and describe whether each measurement is "normal" or "abnormal" on the answer sheet.

CONCLUSIONS: Both bulbs L1 and L2 are operating dimmer than normal. The available voltage at the bulb should be close to the source voltage ($14.00\text{V} \pm$). Your measurements should have indicated that the available voltage at each bulb was less the source voltage, therefore there must be unwanted resistance in the circuits. Because bulb L1 had a voltage drop in the positive circuit, the unwanted resistance must be located there. Because bulb L2 had a voltage drop in the ground circuit, the unwanted resistance must be located there. As has been stated before, voltage drop testing **MUST** be performed on operating circuits. If voltage drop testing is attempted on electrically dead circuits, the results will be erroneous and mean nothing. The next step will demonstrate this.

7. Install the voltmeter to measure available voltage at bulb L1. Now, carefully remove bulb L1 from its socket and record the available voltage for L1 on the answer sheet.
8. Reinstall bulb L1 and measure available voltage and record on answer sheet.

CONCLUSIONS: As stated before, voltage drop testing **MUST** be performed on live operating circuits connected to a load. In the case of bulb L1, when the bulb was removed, the voltmeter reading should be close to source voltage. Why does this happen? Because even though current is still flowing through the installed resistance (R3), the voltmeter reads close to source voltage with no voltage drop due to the very high internal resistance or impedance of the voltmeter (about $10\text{-}20\text{ M}\Omega$) and the current flowing in the circuit is extremely low. The meter therefore does not represent a load to the circuit and it reads close to source voltage at bulb L1 socket because due to the high resistance, it appears as an “open circuit” at the bulb socket. As soon as the bulb is installed in the circuit, the bulb’s resistance combines with resistor R3 to become a series circuit and each component, (bulb and resistor) creates a voltage drop in the circuit. The bulb and the resistor have a much lower resistance than the meter. Today’s digital multimeters are designed with very high impedance so that they don’t “load the circuit” that they are connected to. This feature protects sensitive electronics and solid-state components.

SA-19 IDENTIFYING THE LOCATION OF UNWANTED RESISTANCE

There are several different methods to locate the source of unwanted resistance in a circuit. Let’s examine a few.
NOTE: The power switch and switch SW1 should both be ON to perform the below steps.

9. Make a fused jumper wire by connecting a red jumper wire from any of the four red positive receptacles to one terminal of the fuse F.
10. Connect another red jumper wire from the other terminal of fuse F and hold the other end from touching any ground source. You now have a positive fused jumper wire connected to the power source. We will use it to temporarily bypass all circuit wiring and controls to bulb L1 and L2 to determine if any unwanted resistance is in the positive side of the circuit.
11. Connect the end of the jumper wire to terminal A of bulb L1. Describe any noticed results on the answer sheet.
12. Remove the jumper and connect it to terminal C of bulb L2 and describe any noticed results on the answer sheet.
13. Remove both red jumper wires used to make the fused positive jumper wire.
14. Make a fused ground jumper wire by connecting a black jumper wire from any of the four black ground receptacles to either terminal of fuse F. Connect another black jumper wire from the other terminal of fuse F and hold the other end from touching any positive source.
15. Connect the end of the black jumper wire to terminal B of bulb L1 and describe any noticed results on the answer sheet.

16. Connect the end of the black jumper wire to terminal D of bulb L2 and describe any noticed results on the answer sheet.

CONCLUSIONS: Because the fused jumper wire was used to substitute a known good positive and ground circuits, it is possible to determine if the unwanted resistance is in the positive or ground side of the circuit. Although using a fused jumper wire will work on light bulb circuits that are easily observed, it may not work on motor or other types of circuits where one cannot observe normal circuit performance. Installing fused jumper wires can be a valuable method in diagnosing circuit problems. Using a voltmeter to measure the actual voltage drop in a circuit is the best and most accurate method of circuit testing. In assignment # 19, bulb L1 had resistor R3 in series in the positive side of the circuit and bulb L2 had resistor R4 in series with the ground circuit. Both bulbs had equal voltage drops although in opposite circuits. The bulbs operated equally because the values of resistors 3 and 4 are identical. It is important to remember that unwanted resistances can occur in either the positive or ground sides of a circuit and accurate voltage drop testing will determine which part of the circuit is causing the problem.

SA-19 LIGHT BULB CIRCUITS WITH PROBLEMS - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

3. What is the description of each bulb's performance?

A. _____ Bulb L1's condition.

B. _____ Bulb L2's condition.

4. A. _____ Available voltage at bulb L1. Expressed as: _____

B. _____ Available voltage at bulb L2. Expressed as: _____

5. Voltage drop testing of bulbs L1 and L2:

A. _____ Voltage drop of bulb L1 positive circuit from terminal A to red positive receptacles.

Expressed as: _____

B. _____ Voltage drop of bulb L1 ground circuit from terminal B to black ground receptacles.

Expressed as: _____

C. _____ Voltage drop of bulb L2 positive circuit from terminal C to red positive receptacles.

Expressed as: _____

D. _____ Voltage drop of bulb L2 ground circuit from terminal D to black ground receptacles.

Expressed as: _____

6. Measurement A _____ (NORMAL or ABNORMAL).

Measurement B _____ (NORMAL or ABNORMAL).

Measurement C _____ (NORMAL or ABNORMAL).

Measurement D _____ (NORMAL or ABNORMAL).

7. _____ Available voltage at L1 socket with bulb removed. Expressed as: _____

8. _____ Available voltage at L1 socket with bulb installed. Expressed as: _____

11. _____ Bulb L1 condition with positive fused jumper wire connected to terminal A.

12. _____ Bulb L2 condition with positive fused jumper wire connected to terminal C.

15. _____ Bulb L1 condition with ground fused jumper wire connected to terminal B.

16. _____ Bulb L2 condition with ground fused jumper wire connected to terminal D.

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-20 Relay Circuits

This assignment will demonstrate how relays are used to control circuit components. A relay is an electrical component that is able to switch on and off, components that draw high amounts of current by using a very low current control circuit. Many different relays are typically used in vehicles and in industrial applications.

SA-20A RELAY CONTROL CIRCUIT

Circuit Explanation

A relay has two internal circuits. One is called the “low-current” or “control” circuit. It consists of a power feed to one end of the relay’s internal coil and also a ground to the other end of the coil. The circuit you will construct below is the “control” circuit. As has been previously explained in the COMPONENT EXPLANATION module, when the relay’s coil is energized, terminals # 30 to 87 will be connected. When the relay is shut off, relay terminals # 30 and 87a are connected.

SA-20A PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-20 student answer sheet to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below:
CONNECT **RED** JUMPER WIRES BETWEEN:
A. Any of the four red power receptacles to the left-hand terminal push button switch PB1.
B. Right-hand terminal of push button switch PB1 to terminal 86 of relay RL1.
CONNECT **BLACK** JUMPER WIRES BETWEEN:
A. Any of the four black ground receptacles to terminal 85 of relay RL1.
2. Confirm that trainer is plugged into a 120V receptacle and the master ON/OFF switch is turned ON.
3. Push the PB1 switch button down and listen for a “clicking” sound coming from the relay. This indicates that the relay is receiving a power and ground circuit to the relay coil.
4. Install the ohmmeter leads on relay terminals # 30 and # 87a.
5. Fill in the results of the ohmmeter readings on the student answer sheet with the PB1 switch OFF and ON.
A. ____ ohms with PB1 switch OFF
B. ____ ohms with PB1 switch ON
6. Install the ohmmeter leads on relay terminals # 30 and # 87, then repeat step # 5 and record the results on the answer sheet.
A. ____ ohms with PB1 switch OFF
B. ____ ohms with PB1 switch ON
7. Using the digital multimeter set up to measure amperage, measure the amperage of relay RL1 coil control circuit. Fill in your reading on the student answer sheet.

CONCLUSIONS: The experiment above confirms the operation of the relay and what terminals are connected and not connected with the relay both ON and OFF. The “controlled” side of the relay has not been connected to any component yet, but the relays “control” circuit still operates normally.

SA-20B RELAY CONTROLLED CIRCUIT

Circuit Explanation

The relay controlled circuit is the circuit where the high amperage of the controlled device is turned on and off. It is separated from the control circuit. The controlled circuit often has a separate power supply circuit which normally is connected to terminal # 30 of the relay (there are some exceptions to this depending on application). Terminal # 87 is connected to the component that is controlled by the relay when the relay is turned on.

SA-20B PROCEDURE

8. CONNECT **RED** JUMPER WIRES BETWEEN:
 - A. Any of the four red power receptacles to terminal # 30 of relay RL1.
 - B. Terminal # 87 of relay RL1 to terminal HI of bulb L3.CONNECT BLACK JUMPER WIRES BETWEEN:
 - A. Any of the four black ground receptacles to terminal COM of bulb L3.
9. Push switch PB1 and confirm that bulb L3 HI circuit operates normally.
10. Using the digital multimeter set up to measure amperage, measure the amperage of bulb L3 HI circuit. Fill in your reading on the student answer sheet.

CONCLUSIONS: It should be obvious that the relay is able to control a relatively high current circuit with a very low amount of control circuit. Compare the ammeter reading of step # 7 to the reading taken in step 10. The bulb draws much more current than the coil circuit of the relay.

11. Connect a red jumper wire from terminal # 87a of relay RL1 to terminal C of bulb L2.
12. Connect a black jumper wire from terminal D of bulb L2 to any of the four black ground receptacles.
13. Push the PB1 button and record the circuit performance on the student answer sheet.
 - A. Bulb L2 with relay OFF.
 - B. Bulb L2 with relay ON.
 - C. Bulb L3 HI with relay OFF.
 - D. Bulb L3 HI with relay ON.

CONCLUSIONS: This assignment confirms the normal operation of a relay when it is both ON and OFF. Many emergency vehicles use this type of circuit with a flasher to alternately flash ON/OFF headlights, red and blue lights.

14. Draw the entire circuit you have just constructed on a blank circuit schematic template and label it: SA-20B RELAY CONTROLLED CIRCUITS.

After completion of SA-20 student assignment, ask your instructor TEST 12.

SA-20 RELAY CIRCUITS - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

A. RELAY CONTROL CIRCUIT

3. Connection between # 30 and # 87a:
A. _____ ohms with PB1 switch OFF. Expressed as: _____
B. _____ ohms with PB1 switch ON. Expressed as: _____
6. Connection between # 30 and # 87:
A. _____ ohms with PB1 switch OFF. Expressed as: _____
B. _____ ohms with PB1 switch ON. Expressed as: _____
7. _____ amps of RL1 coil circuit. Expressed as: _____

B. RELAY CONTROLLED CIRCUIT

10. _____ amps of bulb LED L3 HI circuit. Expressed as: _____
13. What is the performance of bulbs LED L3 HI and bulb L2 with the relay ON and OFF?
A. Bulb L2 with relay OFF is _____.
B. Bulb L2 with relay ON is is _____.
C. Bulb LED L3 HI with relay OFF is _____.
D. Bulb LED L3 HI with relay ON is _____.

After completion of SA-20 student assignment, ask your instructor TEST 12.

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-21 Flasher Controlled Circuit

SA-21 CIRCUIT EXPLANATION

This assignment will demonstrate how electronic flashers are used in circuits. Electronic flashers differ from older style “thermal” flashers in that they operate with a different technology. Electronic flashers can control higher amounts of current than thermal flashers and also are not dependent on a specific amount of current flowing through it before it will turn on/off. Thermal flashers were usually identified as a round metal can with two or three electrical terminal blades that plugged into a receptacle. As additional bulbs were added to the circuit, the rate of flashing increased accordingly this creating a rapid on/off rate. This was especially true when hooking up a trailer to a vehicle. Solutions involved obtaining a “heavy duty flasher” which could handle the additional current.

Today’s electronic flashers typically have three electrical terminals. One is for a power feed circuit to the flasher, one is a ground circuit for the flasher and the third is for the circuit controlled on and off by the flasher.

SA-21 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the SA-21 student answer sheet to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below:

CONNECT **RED** JUMPER WIRES BETWEEN:

- A. Any of the four red power receptacles to terminal O of switch SW1.
- B. Terminal I of switch SW1 to BAT of the electronic flasher.
- C. SIG terminal of the electronic flasher to terminal A of bulb L1.
- D. Terminal A of bulb L1 to terminal C of bulb L2.

CONNECT **BLACK** JUMPER WIRES BETWEEN:

- A. Any of the four black ground receptacles to terminal GND of the electronic flasher.
- B. Terminal B of bulb L1 to terminal D of bulb L2.
- C. Terminal B of bulb L1 to any of the four black ground receptacles.

2. Draw the circuit you have just constructed on a blank circuit schematic template and labeled: SA-21 FLASHER CONTROLLED CIRCUIT.
3. Confirm that the trainer is plugged into a 120V receptacle and the master power switch is in the ON position.
4. Turn switch SW1 to the ON position. Bulbs L1 and L2 should now be flashing with equal brightness. Confirm the correct operation of the circuit. After circuit confirmation, turn switch SW1 to the OFF position.

CIRCUIT PROBLEMS:

As with any electrical circuit, unwanted resistance can cause circuit performance problems. The below steps will demonstrate this.

5. Remove the red jumper wire from terminal I of SW1 and connect it to terminal N of resistor R3.
6. Connect a red jumper wire from terminal I of switch SW1 to terminal O of resistor R3.
7. Turn switch SW1 ON and observe circuit performance.

8. Connect another red jumper wire to terminal O of resistor R3 and while the circuit is operating, touch terminal N of resistor R3. This action temporarily bypasses the resistor and the circuit performance should return to normal operation.
9. Describe the circuit performance with the resistance insert in the circuit on the answer sheet.
10. Remove the resistance from the circuit and restore the circuit to normal operating conditions.
11. Remove the black ground wire coming from bulb L2 that connects to terminal B of bulb L1 and re-connect it to terminal L of resistor R2.
12. Connect a black jumper wire from any of the four black ground receptacles to terminal M of resistor R2.
13. Turn on switch SW1 and observe circuit performance. Describe the circuit performance on the answer sheet.

CONCLUSIONS:

When diagnosing circuit problems, it is very important to have a correct wiring diagram for the circuit being repaired. This provides valuable information as to how the power and ground circuits are constructed which can save significant time during diagnosis.

SA-21 FLASHER CONTROLLED CIRCUIT - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

9- _____

13- _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-22 PWM Circuit with Motor

SA-22 THEORY

It is very common in vehicle engine performance circuits to have an internal circuit with transistors controlled by Pulse Width Modulation. A commonly used term is a “Quad Driver”. Quad-Drivers are integrated circuits within the ECM or PCM that control certain types of circuits. Many Quad-Drivers are controlled by using Pulse Width Modulation which are also within the ECM/PCM. Pulse Width Modulation controls a circuit by turning on and off a B+ supply very quickly. For example, a light bulb can be turned on and off very rapidly so that it can be off, on at varying amounts of brightness to being on a full brightness all controlled by Pulse Width Modulation.

Fuel Injectors are also commonly controlled by PWM. PWM circuits operate at varying frequencies. The circuit is either ON or OFF and the quad-driver controls the amount of on time. The amount of “on” time is called DUTY CYCLE. Duty cycle is measured either as a percentage or can also be measured with the amount of on time called “PULSE WIDTH”. The important thing to remember about PWM, it that the voltage to the device being controlled will be either full voltage (14.6 for example) or zero. If a blower motor was controlled by PWM and it was running at half-speed, the DUTY CYCLE would be at 50%. If a digital voltmeter was connected to the blower motor, it would indicate about 7.3V± because the meter cannot read the on/off signals that are occurring in milli-seconds. So, the meter just “averages” the signals.

One must remember, that a PWM circuit cannot be accurately tested or measured with a voltmeter. An oscilloscope is the only tool that will display the true on and off pulse width modulated circuit. Some scan tools can give a DUTY CYCLE or PULSE WIDTH readout, but those also are averages and not the true PWM signals.

SA-22 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-22 student answer sheet to record all of your measurements and question answers.

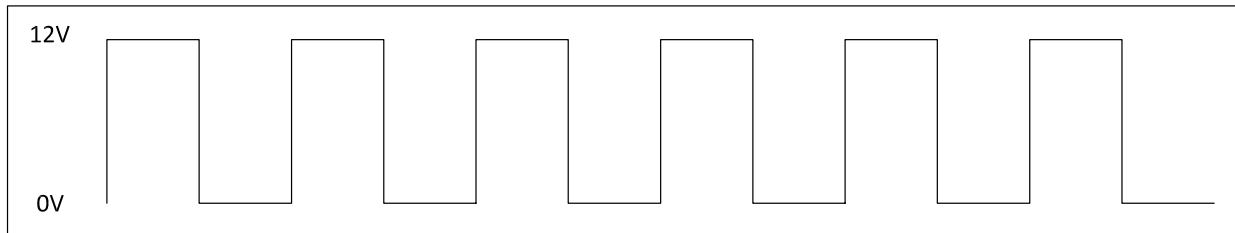
1. Connect red and black jumper wires as instructed below:
CONNECT **RED** JUMPER WIRES BETWEEN:
A. The red + terminal of the PWM generator to the + terminal of the DC motor.
CONNECT **BLACK** JUMPER WIRES BETWEEN:
A. The black – terminal of the PWM generator to the – terminal of the DC motor.
2. Connect the voltmeter to the DC motor to read motor supply voltage.
3. Confirm that the PWM adjustment knob is turned fully counter-clockwise.
4. Confirm that the trainer is plugged into a 120V receptacle and the master power switch is in the ON position.
5. Adjust the trainer supply voltage display until a reading of between 13.00 – 14.00 volts is obtained.
6. Slowly turn the PWM adjustment knob clockwise. As you do, the motor should begin to rotate and increase in speed as the knob is adjusted clockwise.
7. Turn the PWM adjustment knob so that the voltmeter reads about ½ of the trainers display voltage. The reading should be between 6.5 and 7 volts. The motor will be rotating at about ½ of normal speed.

CIRCUIT EXPLANATION:

At this point, the motor is running at what is described as a 50% DUTY CYCLE. It is called that because at 50%, the voltage is on an equal amount of time as it is off. If the voltage is measured at the motor, it will read $\frac{1}{2}$ of the supply voltage.

NOTE: If the digital meter was equipped to measure “DUTY CYCLE”, the correct reading at this point would be 50%. If a digital storage oscilloscope was hooked up to the red positive motor lead, it would show a pattern that had equal horizontal lines at “12 volts” as well as equal horizontal lines at “0” volts.

An example of the oscilloscope pattern would be:

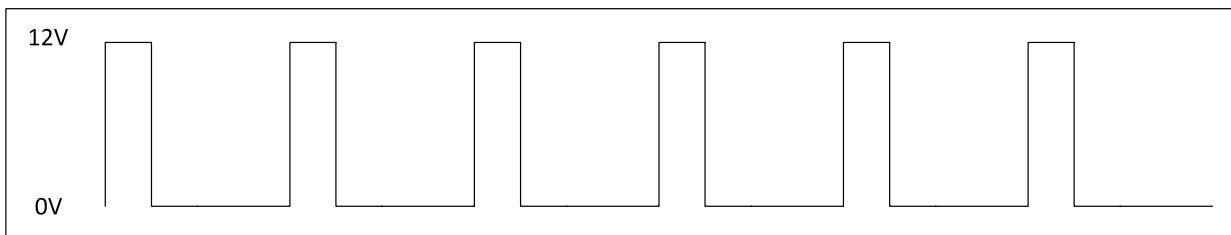


8. Pulse Width Modulation provides an accurate method of controlling circuits such as lights, motors and solenoids.
9. Turn the PWM adjustment knob slowly counter-clockwise until the motor is just barely turning. The voltmeter should be reading between 2.5 and 3.0 volts.

CIRCUIT EXPLANATION:

At this point, the motor is running at what is described as a “low” DUTY CYCLE. The voltage available to the motor is off more than it is on. A meter measuring DUTY CYCLE would read approximately 25%.

An example of the oscilloscope pattern would be:



10. Turn the PWM adjustment knob slowly clockwise to its full CW position. The motor should be running at its fastest speed. The motor is now running at what is described at a 100% DUTY CYCLE. The volt meter should be reading about 1.0 volt less than the display voltage (due to internal circuitry). The voltage available to the motor is on more than it is off.

An example of the oscilloscope pattern would be:



Answer the following questions on the Student Answer Sheet.

11. If a 12 volt circuit was commended to run at 50% duty cycle, what would the digital multimeter display for a voltage at the controlled device?
12. If a 12 volt circuit was connected to run at 25% duty cycle, what would the digital multimeter display for a voltage at the controlled device?
13. True or False Even though a voltmeter displays 6 volts connected to a 12 volt PWM controlled device running at 50% duty cycle, it is really operating at 12 volts.

SA-22 PWM CIRCUIT WITH MOTOR - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

11. _____ V at 50% duty cycle. Expressed as: _____
12. _____ V at 25% duty cycle. Expressed as: _____
13. _____ True or False.

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-23 Transistor Controlled Circuits

This circuit assignment demonstrates how transistors can be used to control components. As has been previously discussed, there are an NPN and PNP transistor types on the CL-1919-06 trainer. Looking at the schematic diagram on each transistor, you will notice that the emitter arrow either points to the base (PNP) or away from the base (NPN). There are several “mental tricks” designed to help you remember how to identify a transistor type. A very common one is to look at the direction of the arrow on the emitter line. If the arrow “points in” to the base of the transistor, the transistor is an PNP type (pointing “N”). If the arrow is not pointing towards the base, the transistor is the NPN type (not pointing “N”). The most important reason to properly identify NPN and PNP transistors is because they are installed in a circuit very differently.

SA-23A NPN TRANSISTOR CIRCUIT AS A “RELAY” CONTROLLED CIRCUIT

SA-23A Circuit Explanation

This circuit will consist of an NPN transistor serving as a “relay” like component that controls a series of components on the CL-1919-06 trainer. Remember that one of the primary uses of a transistor is to control high amounts of current by using a very low current switching circuit flowing through control circuit. The transistor can serve as an electronic relay much the same as an ISO relay does. NOTE: On the CL-1919-06, bulb L3 which was a 3157 incandescent bulb has been replaced with an LED version of the 3157. The primary reason for this change was to eliminate the very hot surfaces of the incandescent 3157 bulb. Because the LED 3157 bulb L3 is not a very high current device, additional devices will be connected in parallel to increase circuit amperage that will be controlled by the transistor.

SA-23A PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-23 student answer sheet to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below. **BE VERY CAREFUL TO CORRECTLY INSTALL EACH WIRE:**

CONNECT **RED** JUMPER WIRES BETWEEN:

- A. Any of the four red power receptacles to terminal A of bulb L1.
- B. Terminal A of bulb L1 (piggy back) to terminal C of bulb L2.
- C. Terminal C of bulb L2 (piggy back) to terminal P of resistor R4.
- D. Terminal P of resistor R4 (piggy back) to terminal N of resistor R3.
- E. Any of the four red power receptacles to terminal O of switch SW1.
- F. Terminal I of switch SW1 to terminal K of resistor R1.
- G. Terminal J of resistor R1 to terminal B (BASE) of transistor T1 (NPN).
- H. Terminal D of bulb L2 to terminal C (COLLECTOR) of transistor T1 (NPN).
- I. Terminal D of bulb L2 (piggy back) to terminal B of bulb L1.
- J. Terminal B of bulb L1 (piggy back) to terminal Q of resistor R4.
- K. Terminal Q of resistor R4 (piggy back) to terminal O of resistor R3.

CONNECT **BLACK** JUMPER WIRES BETWEEN:

- A. Any of the four black ground receptacles to terminal E of transistor T1 NPN.

NOTE: It will be noticed that this NPN circuit uses red wires on both sides of the load components. This is correct because schematics show circuits in the OFF position and full supply voltage can be measured to ground at both terminals of all loads until the transistor turns on. This will then switch half of the loads to ground.

2. Draw the circuit you have just constructed on a blank circuit schematic template and label it: SA-23A NPN TRANSISTOR CIRCUIT AS A RELAY CIRCUIT.
3. Confirm that the trainer is plugged into a 120V receptacle and the master power switch is in the ON position.
4. Adjust the trainer voltage to about $14.6 \pm$ volts.
5. Turn switch SW1 to ON position. Bulbs L1 and L2 should both be on at full brightness. Confirm proper circuit operation and repair any mistakes in wiring the components.

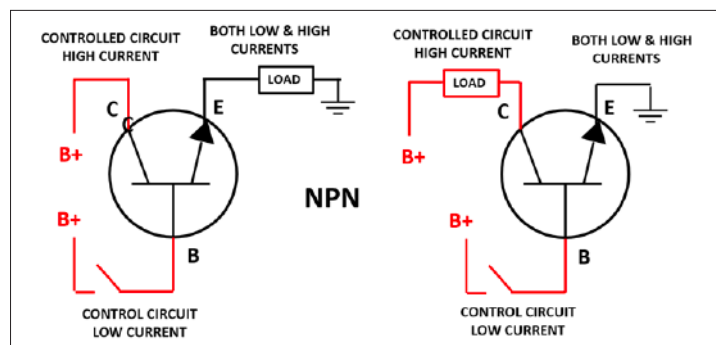
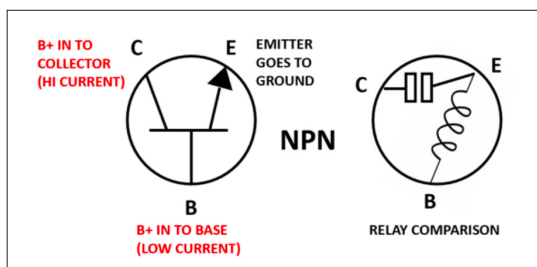
CIRCUIT DESCRIPTION: In an NPN transistor circuit, the current of the controlled device (Bulbs L1, L2 and resistors 3 & 4) passes from the source voltage to terminals A & C of bulbs L1 and L2, through the bulb's filaments and exits bulb L1 & L2 at terminals B & D, then on to the COLLECTOR of transistor T1. In addition, bulbs L1 and L2 and connected in parallel with resistors R3 and R4. Remembering Ohm's Law, adding resistances in a parallel circuit will increase the current flow. These four components were connected in this circuit to create a "load" of about 2 amps.

Using a single bulb or L3 LED would create a current draw in milli-amps and would not demonstrate the "relay" operation of the transistor. When the transistor is turned on by switch SW1, low current (control) circuit passes into the transistor's BASE (B) circuit, through the transistor and out at the EMITTER terminal and continues to ground. The COLLECTOR to EMITTER portion of the transistor is called the "HIGH CURRENT" portion of the circuit. The LOW CURRENT control circuit flows from source voltage through switch SW1 and on to the BASE terminal of transistor T1. The control circuit then exits the transistor through the EMITTER terminal (E) and on to ground. The EMITTER circuit carries both the control and the controlled circuit currents.

Therefore:

- A. In an NPN circuit, the low current control circuit is connected BASE to EMITTER.
- B. In an NPN circuit, the high current controlled circuit is connected between COLLECTOR and EMITTER.
- C. The EMITTER to ground circuit carries both the low current control circuit (B to E) and the high current controlled circuit (C to E).

COMPARISON OF AN NPN TRANSISTOR TO A RELAY: Look at the below drawings comparing an NPN transistor to a standard 4-pin relay. The low current control circuit is the relay's coil and in a transistor is BASE to EMITTER. The high current controlled circuit is the relay's contacts and in a transistor is COLLECTOR to EMITTER. With in NPN transistor, the "LOAD" can be either on the positive side (COLLECTOR) or the ground side (EMITTER) of the transistor.



SA-23A PROCEDURE (CONTINUED):

6. Carefully examine and understand the circuit you have constructed.
7. Measure the available voltage to the following components. Put your readings on the student answer sheet.
 - A. Bulb L1: _____ volts. Expressed as: _____
 - B. Bulb L2: _____ volts. Expressed as: _____
 - C. Resistor R3: _____ volts. Expressed as: _____
 - D. Resistor R4: _____ volts. Expressed as: _____
8. What type of circuit construction are L1, L2, R3 and R4 connected in? _____
9. Turn trainer on, turn switch SW1 on and measure the current flowing through the following circuits:
 - A. COLLECTOR CIRCUIT: _____ amps. Expressed as: _____
 - B. EMITTER CIRCUIT: _____ amps. Expressed as: _____
 - C. BASE CIRCUIT: _____ amps. Expressed as: _____
10. While monitoring COLLECTOR current, predict what will happen if you temporarily disconnect the two-wire connection at bulb L1 terminal A. Predict what happened on the answer sheet.
11. Disconnect the two-wire connection at bulb L2 terminal A and describe what happened. Describe what happened on the answer sheet.
12. Disconnect the EMITTER ground wire at either the EMITTER receptacle or any of the four black ground receptacles. Describe what happened on the answer sheet.
13. Explain why the circuit behaved the way it did when you disconnected the EMITTER wire. Use the answer sheet.
14. Measure the voltage to ground at loads L1, L2, Resistors R3 & R4 and COLLECTOR of NPN transistor. Put your reading on the student answer sheet.
15. Is the NPN control circuit a positive switched or negative switched? _____
16. Turn SW1 OFF and turn trainer OFF. Remove all red and black wires from the trainer.
17. Proceed on to SA-23B Assignment which uses the same answer sheet as SA-23A.

SA-23B PNP TRANSISTOR CIRCUIT AS A “RELAY” CONTROLLED CIRCUIT

SA-23B Circuit Explanation

This circuit will consist of a PNP transistor serving as a “relay” like component that controls a series of components on the CL-1919-06 trainer. A PNP transistor is connected differently than an NPN transistor. The BASE of a PNP transistor is the switched circuit, but is on the ground side of the transistor circuit. The EMITTER is connected to the power supply and the COLLECTOR is connected to the LOAD. The COLLECTOR circuit goes to the LOAD, then connects to ground.

The control circuit of a PNP transistor is “ground switched”. NOTE- On the CL-1919-06, bulb L3 which was a 3157 incandescent bulb has been replaced with an LED version of the 3157. The primary reason for this change was to eliminate the very hot surfaces of the incandescent 3157 bulb. Because the LED 3157 bulb L3 is not a very high current device, additional devices will be connected in parallel to increase circuit amperage that will be controlled by the transistor.

SA-23B PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the SA-23 student answer sheet to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below. **BE VERY CAREFUL TO CORRECTLY INSTALL EACH WIRE:**

CONNECT **RED** JUMPER WIRES BETWEEN:

- A. Any of the four red power receptacles to the EMITTER terminal of transistor T2 (PNP)

CONNECT **BLACK** JUMPER WIRES BETWEEN:

- A. Any of the four black ground receptacles to terminal O of switch SW1
- B. Terminal I of switch SW1 to the BASE terminal of transistor T2 (PNP)
- C. Terminal C of bulb L2 to the COLLECTOR of transistor T2 (PNP)
- D. Terminal C of bulb L2 (piggy back) to terminal A of bulb L1
- E. Terminal A of bulb L1 (piggy back) to terminal P of resistor R4
- F. Terminal P of resistor R4 to terminal N of resistor R3
- G. Terminal B of bulb L1 (piggy back) to terminal D of bulb L2
- H. Terminal D of bulb L2 (piggy back) to terminal Q of resistor R4
- I. Terminal Q of resistor R4 (piggy back) to terminal O of resistor R3
- J. Terminal O of resistor R4 (piggy back) to any of the four black ground terminals

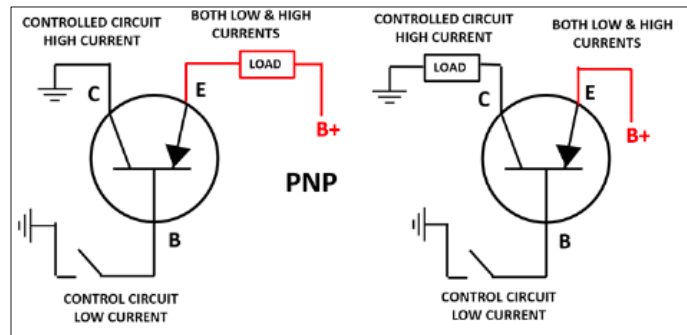
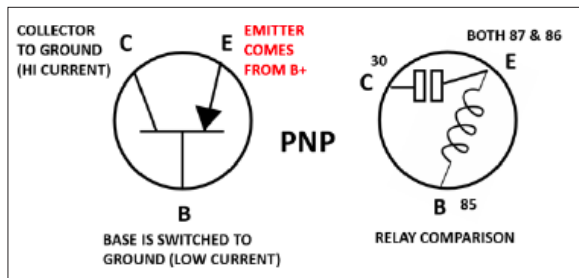
NOTE: It will be noticed that this PNP circuit uses black wires on both sides of the load components. This is correct because schematics show circuits in the OFF position and full supply voltage can be measured to positive at both terminals of all loads until the transistor turns on. This will then switch half of the loads to B+ positive.

2. Draw the circuit you have just constructed on a blank circuit schematic template labelled: SA-23B PNP TRANSISTOR CIRCUIT AS A RELAY CIRCUIT.
3. Confirm that the trainer is plugged into a 120V receptacle and the master power switch is in the ON position.
4. Adjust the trainer voltage to about $14.6 \pm$ volts.
5. Turn switch SW1 to ON position. Bulbs L1 and L2 should both be on at full brightness. Confirm proper circuit operation and repair any mistakes in wiring the components.

CIRCUIT DESCRIPTION: In an PNP transistor circuit, the current of the controlled device (Bulbs L1, L2 and resistors 3 & 4) passes from the COLLECTOR of transistor T2 (PNP) to terminals A & C of bulbs L1 and L2, terminals P and N of resistors R3 and R4. It then flows through the bulbs filaments and resistors R3 & R4 to ground. Remembering Ohm's Law, adding resistances in a parallel circuit will increase the current flow. These four components were connected in this circuit to create a "load" of about 2 amps. Using a single bulb or L3 LED would create a current draw in milli-amps and would not demonstrate the "relay" operation of the transistor. The PNP transistor is "turned on" by switch SW1 connecting the BASE transistor terminal to ground. The lower CONTROL current flows from the EMITTER to BASE to ground. This then connects the EMITTER (+) circuit to the COLLECTOR (-) terminal which then connects to the load. The HIGH controlled current flows from the EMITTER to COLLECTOR to ground through each load.

Therefore:

- In an PNP circuit, the low current control circuit is connected EMITTER (+) TO BASE (-) through a switch to ground.
- In an PNP circuit, the high current controlled circuit is connected between EMITTER (+ FEED) and the COLLECTOR (- LOAD) to ground.
- The EMITTER (+) to positive circuit carries both the low current control circuit (E+ to B-) and the high current controlled circuit (E+ to C-).



SA-23B PROCEDURE (CONTINUED):

- What type of circuit construction are L1, L2, R3 and R4 connected in?: _____.
- Turn trainer on, turn switch SW1 on and measure the current flowing through the following circuits:
NOTE: You must completely understand this circuit in order to correct conduct the below measurement.
 - CONTROLLED CIRCUIT: _____ amps. Expressed as: _____
 - EMITTER CIRCUIT: _____ amps. Expressed as: _____
 - CONTROL CIRCUIT: _____ amps Expressed as: _____
- Which circuit are both the control and controlled currents carried on? _____.
- Is this PNP relay control circuit ground switched or positive switched? _____.
- Measure the voltage to positive at loads L1, L2, Resistors R3 & R4 and COLLECTOR of PNP transistor: _____ volts. Expressed as: _____
- Confirm your answer sheet has been correctly filled out, then turn in to your instructor.
- Turn switch SW1 OFF, then remove all red and black wires from the trainer.

DESCRIPTION	PNP	NPN
TRANS OFF-POWER AVAILABLE AT:	EMITTER & BASE	COLLECTOR
LOW CONTROL CURRENT CKT:	BASE - to EMITTER +	BASE + to EMITTER -
HIGH CONTROLLED CURRENT CKT:	EMITTER to COLLECTOR	COLLECTOR to EMITTER
SWITCHED IN:	GROUND SIDE	POSITIVE SIDE

TRANSISTOR REFERENCE CHART FOR PNP AND NPN TRANSISTORS

SA-23 TRANSISTOR CONTROLLED CIRCUITS - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

SA-23A NPN TRANSISTOR CIRCUIT

7. Measure the available voltage to the following components. Put your readings on the student answer sheet.
- A. Bulb L1: _____ volts. Expressed as: _____
- B. Bulb L2: _____ volts. Expressed as: _____
- C. Resistor R3: _____ volts. Expressed as: _____
- D. Resistor R4: _____ volts. Expressed as: _____
8. Bulbs L1, L2 and resistors R3 and R4 are connected in: _____
9. Turn trainer on, turn switch SW1 on and measure the current flowing through the following circuits:
- A. COLLECTOR CIRCUIT: _____ amps. Expressed as: _____
- B. EMITTER CIRCUIT: _____ amps. Expressed as: _____
- C. BASE CIRCUIT: _____ amps. Expressed as: _____
10. Prediction:
- _____
- _____
11. Description:
- _____
- _____
12. Description:
- _____
- _____
13. Explanation:
- _____
- _____
14. Voltage to ground at loads L1, L2, Resistors R3 & R4 and COLLECTOR of NPN transistor:
_____ volts. Expressed as: _____.
15. Positive or Negative switched control circuit? _____.

SA-23 TRANSISTOR CONTROLLED CIRCUITS - Student Answer Sheet (continued)

SA-23B PNP TRANSISTOR CIRCUIT

6. What type of circuit construction are L1, L2, R3 and R4 connected in? _____
7. Turn trainer on, turn switch SW1 on and measure the current flowing through the following circuits:
NOTE: You must completely understand this circuit in order to correct conduct the below measurement.
 - A. CONTROLLED CIRCUIT: _____ amps. Expressed as: _____
 - B. EMITTER CIRCUIT: _____ amps. Expressed as: _____
 - C. CONTROL CIRCUIT: _____ amps Expressed as: _____
8. Which circuit are both the control and controlled currents carried on? _____
9. Is this PNP relay control circuit ground switched or positive switched? _____
10. Measure the voltage to the ground of all points of LOAD (L1, L2, Resistors R3 & R4 and PNP COLLECTOR):
_____ volts. Expressed as: _____.
11. Confirm your answer sheet has been correctly filled out, then turn in to your instructor.

INSTRUCTOR GRADE: _____ **DATE:** _____ **COMMENTS:** _____

MODULE 6

Advanced Student Circuit Assignments

SA-24 Using M1 as a Generator

The M1 motor used on this trainer is a DC motor with an armature (coil of wire) and a magnetic field (magnets). The pulley is attached to a gear reduction system that was designed to allow the flywheel to turn very slowly. If the motor pulley is rotated by hand, because of the gear reduction system, the motor would turn at a much faster rate than if it was powered by the voltage supplied by the trainer. This phenomenon will cause the motor to become a “GENERATOR”.

The Laws of Physics state that in electricity, in order to generate electricity, three things are required. They are: 1- A coil of wire, 2- A magnetic field and 3- Motion of either 1 or 2. Given those three things, you can generate electricity. In addition, if you have 1- A coil of wire and 2- A magnetic field and also supply electricity, you will obtain “MOTION” which is how any electric motor works. So, M1 motor has a magnetic field and a coil of wire. If we supply electricity to the red and black receptacles, M1 starts to rotate and becomes a MOTOR. However, M1 can also become a generator. Let's experiment with this concept.

SA-24 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the SA-24 student answer sheet to record all of your measurements and question answers.

1. Leave the trainer OFF. No power supplied and the voltage display should be blank.
2. Connect a red wire from M1 red receptacle to the red receptacle of D1.
3. Connect a black wire from M1 black receptacle to the black receptacle of D1.
4. Grab the M1 flywheel and rotate in one direction. (Clock-wise or Counter-Clockwise)
5. Fill in the Student Answer Sheet describing what D1 does in either direction of M1.
6. Carefully remove D1 and rotate it 180° then reinstall it into the D1 receptacle.
7. Fill in the Student Answer Sheet describing what D1 does in either direction of M1.
8. Explain the “why” of the behavior of D1 from steps #4 and #6.
9. Leave the trainer OFF. Then connect the voltmeter to both the red and black M1 receptacles.
10. Rotate M1 in a clock-wise direction and measure the output voltage of M1 generator on the answer sheet.
11. Rotate M1 in a counter-clockwise direction and measure the output voltage of M1 generator on the answer sheet.
12. Answer this question on the Student Answer Sheet: Why does the M1 generator generate a voltage in either direction, but D1 only operates in one direction?
13. Connect an ammeter in series with either the red or black wires to D1 and measure the current in both directions of rotation. CW = _____ amps CCW = _____ amps.

NOTE: The Fluke digital multimeter used with this trainer does not have a “milli-amp” scale. Therefore, for the purposes of measuring the current output of M1 as directed, you will have to turn the flywheel very fast in order to generate only 1-2 milliamps of current. The meter may show only “zeros” depending on how fast you can turn M1's flywheel.

14. Explain the results of step #13 on the Student Answer Sheet. Why did you get the results as measured?
15. Remove the red and black wires connecting to D1 and switch them to bulb L1.
16. Rotate the flywheel in an attempt to light bulb L1. What happens?
17. Explain the results of step #16 on the answer sheet.
18. Remove the wires you used to complete SA-24 assignment and turn the trainer power switch to OFF
19. Turn in your completed answer sheet to your instructor.

After completing this assignment, you should understand that a MOTOR can also become a GENERATOR given certain conditions. In hybrid and electric vehicles (EV), the term MG1 and MG2 are often used. “MG” stands for “MOTOR GENERATOR”. This component is used in hybrids and EV’s to either propel the vehicle down the road by using battery voltage or can become generator when the vehicle goes in “regenerative braking” using the inertia of the vehicle to drive the electric drive motors as generators. “Re-Gen” braking is a very common system used on most hybrids and EV vehicles.

The desired understanding with this assignment is that a motor can also become a generator. The difference deals with the four elements of motor and power generation. They are:

1. A coil of wire
2. A magnetic field
3. Electricity
4. Motion.

If you have two of the three, you can obtain the third. For example: A generator would need a coil of wire, a magnetic field and motion (of the field or the coil of wire). Doing so will generate electricity. For a motor, you would need electricity, a magnetic field and coil of wire. As soon as electricity is applied to the coil of wire, motion will occur. There are many variations of how the three required components are arranged and constructed in motors and generators, but the physics are the same.

SA-24 USING M1 AS A GENERATOR - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

5. Clockwise direction: _____
Counter-Clockwise direction: _____

7. Clockwise direction: _____
Counter-Clockwise direction: _____

8. Explain why:

10. _____ volts. Expressed as: _____

11. _____ volts. Expressed as: _____

12. _____

BE SURE TO READ THE NOTE INCLUDED WITH STEP 13 BEFORE COMPLETING ATTEMPTING TO MEASURE CURRENT.

13. CW = _____ amps. Expressed as: _____
CCW = _____ amps. Expressed as: _____

14. Explanation of Step 13:

16. _____

17. Why?

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-25 Alarm System — Option 1

The CL-1919-06 trainer has components that can be used to create many other types of circuits that were not covered to date by the 24 previous assignments. SA-25 and additional assignments ask you to apply the knowledge and understanding from the activities you have completed to create some of these circuits.

There will NOT be step by step instructions given that guide you through connecting the red and black wires. You will be responsible to designing each circuit that matches the performance criteria listed for each one. Be sure to use a blank template of the trainer to properly draw the red and black wires as you build each circuit. Be sure to label each schematic with the proper assignment number.

SA-25 CIRCUIT CRITERIA

Using the components on the trainer, design and build an alarm circuit that will turn on a buzzer if the push button (which will be consider a vehicle door tamper switch) is in the "OPEN" or OFF position and shuts off the buzzer when the door is "CLOSED", the switch is in the ON position.

1. Draw your designed circuit for assignment SA-25 on a blank schematic template and label it:
SA-25 ALARM SYSTEM - OPTION 1.

SA-25 CIRCUIT EXPLANATION

Use the SA-25 student answer sheet to record all of your question answers.

2. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit.
3. Does circuit work properly according to the described circuit criteria? Yes ____ No ____
4. Turn in your answer sheet to your instructor.

SA-25 ALARM SYSTEM — OPTION 1 - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

1. Draw your designed circuit for assignment SA-25 ALARM SYSTEM - OPTION 1 on a blank schematic template and label it properly.
2. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit: _____

3. Does circuit work properly according to the described circuit criteria? Yes ____ No ____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-26 Alarm System — Option 2

SA-26 CIRCUIT CRITERIA

Design and build an alarm circuit similar to the OPTION 1 circuit, except now lights L1 and L2 will flash on and off when the alarm system is tripped. The buzzer will be on constantly, but the lights will flash on an off. The push button simulates the door switches of the vehicle and when the door is closed the alarm system is “armed”, but all warning devices are OFF. As soon as the “door” opens, the alarm will trip and turn on the devices.

1. Draw your designed circuit for assignment SA-26 on a blank schematic template and label it:
SA-26 ALARM SYSTEM - OPTION 2.

SA-26 CIRCUIT EXPLANATION

Use the SA-26 student answer sheet to record all of your question answers.

2. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit.
3. Does circuit work properly according to the described circuit criteria? Yes ____ No ____
4. Turn in your answer sheet to your instructor.

SA-26 ALARM SYSTEM — OPTION 2 - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

1. Draw your designed circuit for assignment SA-26 ALARM SYSTEM - OPTION 2 on a blank schematic template and label it properly.
2. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit: _____

3. Does circuit work properly according to the described circuit criteria? Yes ____ No ____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-27 Light Bulb Dimming

SA-27 CIRCUIT CRITERIA

Design and build a circuit that will cause bulb L1 and bulb L3 HI both get brighter and dimmer and the control knob is rotated. Make the circuit so that the bulbs get dimmer when the control knob is turned counter-clockwise and get brighter when the knob is turned clockwise.

1. Draw your designed circuit for assignment SA-27 on a blank schematic template and label it:
SA-27 LIGHT BULB DIMMING.

Use the SA-27 student answer sheet to record all of your question answers.

2. Does the circuit operate exactly as the criteria describes? Yes ____ No ____

SA-27 CIRCUIT EXPLANATION

3. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit.
4. Did the circuit work properly as described in the explanation? Yes ____ No ____
5. Now re-wire the circuit so that the control knob causes the bulbs to get brighter in the counter-clockwise rotation and dimmer in the clockwise position. Describe what you re-wired on the answer sheet.
6. What was the only device that you had to change the wiring on to reverse dimming direction?
7. Turn in your answer sheet to your instructor.

SA-27 LIGHT BULB DIMMING - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

1. Draw your designed circuit for assignment SA-27 LIGHT BULB DIMMING on a blank schematic template and label it properly.
2. Does circuit work properly according to the described circuit criteria? Yes ____ No ____
3. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit: _____

4. Did the circuit work properly as described in the explanation? Yes ____ No ____
5. What did you have to do to reverse the dimming direction with the control knob?

6. What was the only device that you had to change the wiring on to reverse dimming direction?

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-28 Horn Circuit with Relay

SA-28 CIRCUIT CRITERIA

Design and build a circuit that will operate the horn (buzzer B1) which will be turned on by relay R1 using push button PB1 to control the relay. This is very typical non-CAN Bus horn circuit.

1. Draw your designed circuit for assignment SA-28 on a blank schematic template and label it:
SA-28 HORN CIRCUIT WITH RELAY.

Use the SA-28 student answer sheet to record all of your question answers.

2. Does circuit work properly according to the described circuit criteria? Yes ____ No ____

SA-28 CIRCUIT EXPLANATION

2. Does the circuit operate exactly as the criteria describes?
3. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit.
4. Demonstrate proper circuit performance to your instructor.
5. Now, make a modification to the circuit that will cause LED D1 to be “on” when the horn is “off”. This could be a horn location indicator light circuit on a vehicle. The important thing is that the LED goes off when the horn comes on.
6. Describe what modifications you had to make to the circuit to comply with step 5?
7. Turn in your answer sheet to your instructor.

SA-28 HORN CIRCUIT WITH RELAY - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

1. Draw your designed circuit for assignment SA-28 HORN CIRCUIT WITH RELAY on a blank schematic template and label it properly.
2. Does circuit work properly according to the described circuit criteria? Yes ____ No ____
3. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit: _____

6. Describe what modifications you had to make to the circuit to comply with step 5?

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-29 Alternately Flashing Lights

SA-29 CIRCUIT CRITERIA

Design and build a circuit that will cause bulb L1 and bulb L2 to alternately flash on and off. Control this circuit with switch SW1, but when switch SW1 is in the OFF position, no lights will be on.

1. Draw the designed circuit on a blank schematic template and label it:
SA-29 ALTERNATELY FLASHING LIGHTS.

Use the student answer sheet SA-29 to record all of your question answers.

2. Does the circuit operate exactly as the criteria describes?
3. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit.
4. Demonstrate proper circuit performance to your instructor.
5. Turn in your answer sheet to your instructor.

SA-29 ALTERNATELY FLASHING LIGHTS - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

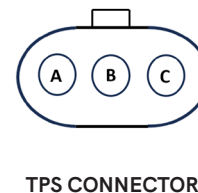
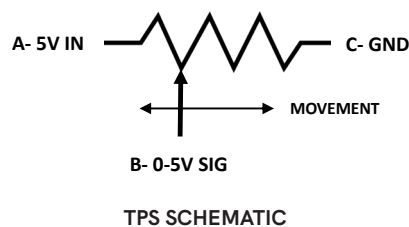
1. Draw the designed circuit on a blank schematic template and label it:
SA-29 ALTERNATELY FLASHING LIGHTS.
2. Does circuit work properly according to the described circuit criteria? Yes ____ No ____
3. In your own words, explain how this circuit works explaining both the positive and negative sides of the circuit: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-30 Throttle Position Sensor Circuit

SA-30 CIRCUIT EXPLANATION

Many position sensors in the automobile use a three-wire circuit design. The sensor consists of a fixed resistance manufactured in either a straight line or in a circle design. The “third” wire is a movable arm that contacts the fixed resistance as it is moved either in a straight line or rotates in a circular movement. A throttle position sensor is typically the circular design and the movable arm is connected to the throttle linkage of the engine and rotates as the throttle is opened or closed. The TPS (throttle position sensor) is used to tell the ECM and other computers what the position of the throttle plate is. See below for further explanation:



As the throttle linkage is moved, the terminal B signal circuit will vary from 0 to $5V\pm$. Terminal A will be a constant $5V\pm$ and terminal C is the Ground circuit. NOTE: The resistor is shown in a straight-line format here, but could be in a circular shape with no change in sensor operation. The important thing to remember is that the movable arm (terminal B) moves with the throttle linkage and varies the signal voltage from $0-5V\pm$. This is how the ECM “knows” the position of the throttle plate. NOTE: Newer vehicles with “drive by wire” systems use two throttle position sensors and the name of the sensors is changed to Accelerator Pedal Position sensor (APP). One APP sensor will have the signal voltage go up with throttle movement and the other will have the signal voltage go down with throttle movement. These redundant signals are used to verify proper APP circuit operation.

The CL-1919-06 Trainer can be used to create a “TPS” circuit using the potentiometer (POT). Terminals G and I can be either the 5V or Ground circuits and terminal H is the TPS signal circuit. The trainer’s voltage supply will be adjusted as close to 5.0V as possible. Abnormal conditions can be introduced by using resistors R1 through R5 in any of the three circuits of the TPS sensor.

SA-30 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-30 student answer sheet SA-30 to record all of your measurements and question answers.

1. Obtain the schematic labeled: THROTTLE POSITION SENSOR CIRCUIT PART 1 and build the circuit on your trainer. Double check all connections.
NOTE: Switch SW1 will be used for an ignition switch.
2. Using very light adjustments, try to adjust the trainer’s voltage supply readout so that it is as close to 5 volts as possible. Most vehicle manufacturers use 5V as the operating voltage of position sensors.
3. Turn the trainer off and disconnect the three wires to the potentiometer (POT).
4. Now, measure the total resistance value of the potentiometer. Use the answer sheet.

5. The trainers potentiometer is being used as a typical throttle position or accelerator pedal position sensor. Connect your ohmmeter red lead to terminal G of the potentiometer and the black ohmmeter lead to terminal H of potentiometer.
6. Turn POT adjustment knob fully counter-clockwise and read the resistance. Use the answer sheet.
7. Turn POT adjustment knob fully clockwise and read the resistance. Use the answer sheet.
8. With the POT still at full CW, make a prediction of what the resistance measurement be if your ohmmeter leads were connected to terminals I and H, and then H and G? Put your answer on the answer sheet.
9. Make those changes and confirm your prediction by making measurements. What happened to the resistance readings? Use the answer sheet.
10. Reconnect all wires removed from Step 3, remove ohmmeter leads and turn on the trainer.
11. Connect red lead of voltmeter to terminal H of POT and black lead of voltmeter to ground.
12. With “ignition key” (SW1) turned on, rotate the POT adjustment knob while watching the voltage.
13. Make voltage measurements at the following knob positions.
 - A. Fully counter-clockwise. Use the answer sheet.
 - B. $\frac{1}{4}$ way between full CCW. Use the answer sheet.
 - C. $\frac{1}{2}$ way between full CCW. Use the answer sheet.
 - D. $\frac{3}{4}$ way between full CCW. Use the answer sheet.
 - E. Fully clockwise. Use the answer sheet.
14. Many cars use two APP sensors, with each one giving an “opposite” signal as the other one in the pair. This is a safety design. So, to simulate this, re-wire your potentiometer so that the signal voltage readings now read opposite as they did before. What circuit changes did you have to make to accomplish this? Use the answer sheet.
15. Upon completion of steps 1 through 15, in your own words, describe what a throttle position or accelerator pedal position sensor are? How do they work? Use the answer sheet.
16. With ignition key “ON”, adjust the POT knob until you have a TPS signal voltage to ground of about 2.5 V (one-half way). Put your TPS signal voltage on the answer sheet. Turn switch SW1 to OFF.
17. Obtain the schematic labeled: THROTTLE POSITION SENSOR CIRCUIT PART 2 and build the circuit on your trainer. Notice that resistor R4 is now in the TPS signal circuit. Double check all connections.

EXPLANATION: You have inserted an unwanted resistance (R4) in the TPS signal circuit. The next steps will explain how to properly diagnose this circuit and what effect unwanted resistance in the circuit will have on TPS operation.

18. With trainer on, measure the TPS signal voltage. Use the answer sheet SA-30.
19. Explain in your own words, why the signal voltage changed? Use the answer sheet.

SA-30 USING VOLTAGE DROP TESTING TO FIND THE LOCATION OF THE UNWANTED RESISTANCE

20. Move the red lead of your voltmeter from terminal H of POT to terminal P of resistor R4. Make a TPS signal voltage measurement. Use the answer sheet.
21. Move the red lead of your voltmeter from terminal P of R4 to terminal Q of R4 and measure TPS signal voltage. Use the answer sheet.

22. Now, remove the end of the black wire from the black system ground receptacles that connects to terminal Q of R4 (do not remove it from the resistor) and measure TPS signal voltage again. Use the answer sheet. After making the voltage measurement, re-connect the black wire back to the system ground receptacles.
23. The above tests reveals that there is unwanted resistance in the TPS signal circuit which causes the correct signal voltage of $2.5\pm\text{VDC} = \frac{1}{2}$ throttle, to be about $1.25\pm\text{VDC} = \frac{1}{4}$ throttle. This condition would cause vehicle performance issues as the vehicle ECM thinks the throttle is at $\frac{1}{4}$ open when it is really $\frac{1}{2}$ open.
24. Now, let's use **VOLTAGE DROP TESTING** to locate the unwanted resistance even though in this case, you can obviously see that it is resistor R4.
25. With ignition switch SW1 in the ON position, measure the voltage between terminal H of POT and terminal P of resistor R4. Use the answer sheet.
26. Explain in your own words what a desirable or "normal" reading should be. Use the answer sheet.
27. Measure the voltage between terminal P and terminal Q of resistor R4. Use the answer sheet.
28. Explain in your own words what a desirable or "normal" reading should be. Use the answer sheet.
29. Measure the voltage between terminal Q of resistor R4 and system ground. Use the answer sheet.
30. Explain in your own words what a desirable or "normal" reading should be. Use the answer sheet.
31. Now, evaluate your voltage measurements and describe your conclusions from the three voltage readings you have made. Use the answer sheet.
32. Now, place the red voltmeter lead to terminal H of POT and the black voltmeter lead to system ground.
33. Remove the black wire connected to system ground coming from terminal Q of resistor R1 and measure the TPS signal voltage. Use the answer sheet.
34. Explain in your own words why the TPS signal voltage changed when the ground wire was disconnected. Use the answer sheet.
35. Remove all wires from the trainer, double check your answer sheet for missing answers, then turn in to your instructor.

SA-30 THROTTLE POSITION SENSOR CIRCUIT - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

4. _____ ohms
6. _____ ohms at full CCW
7. _____ ohms at full CW
8. _____
9. _____ ohms between H and I and _____ ohms between H and G
13. A- _____ volts full CCW
B- _____ volts $\frac{1}{4}$ from full CCW
C- _____ volts $\frac{1}{2}$ from full CCW
D- _____ volts $\frac{3}{4}$ from full CCW
E- _____ volts at full CW
14. _____

15. _____

16. _____ TPS volts
18. _____ TPS volts
19. _____

20. _____ TPS volts
21. _____ TPS volts
22. _____ TPS volts (with ground wire removed)
25. _____ volts between terminal H of POT to terminal P of resistor R4
26. A normal voltage reading should be: _____
27. _____ volts between terminal P and terminal Q of resistor R4.
28. A normal voltage reading should be: _____
29. _____ volts between terminal Q of resistor R4 and system ground.
30. A normal voltage reading should be: _____

31. **EVALUATION:** _____

33. _____ volts

34. **EXPLANATION:** _____

INSTRUCTOR GRADE: _____ **DATE:** _____ **COMMENTS:** _____

SA-31 PWM Controlled NPN Transistor Circuit

SA-31 CIRCUIT EXPLANATION & THEORY

It is very common in vehicle engine performance circuits to have an internal circuit with transistors controlled by Pulse Width Modulation. A commonly used term is a “Quad Driver”. Quad-Drivers are integrated circuits within the ECM or PCM that control certain types of circuits. Many Quad-Drivers are controlled by using Pulse Width Modulation which are also within the ECM/PCM. Pulse Width Modulation controls a circuit by turning on and off a B+ supply very quickly. For example, a light bulb can be turned on and off very rapidly so that it can be off, on at varying amounts of brightness to being on a full brightness all controlled by Pulse Width Modulation.

Fuel Injectors are also commonly controlled by PWM. PWM circuits operate at varying frequencies. The circuit is either ON or OFF and the quad-driver controls the amount of on time. The amount of “on” time is called DUTY CYCLE. Duty cycle is measured either as a percentage or can also be measured with the amount of on time called “PULSE WIDTH”. The important thing to remember about PWM, it that the voltage to the device being controlled will be either full voltage (14.6 for example) or zero. If a blower motor was controlled by PWM and it was running at half-speed, the DUTY CYCLE would be at 50%. If a digital voltmeter was connected to the blower motor, it would indicate about $7.3V \pm$ because the meter cannot read the on/off signals that are occurring in milli-seconds. So, the meter just “averages” the signals.

One must remember, that a PWM circuit cannot be accurately tested or measured with a voltmeter. An oscilloscope is the only tool that will display the true on and off pulse width modulated circuit. Some scan tools can give a DUTY CYCLE or PULSE WIDTH readout, but those also are averages and not the true PWM signals.

SA-31 PROCEDURE

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.

Use the SA-31 student answer sheet to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below.

BE VERY CAREFUL TO CORRECTLY INSTALL EACH WIRE:

CONNECT **RED** JUMPER WIRES BETWEEN:

- A. Any of the four red power receptacles to terminal O of switch SW1
- B. Terminal I of switch SW1 to terminal A of bulb L1
- C. Terminal B of bulb L1 to terminal C (collector) of transistor T1
- D. Red receptacle of the PWM generator to terminal K of resistor R1 (Make sure the PWM knob is fully CCW)
- E. Terminal J of resistor R1 to terminal B (base) of transistor R1

CONNECT **BLACK** JUMPER WIRES BETWEEN:

- A. Any of the four black ground terminals to terminal E (emitter) of transistor T1
- B. Any of the four black ground terminals to the black terminal of the PWM generator

NOTE: It will be noticed that this NPN circuit uses red wires on both sides of bulb L1. This is correct because schematics show circuits in the OFF position and full supply voltage can be measured to ground at both terminals of bulb L1. When the transistor turns ON, the wires connected to the COLLECTOR become ground wires and turn the bulb on.

2. Draw the circuit you have just constructed and label it:
SA-31 PWM NPN TRANSISTOR CONTROLLED CIRCUIT.

EVALUATION OF THE CIRCUIT:

3. Make sure switch SW1 is in the OFF position.
4. Measure the voltage from terminal K of resistor R1 to ground in the following conditions (use answer sheet):
 - A. With PWM knob fully CCW. _____ volts
 - B. With PWM knob one-half way between fully CCW & CW _____ volts
 - C. With PWM knob fully CW. _____ volts. (Return to fully CCW position)
5. Measure the voltage at terminal J of resistor R1 to ground in the following conditions: (use answer sheet):
 - A. With PWM knob fully CCW. _____ volts
 - B. With PWM knob one-half way between fully CCW & CW _____ volts
 - C. With PWM knob fully CW. _____ volts. (Return to fully CCW position)
6. The above steps demonstrate the resistor R1 serves as a current limiting device for transistor T1 (NPN) BASE circuit. And, it also demonstrates that the transistor can be turned on at different voltages even though it is not actually controlling anything at this point (WHY? Because switch SW1 is still in the OFF position). Remember that the “control” circuit of an NPN transistor is BASE to EMITTER) (Return to fully CCW position).
7. Turn switch SW1 to the ON position.
8. Measure the voltage to ground at terminal C (COLLECTOR) of transistor T1 (NPN). _____ volts. This step demonstrates that there is voltage present at the transistor COLLECTOR but the transistor is turned OFF so the light bulb does not illuminate.
9. Now adjust the PWM knob to the below positions and measure the voltage of COLLECTOR to ground and describe bulb L1’s operation at each position (use answer sheet):
 - A. Fully CCW _____ volts. Bulb L1’s performance _____
 - B. ½ between full CCW and CW. _____ volts Bulb L1’s performance _____
 - C. Fully CW _____ volts. Bulb L1’s performance _____ (Return to fully CCW position)
10. **EXPLANATION:** As soon as the PWM generator starts to turn on the transistor, terminal B of bulb L1 and the COLLECTOR terminal becomes a path to ground. Therefore, the voltage at the COLLECTOR will start to drop as the transistor is turned on for longer periods of time. The voltage at terminal A of bulb L1 will stay the same at system voltage because it is on the positive side of the circuit.
11. The PWM generator is simply used in this case as a “variable” ON circuit to control the brightness of the bulb. Other examples of component control could be electric motors, relays, solenoids, fuel injectors or ignition coils which can be all controlled by PWM and transistors.
12. Predict what would happen if you connected a red jumper wire from B+ supply voltage to terminal K of resistor R1. (use answer sheet)

13. Without making any other circuit changes, install a red jumper wire from any of the four red B+ supply voltage receptacles to the K terminal of resistor R1. Describe what happened (use answer sheet).
14. Make sure your answer sheet is completely filled out, then turn in to instructor.
15. Remove all wires from the trainer and turn off both the trainer and the digital multimeter.

SA-31 PWM CONTROLLED NPN TRANSISTOR CIRCUIT - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

4. A. PWM knob fully CCW _____ volts. Expressed as: _____
B. PWM knob $\frac{1}{2}$ way _____ volts. Expressed as: _____
C. PWM knob fully CW _____ volts. Expressed as: _____

5. A. PWM knob fully CCW _____ volts. Expressed as: _____
B. PWM knob $\frac{1}{2}$ way _____ volts. Expressed as: _____
C. PWM knob fully CW _____ volts. Expressed as: _____

8. _____ volts at COLLECTOR. Expressed as: _____

9. A. PWM knob fully CCW _____ volts. Expressed as: _____
B. PWM knob $\frac{1}{2}$ way _____ volts. Expressed as: _____
C. PWM knob fully CW _____ volts. Expressed as: _____

12. **PREDICTION:** _____

13. **DESCRIPTION:** _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-32 PWM Controlled PNP Transistor Circuit

CIRCUIT EXPLANATION & THEORY: In the previous assignment SA-31, an NPN transistor was used to control bulb L1 and the transistor was controlled by the PWM generator. In this assignment (SA-32), you will use a PNP transistor and learn the differences between the NPN and PNP in how they control circuits and how they are properly wired in a circuit. The NPN transistor controlled the “positive” side of the bulb circuit. The PNP circuit controls the “ground” side of the circuit. The EMITTER of both an NPN and a PNP transistor carries both the low “control” current and the higher “controlled” current. The BASE to EMITTER is the “control” or low current circuit and the COLLECTOR to EMITTER is the “controlled” or high current circuit.

SA-32 PWM PNP TRANSISTOR CONTROLLED CIRCUIT — Part A

PROCEDURE:

Be sure to carefully follow all instructions and always ask your instructor if you have any questions.
Use the student answer sheet SA-32 to record all of your measurements and question answers.

1. Connect red and black jumper wires as instructed below.

BE VERY CAREFUL TO CORRECTLY INSTALL EACH WIRE:

CONNECT **RED** JUMPER WIRES BETWEEN:

- A. Red receptacle of the PWM generator to the terminal E (emitter) of transistor T2 (PNP).
(Make sure the PWM knob is fully CCW)

CONNECT **BLACK** JUMPER WIRES BETWEEN:

- A. Any of the four black ground terminals to terminal O of switch SW1
- B. Terminal I of switch SW1 to terminal K of resistor R1
- C. Terminal J of resistor R1 to terminal B (base) of transistor T2 (PNP)
- D. Any of the four black ground terminals to the black terminal of the PWM generator.
- E. Any of the four black ground terminals to terminal B of bulb L1
- F. Terminal A of bulb L1 to terminal C (collector) of transistor T2 (PNP)

NOTE: It will be noticed that this PNP circuit uses black wires on both sides of bulb L1. This is correct because schematics show circuits in the OFF position and both terminals of bulb L1 are “technically” ground until the transistor is turned on. When the transistor turns ON, the wire connected to the COLLECTOR becomes positive wire and turns the bulb on.

2. Draw the circuit you have just constructed and label it:
SA-32 PWM PNP TRANSISTOR CONTROLLED CIRCUIT - Part A.

EVALUATION OF THE CIRCUIT:

3. Make sure the PWM adjustment knob is fully counter-clockwise.

UNDERSTANDING THE LOW AND HIGH CURRENT CIRCUITS IN A PNP TRANSISTOR:

4. Turn switch SW1 to ON and also turn the PWM adjustment knob fully clockwise and confirm that bulb L1 is illuminated.

5. Measure the current in the following circuits: (use answer sheet)
 - A. The PNP BASE circuit _____ amps
 - B. The PNP COLLECTOR circuit _____ amps
 - C. The PNP EMITTER circuit _____ amps (Return PWM knob to fully CCW position)
6. Which PNP circuit draws the least current? _____
7. Which PNP circuit draws the most current? _____
8. Which PNP circuit carries both the control and controlled current? _____
9. Which PNP circuit is the “controlled” circuit? _____
10. Which PNP circuit is the “control” circuit? _____
11. Turn PWM adjustment knob fully counter-clockwise and turn switch SW1 to the OFF position.

EXPLANATION OF CIRCUIT: Transistor T2 (PNP) is serving as a relay. Relays have a low current control circuit which is the relay coil (terminals 86 & 85). A PNP transistor’s low current control circuit is from the BASE to the EMITTER. Relays also have a high current controlled circuit which is from 30 to 87. A PNP transistor’s high current circuit is from COLLECTOR to EMITTER and controls the ground side. A current limiting resistor is usually installed in the BASE circuit to control the amount of current flowing in the control circuit.

SA-32 PWM PNP TRANSISTOR CONTROLLED CIRCUIT — Part B

PROCEDURE:

12. Make the following modifications to the circuit: CONFIRM THAT THE TRAINERS POWER IS TURNED OFF.
 - A. Remove the red wire from PWM red receptacle to terminal E (emitter) of transistor T2 (PNP)
 - B. Install a red wire from terminal E (emitter) of transistor T2 (PNP) to terminal I of switch SW1
 - C. Install a red wire from any of the four red positive receptacles to terminal O of switch SW1.
13. Draw the circuit you have just constructed and label it:
SA-32 PWM PNP TRANSISTOR CONTROLLED CIRCUIT - Part B.

EXPLANATION OF CIRCUIT CHANGES: The PWM generator has been removed from the circuit. Switch SW1 now supplies full battery voltage to the transistor and it will come on at full current control whenever the switch SW1 is closed. This change eliminated the ability to vary the amount of current flowing through transistor T2 (PNP) which previously served as a “dimmer” function for bulb L1. Transistors can either be ON/OFF switches or can be a variable ON/OFF switches.

14. Study the circuit and determine two different methods of adding bulb L2 to the circuit so that the transistor will control both L1 and L2 bulbs together. Describe them on the answer sheet. Once you have decided both methods, make one of your options to the circuit. After your modification, confirm that the circuit operates with both bulbs L1 and L2 coming on together.

Modification #1 _____

Modification #2 _____

15. Which modification did you choose? Use the answer sheet. _____
16. With the circuit modification in place, measure the controlled current (answer sheet)
_____ amps
17. Did the BASE current change from the previous circuit? Y/N _____
If yes, what is the new reading? _____ amps
18. Measure the EMITTER circuit current. _____ amps
19. Compare it to the circuit where only L1 was on. What is the difference?

20. Make sure your answer sheet is completely filled out, then turn in to instructor.
21. Remove all wires from the trainer and turn off both the trainer and the digital multimeter.

SA-32 PWM CONTROLLED PNP TRANSISTOR CIRCUIT - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

SA-32 Part A

5. A- The PNP BASE circuit: _____ amps. Expressed as: _____
B- The PNP COLLECTOR circuit: _____ amps. Expressed as: _____
C- The PNP EMITTER circuit: _____ amps. Expressed as: _____
6. Which PNP circuit draws the least current? _____
7. Which PNP circuit draws the most current? _____
8. Which PNP circuit carries both the control and the controlled circuits? _____
9. Which PNP circuit is the "controlled" circuit? _____
10. Which PNP circuit is the "control" circuit? _____

SA-32 Part B

14. What two circuit modifications can be made to control bulb L2.
A: _____

B: _____

15. Which modification did you choose? _____

16. Controlled current (with modification made): _____ amps.
Expressed as: _____
17. Did the BASE current change? Y/N ____ If YES, what is the new reading? _____ amps
Expressed as: _____
18. What is the EMITTER current? _____ amps. Expressed as: _____
19. Compare EMITTER current to the circuit before modifications.
Comparison: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

SA-33 Flashing Lights Transistor Controlled Circuit

CIRCUIT EXPLANATION & THEORY: In assignments SA-31 & SA-32, both transistors were individually connected to a circuit. In SA-33, both NPN and PNP transistors will be used to control alternate flashing of L1 and L2. This is the most complex circuit you will be constructing and the proper connections of all black and red wires is critical. SA-33A will connect all of the black ground circuits and SA-33B will connect all the positive feed circuits.

SA-33A FLASHING LIGHTS TRANSISTOR CONTROLLED GROUND CIRCUITS

PROCEDURE:

Be sure to carefully follow all instructions and always ask your instructor if you have any questions. Use the student answer sheet SA-33 to record all of your measurements and question answers.

1. **BE VERY CAREFUL TO CORRECTLY INSTALL EACH WIRE:**

CONNECT **BLACK** JUMPER WIRES BETWEEN:

- A. Any of the four black ground terminals to terminal K of resistor R1
- B. Terminal J of resistor R1 to the B (base) terminal K of transistor T2
- C. Any of the four black ground terminals to the E (emitter) terminal of transistor T1 (NPN)
- D. Any of the four black ground terminals to terminal 85 of relay R1.
- E. Any of the four black ground terminals to terminal B of bulb L1
- F. Any of the four black ground terminals to terminal D of bulb L2
- G. Terminal A of bulb L1 to terminal C (collector) of transistor T2 (PNP)
- H. Any of the four black ground terminals to the GND terminal of the electronic flasher

NOTE: It will be noticed that this PNP circuit uses black wires on both sides of bulb L1. This is correct because schematics show circuits in the OFF position and both terminals of bulb L1 are “technically” ground until the transistor is turned on. When the transistor turns ON, the wire connected to the COLLECTOR becomes positive wire and turns the bulb on.

2. Draw the circuit you have just constructed and label it:

SA-30A FLASHING LIGHTS TRANSISTOR CONTROLLED GROUND CIRCUITS

SA-33B FLASHING LIGHTS TRANSISTOR CONTROLLED POSITIVE CIRCUITS

PROCEDURE:

3. CONNECT **RED** JUMPER WIRES BETWEEN:

- A. Any of the four red positive terminals to terminal C of bulb L2
- B. Any of the four red positive terminals to terminal O of switch SW1
- C. Terminal I of switch SW1 to terminal 30 of relay R1
- D. Terminal I of switch SW1 to BAT terminal of the electronic flasher
- E. Terminal M of resistor R2 to terminal 87 of relay R1

- F. Terminal L of resistor R2 to B (base) terminal of transistor T1 (NPN)
 - G. Terminal 86 of relay R1 to the SIG terminal of the electronic flasher
 - H. Terminal 87a of relay R1 to the E (emitter) terminal of transistor T2 (PNP)
 - I. Terminal D of bulb L2 to the C (collector) terminal of transistor T1 (NPN)
4. Draw the circuit you have just constructed and label it:
SA-33B FLASHING LIGHTS TRANSISTOR CONTROLLED POSITIVE CIRCUITS

CIRCUIT EXPLANATION:

Transistor T1 and Bulb L2

Transistor T1 controls the flashing of bulb L2 by having transistor T1 turned on and off by the electronic flasher controlling the relay R1 coil. The relay coil then turns on terminals 87 and 87a alternately because of the electronic flasher operation. When the relay turns on terminal 87, power exits the relay and flows through resistor R2 which limits the current in the BASE circuit of transistor T1. Power which was fed to bulb L2 and enters the C (collector) terminal of transistor T1 then flows out of terminal E (emitter) of transistor T1 when the transistor is turned on.

Power then flows back to ground and bulb L2 is turned on. As soon as the flasher turns the relay off, bulb L2 also goes off because transistor T1 is shut off.

Transistor T2 and Bulb L1

Transistor T2 controls the flashing of bulb L1 by having transistor T1 turned on and off by the electronic flasher controlling the relay R1 coil. The relay coil then turns on terminals 87 and 87a alternately because of the electronic flasher operation. When the relay is turned off, power exits the relay from terminal 87a and flows to the E (emitter) terminal of transistor T2. The B (base) terminal of transistor T2 is connected through resistor R1 to ground which limits BASE current in the transistor. Terminal C (collector) of transistor T2 is connected to bulb L1, through the bulb and to ground. Thus, when power from relay terminal 87a is turned on, power flows into the E (emitter) circuit of transistor T2, it turns on the transistor and provides a ground path to bulb L1 which turns it on. The transistor T2 B (base) circuit is also connected to ground through resistor R1 and when power enters the E (emitter) terminal, transistor T2 is turned on providing a connection between E (emitter) and C (collector).

The process is reversed on and off as the electronic flasher controls the coil of relay R1. Turning on terminals 30 to 87 of the relay R1 will turn on bulb L2. When the flasher turns the relay coil off, it connects power from relay terminals 30 to 87a which provides power to the E (emitter) terminal of transistor T2 which turns on and provides a ground circuit for bulb L1.

USE YOUR ANSWER SHEET FOR ANSWERING THE FOLLOWING QUESTIONS. ADJUST THE TRAINER'S SUPPLY VOLTAGE AS CLOSE TO 14.6 AS YOU CAN.

- 5. Which transistor controls bulb L1? _____
- 6. Which resistor provides current limiting for transistor T1? _____
- 7. What component provides power to the relay and the electronic flasher? _____
- 8. When transistor T1 is turned on, what bulb also turns on? _____
- 9. Which bulb would stay on constantly if the electronic flasher failed to operate? _____
- 10. Which bulb would not come if resistor R1 opened? _____
- 11. What bulb would stay on if the wire from switch SW1 to terminal 30 of relay R1 was open? _____

12. Measure the current flow through bulb L1: _____ amps (You may have to “modify” the circuit to keep that circuit ON in order to measure current)
13. Measure the current flow through bulb L2: _____ amps (You may have to “modify” the circuit to keep that circuit ON in order to measure current)
14. Measure the current flow in the wire from terminal 87a to terminal E (emitter) of transistor T2:
_____amps (You may have to “modify” the circuit to keep that circuit ON in order to measure current)
15. Measure the current of just the C (collector) circuit of transistor T2. _____amps
16. Make sure your answer sheet is completely filled out, then turn in to instructor.
17. Remove all wires from the trainer and turn off both the trainer and the digital multi-meter.

After completion of SA-33, turn in your answer sheet to the instructor and ask for Test 13, then Test 14.

SA-33 FLASHING LIGHTS TRANSISTOR CONTROLLED CIRCUIT - Student Answer Sheet

NAME _____ CLASS _____ DATE _____

5. Which transistor controls bulb L1? _____
6. Which resistor provides current limiting for transistor T1? _____
7. What component provides power to the relay coil and the electronic flasher? _____
8. When transistor T1 is turned on, what bulb also turns on? _____
9. Which bulb would stay on constantly if the electronic flasher failed to operate? _____
10. Which bulb would not come on if resistor R1 opened? _____
11. What bulb would stay on if the wire from switch SW1 to terminal 30 of relay R1 was open?

12. Measure the current flow through bulb L1: _____ amps.
Expressed as: _____
13. Measure the current flow through bulb L2: _____ amps.
Expressed as: _____
14. Measure the current flow in the wire from terminal 87a to terminal E (emitter) of transistor T2.
_____ amps. Expressed as: _____
15. Measure the current of just the C (collector) circuit of transistor T2. _____ amps.
Expressed as: _____

INSTRUCTOR GRADE: _____ DATE: _____ COMMENTS: _____

NOTE: A schematic for Assignment SA-33 showing both positive (red) and ground (black) circuits is provided in the Instructors manual in case you wish to have students draw the entire circuit.

After completion of SA-33, turn in your answer sheet to the instructor and ask for Test 13, then Test 14.

This image shows a single page of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

