

Simple circuits worksheet

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This worksheet covers the following concepts:

- How to build simple battery-powered circuits.
 - Relating illustrations to schematic diagrams, and visa-versa.
 - Basic meter usage (measuring voltage, current, and resistance).
 - Using meters to measure electrical quantities on a printed circuit board.
 - Different types of electrical switches.
 - Simple series and simple parallel light bulb circuits.
 - Resistors and their function.
 - Troubleshooting a simple light bulb circuit.
-

Resources and methods for learning about these subjects (list a few here, in preparation for your research):

Questions

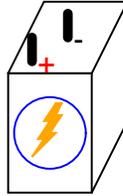
Question 1

In the simplest terms you can think of, define what an electrical *circuit* is.

file 00017

Question 2

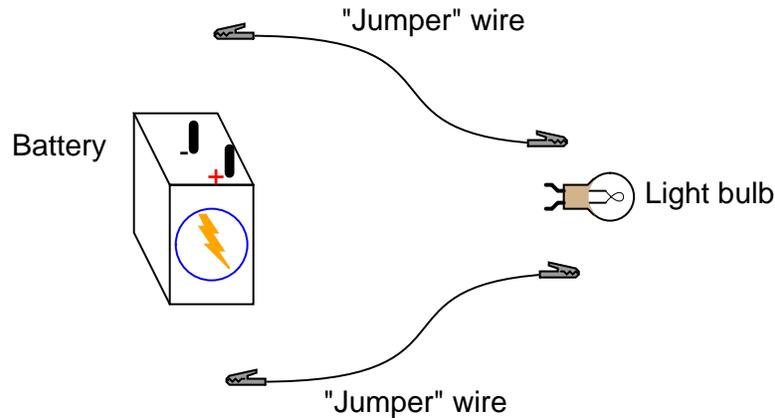
Given a battery and a light bulb, show how you would connect these two devices together with wire so as to energize the light bulb:



file 00001

Question 3

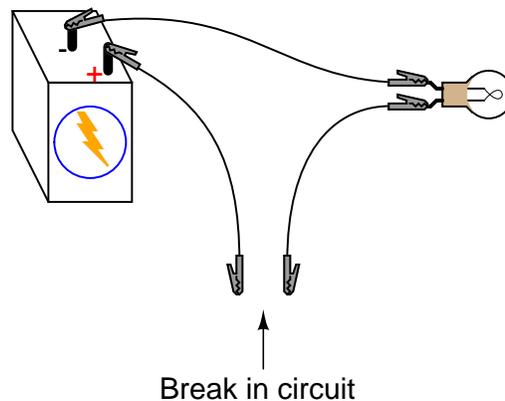
Build a simple electric circuit using a battery as the electrical energy *source*, and a small light bulb as the electrical *load* (I suggest using a 6-volt "lantern" battery and a miniature incandescent light bulb rated for either 6 or 12 volts). Use "jumper" wires with metal clips at the ends to join these two electrical devices together:



After connecting the components together properly so the light bulb lights up, answer the following questions:

- What conditions must be met for the light bulb to light up?
- What happens if the circuit is "broken"?
- Does it matter where the circuit is "broken"?

Then, add a third jumper wire to the circuit so you have a ready "break" to experiment with:



Try bridging this "break" with various materials, and note whether or not the light bulb lights up:

- Paper
- Steel paper clip
- Gold ring
- Rubber eraser
- Pencil lead (graphite)

Also, try touching the jumper wire ends together along their plastic exteriors, rather than at the metal "clip" ends. Does the light bulb light up when you do this?

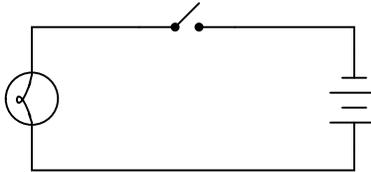
Explain what this experiment demonstrates about the electrical *conductivity* of the various substances listed as well as the plastic coating of the jumper wires. Also explain why electrical wires are provided with that plastic coating, instead of being bare metal. Finally, explain what this experiment has taught you about electric circuits in general.

file 01697

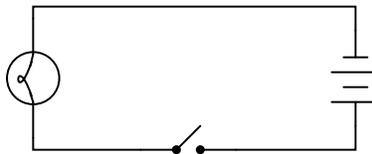
Question 4

What difference will it make if the switch is located in either of these two alternate locations in the circuit?

Switch on negative side of circuit



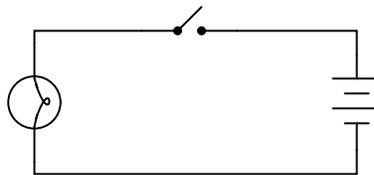
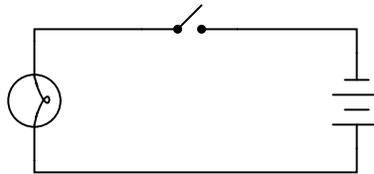
Switch on positive side of circuit



file 00014

Question 5

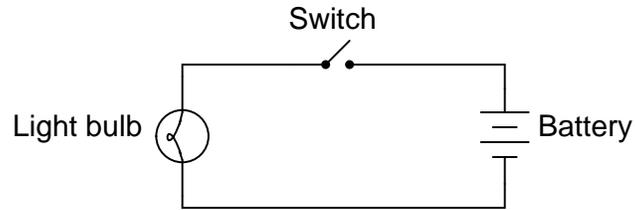
What difference will it make if the battery in this circuit is reversed in direction?



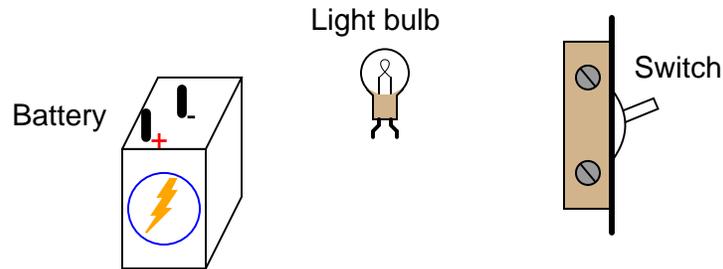
file 00076

Question 6

Examine this schematic diagram:



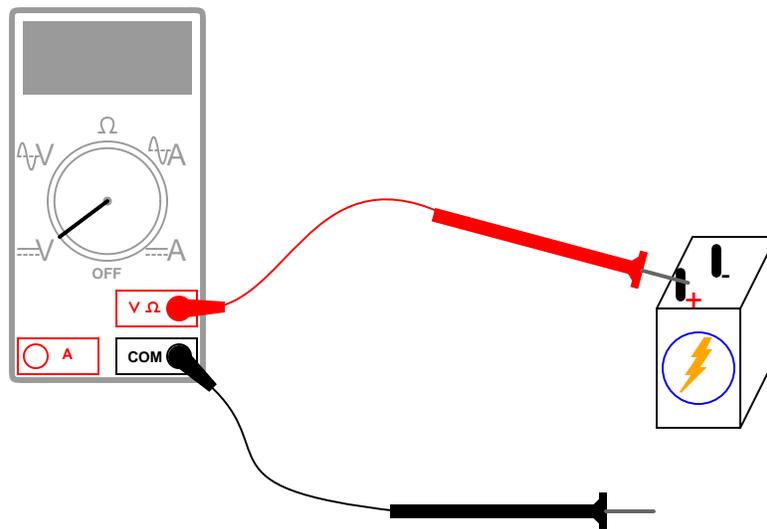
Now, without moving the following components, show how they may be connected together with wires to form the same circuit depicted in the schematic diagram above:



file 00069

Question 7

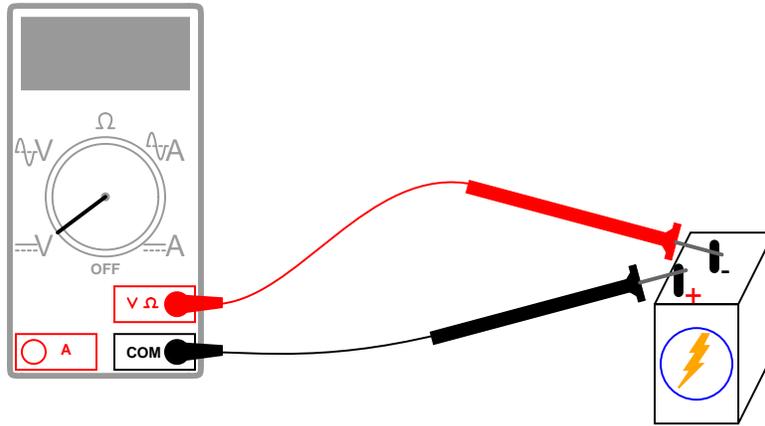
What will this voltmeter register when connected to a battery as shown (assume a battery voltage of 6 volts)? Explain your answer.



file 00020

Question 8

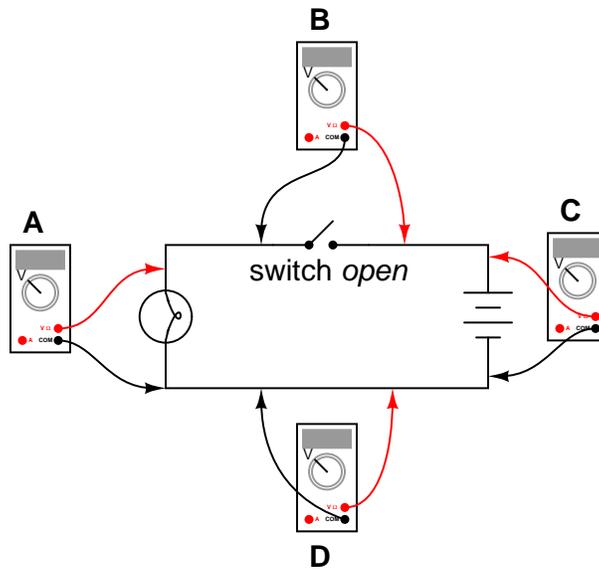
What will this voltmeter register when connected to a battery as shown (assume a battery voltage of 6 volts)? Explain your answer.



file 00021

Question 9

Determine what these four voltmeters (A, B, C, D) will register when connected to this circuit in the following positions (assume a battery voltage of 6 volts):

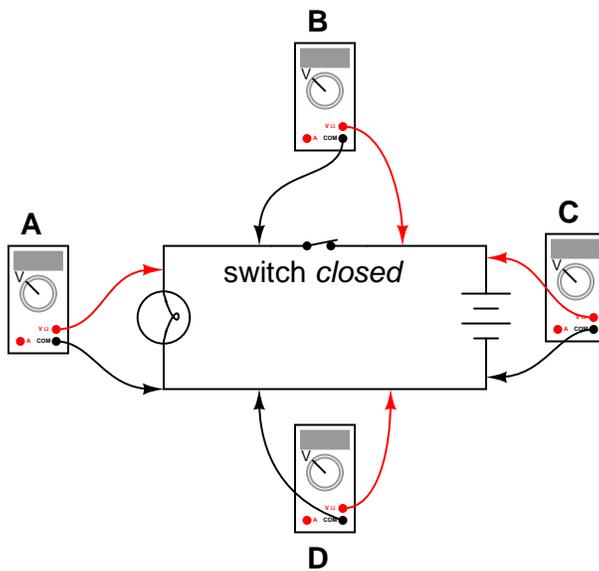


- Voltmeter A =
- Voltmeter B =
- Voltmeter C =
- Voltmeter D =

file 00015

Question 10

Determine what these four voltmeters (A, B, C, D) will register when connected to this circuit in the following positions (assume a battery voltage of 6 volts):

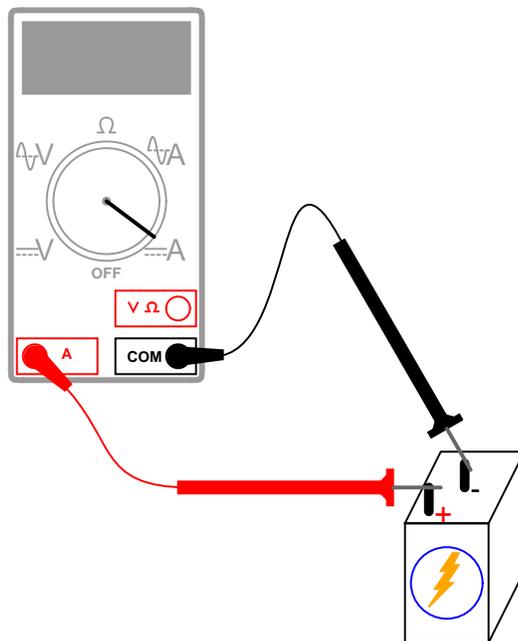


- Voltmeter A =
- Voltmeter B =
- Voltmeter C =
- Voltmeter D =

file 00016

Question 11

Why is it a very bad idea to connect an ammeter directly across a voltage source, like this?

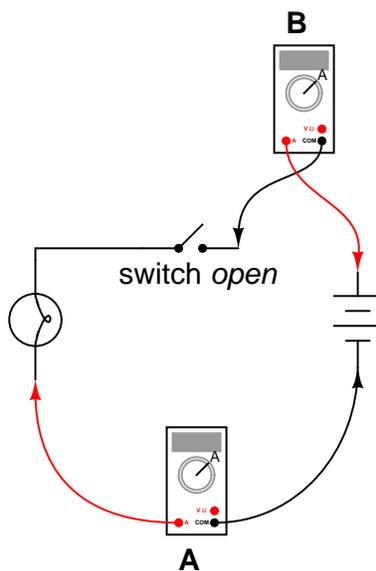


file 00070

Question 12

In this circuit, is the light bulb lit? Why or why not?

Also, compare the relative indications of the two ammeters (which ammeter registers the greatest amount of current, and which ammeter registers the least amount of current, or do they both register the same amount of current?).

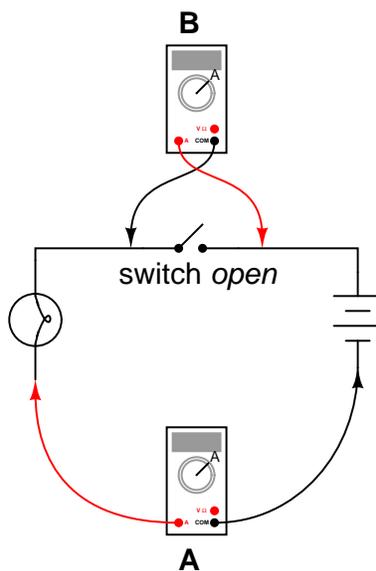


file 00023

Question 13

In this circuit, is the light bulb lit? Why or why not?

Also, compare the relative indications of the two ammeters (which ammeter registers the greatest amount of current, and which ammeter registers the least amount of current, or do they both register the same amount of current?).

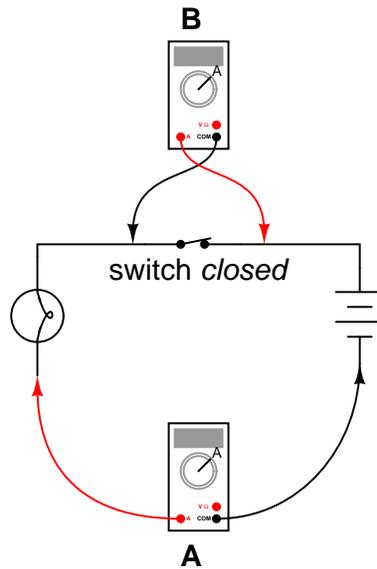


file 00025

Question 14

In this circuit, is the light bulb lit? Why or why not?

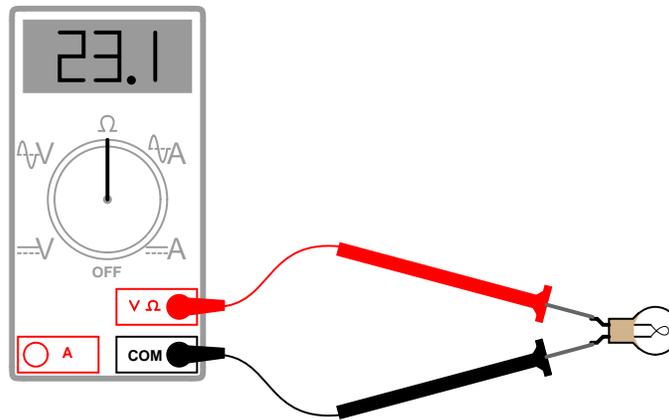
Also, compare the relative indications of the two ammeters (which ammeter registers the greatest amount of current, and which ammeter registers the least amount of current, or do they both register the same amount of current?).



file 00029

Question 15

Explain how an ohmmeter is able to measure the resistance of a component (in this case, a light bulb) when there is no battery or other source of power connected to it:

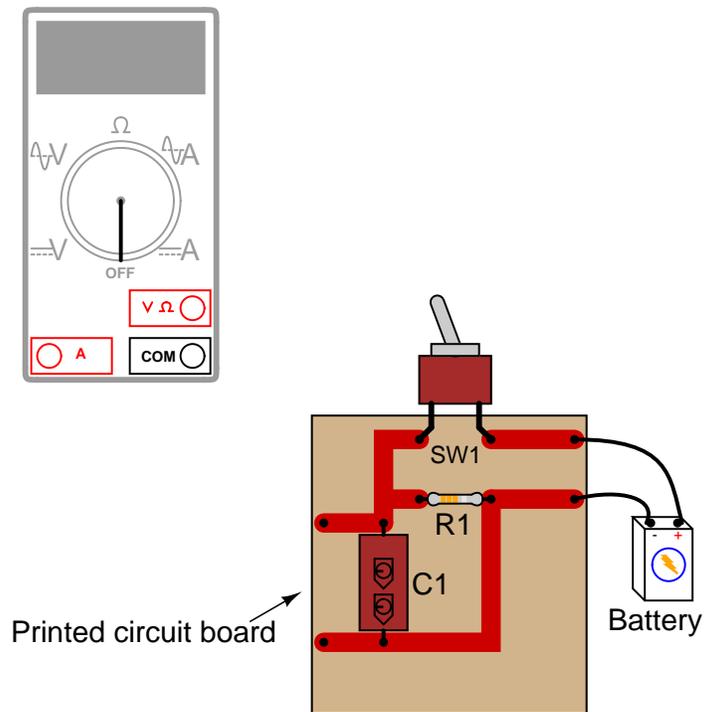


Also, identify the reading you would expect the ohmmeter to indicate if the light bulb were burnt out (failed "open").

file 00101

Question 16

Shown here is a circuit constructed on a PCB (a "Printed Circuit Board"), with copper "traces" serving as wires to connect the components together:



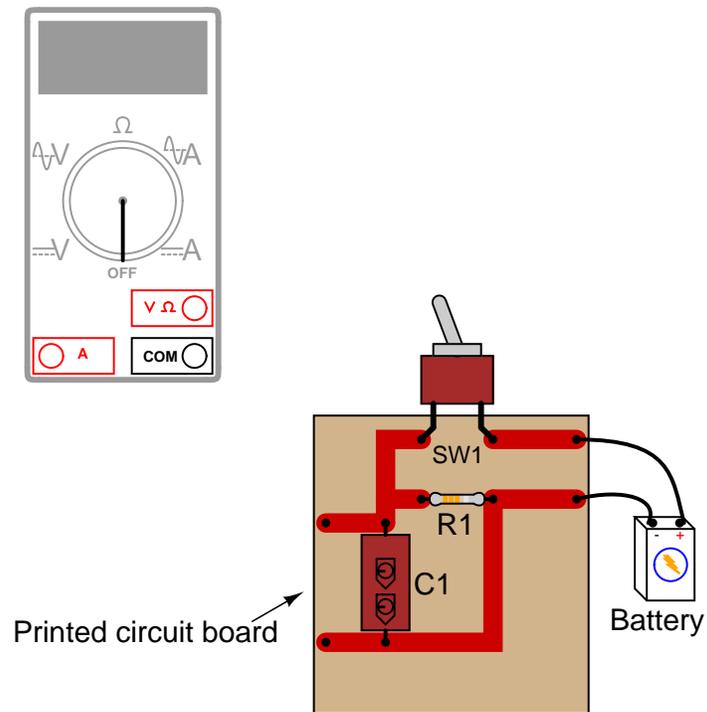
How would the multimeter be used to measure the voltage across the component labeled "R1" when energized? Include these important points in your answer:

- The configuration of the multimeter (selector switch position, test lead jacks)
- The connections of the meter test leads to the circuit
- The state of the switch on the PCB (open or closed)

[file 00096](#)

Question 17

Shown here is a circuit constructed on a PCB (a "Printed Circuit Board"), with copper "traces" serving as wires to connect the components together:



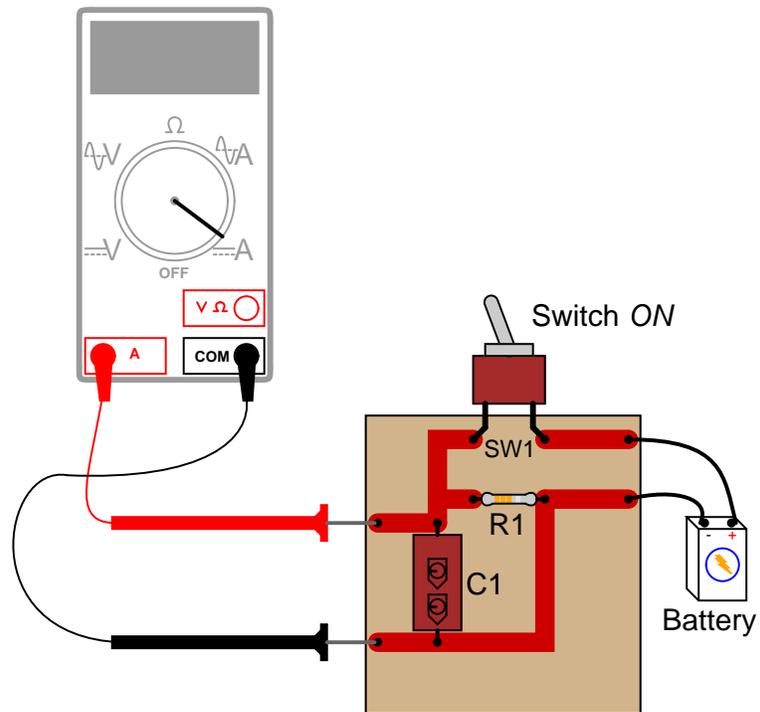
How would the multimeter be used to measure the current through the component labeled "R1" when energized? Include these important points in your answer:

- The configuration of the multimeter (selector switch position, test lead jacks)
- The connections of the meter test leads to the circuit
- The state of the switch on the PCB (open or closed)

file 00097

Question 18

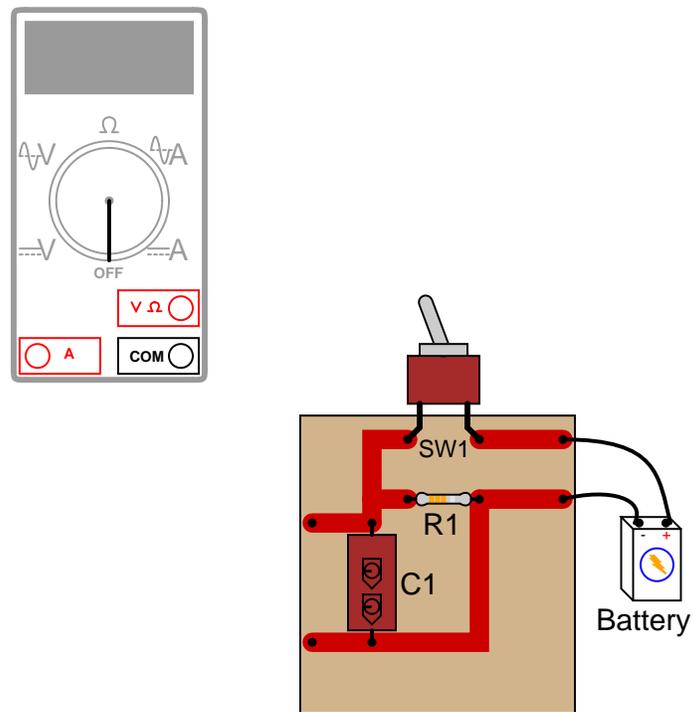
What would happen if a multimeter were connected across the component labeled "C1" on this printed circuit board, as shown?



file 00098

Question 19

Shown here is a circuit constructed on a PCB (a "Printed Circuit Board"), with copper "traces" serving as wires to connect the components together:



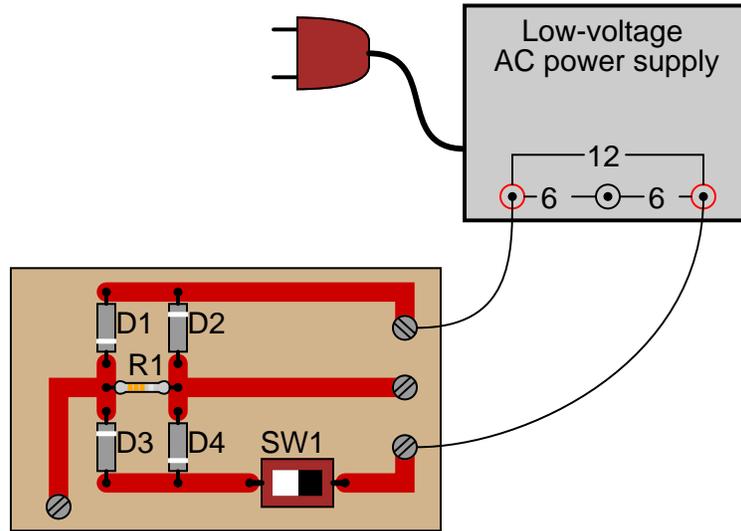
How would the multimeter be used to measure the resistance of the component labeled "R1"? Include these important points in your answer:

- The configuration of the multimeter (selector switch position, test lead jacks)
- The connections of the meter test leads to the circuit
- The state of the switch on the PCB (open or closed)

file 00099

Question 20

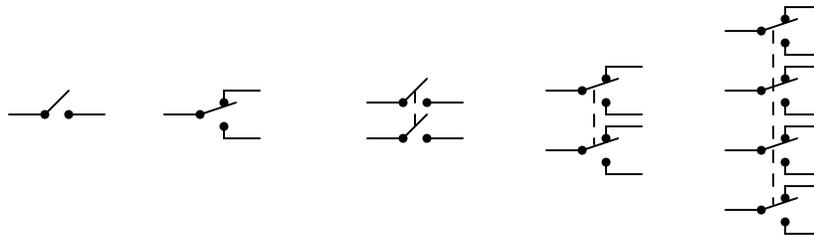
The circuit shown here is called a "bridge rectifier," and its purpose is to convert alternating current (from the "power-supply" unit) into direct current. Suppose you were instructed to check the continuity of the switch (SW1) mounted on the printed circuit board. What would be a fast and effective way of testing this switch's continuity (ideally, without removing the switch from the circuit board)?



[file 00100](#)

Question 21

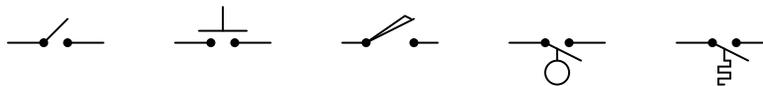
Identify the following types of switches, according to the number of "poles" and "throws" each switch has:



[file 00046](#)

Question 22

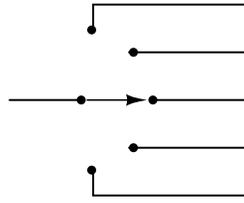
Identify the following types of switches, according to their style of actuation (how each switch is physically operated):



[file 00047](#)

Question 23

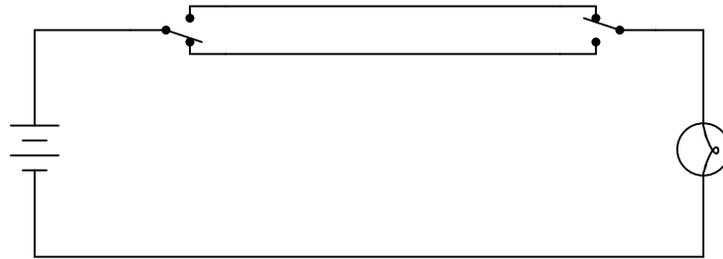
What type of switch is represented by this schematic symbol?



file 00049

Question 24

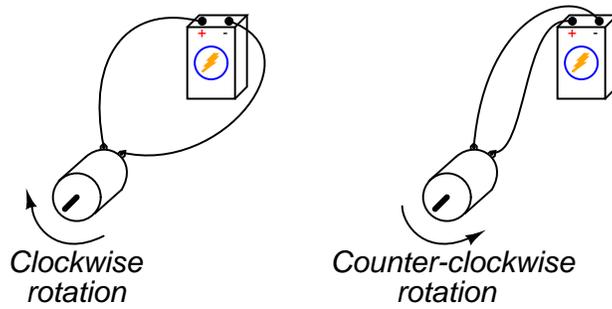
What positions do the switches have to be in for the light bulb to receive power?



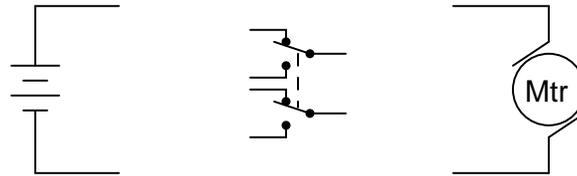
file 00045

Question 25

Electric motors of the *permanent magnet* design are very simple to reverse: just switch the polarity of the DC power to the motor, and it will spin the other direction:



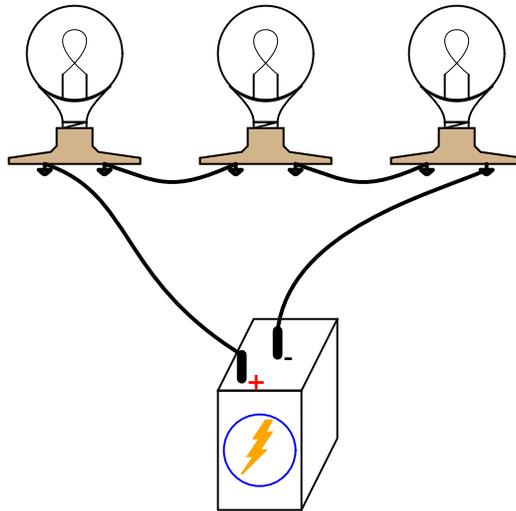
Complete this schematic diagram, showing how a DPDT switch may be placed in this circuit to reverse the motor's direction of rotation without the need to disconnect and re-connect wires:



file 00048

Question 26

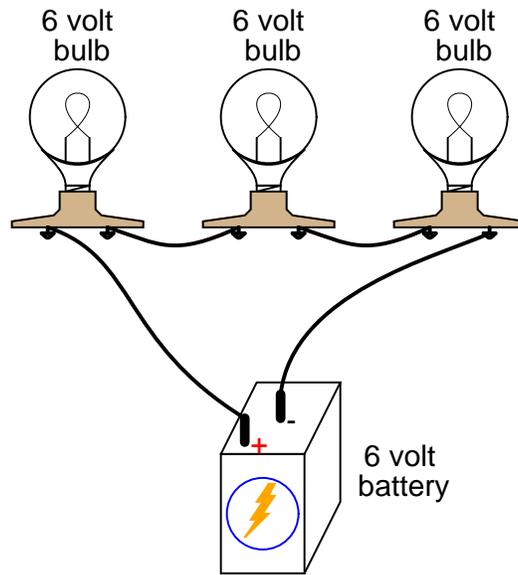
Re-draw this circuit in the form of a schematic diagram:



file 00068

Question 27

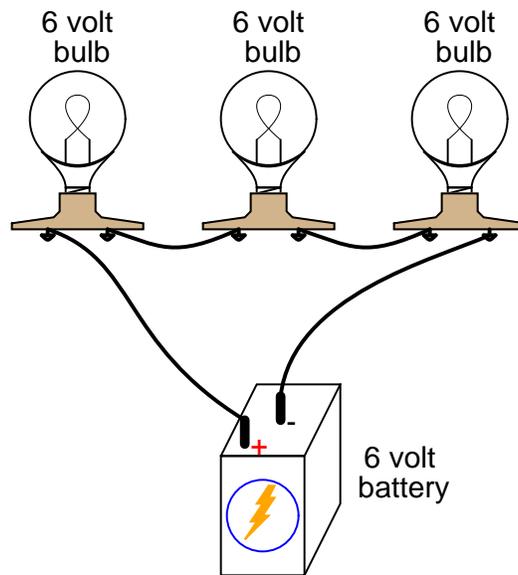
What would happen if three 6-volt light bulbs were connected as shown to a 6-volt battery? How would their brightnesses compare to just having a single 6-volt light bulb connected to a 6-volt battery?



file 00035

Question 28

Qualitatively compare the voltage and current for each of the three light bulbs in this circuit (assume the three light bulbs are absolutely identical):



file 00036

Question 29

Shown here is the schematic symbol for a *resistor*:



What is the purpose of a resistor? What function does it perform? Also, draw an illustration of what a real resistor looks like.

[file 00059](#)

Question 30

Resistors are sometimes represented in electrical and electronic schematic diagrams by a symbol other than this:

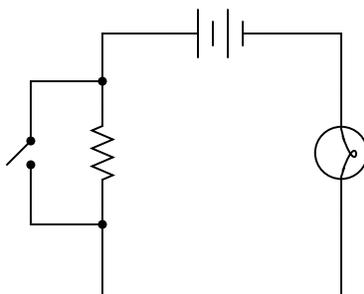


Draw this other symbol next to the one shown above.

[file 00060](#)

Question 31

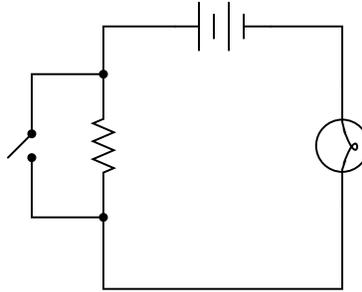
What will the light bulb do when the switch is open, and when the switch is closed?



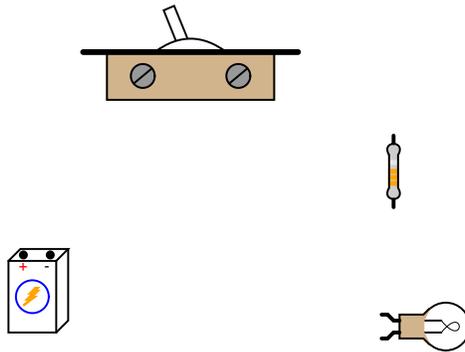
[file 00058](#)

Question 32

Examine this schematic diagram:



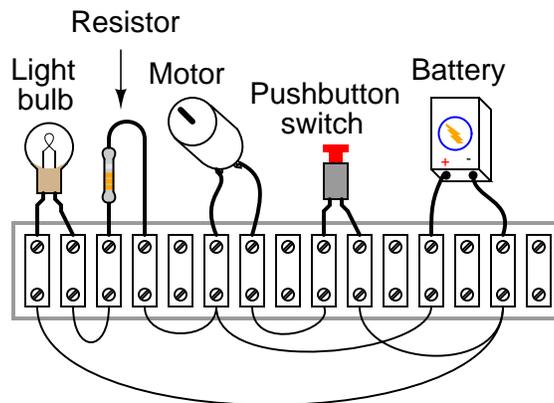
Now, without moving the following components, show how they may be connected together with wires to form the same circuit depicted in the schematic diagram above:



file 00067

Question 33

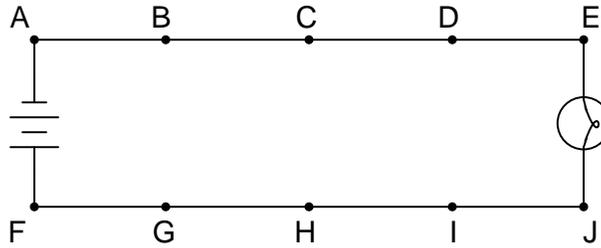
From observation of this circuit (with components attached to a "terminal strip"), draw an appropriate schematic diagram:



file 00115

Question 34

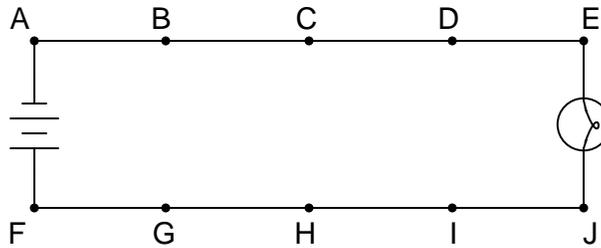
In this circuit, where would you expect to measure full battery voltage (between what pairs of test points)?



file 00119

Question 35

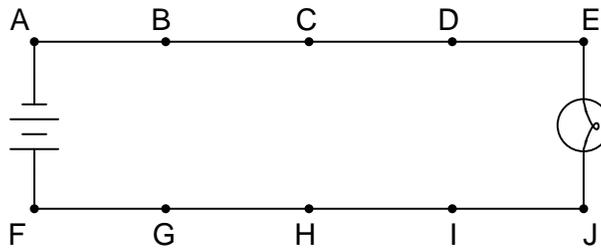
In this circuit, where would you *not* expect to measure significant voltage (between what pairs of test points)?



file 00120

Question 36

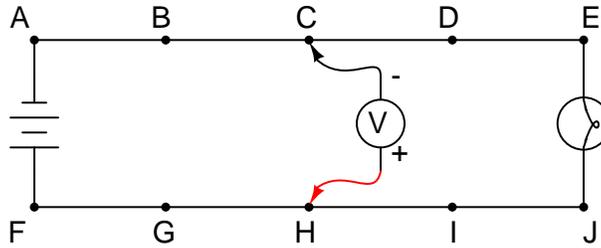
Suppose this battery and light bulb circuit failed to work. Using nothing but a voltmeter, how would you check the circuit to determine where the problem is located? Note: the letters indicate "test points" along the wiring where you may probe with the circuit with your voltmeter.



file 00118

Question 37

Suppose this battery and light bulb circuit failed to work:

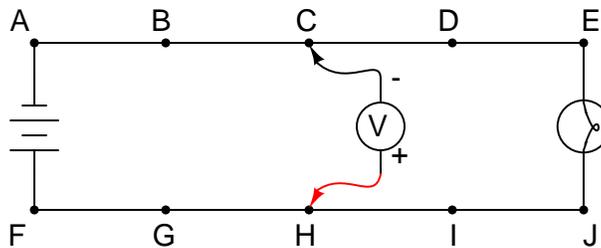


Using a voltmeter, a technician measures full battery voltage between the points C and H. What does this single measurement indicate about the condition of the circuit? Be as specific as you can.

[file 00122](#)

Question 38

Suppose this battery and light bulb circuit failed to work:

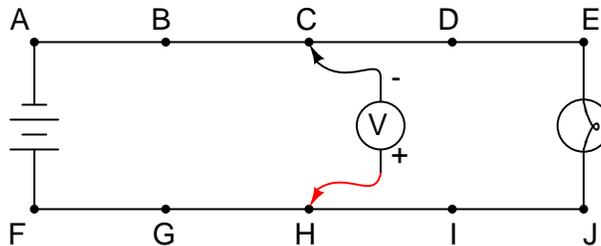


Using a voltmeter, a technician measures full battery voltage between the points C and H. The result of this single measurement indicates which half of the circuit there is a definite problem in. What would you recommend as the *next* voltmeter measurement to take in troubleshooting the circuit, following the same "divide in half" strategy?

[file 00124](#)

Question 39

Suppose this battery and light bulb circuit failed to work:

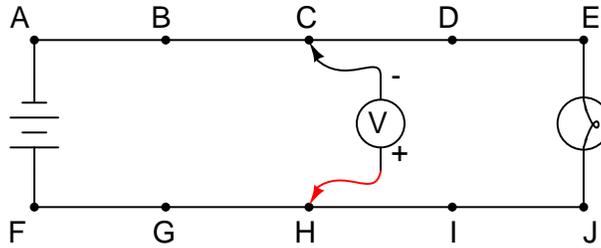


Using a voltmeter, a technician measures 0 volts between the points C and H. What does this single measurement indicate about the condition of the circuit? Be as specific as you can.

[file 00123](#)

Question 40

Suppose this battery and light bulb circuit failed to work:

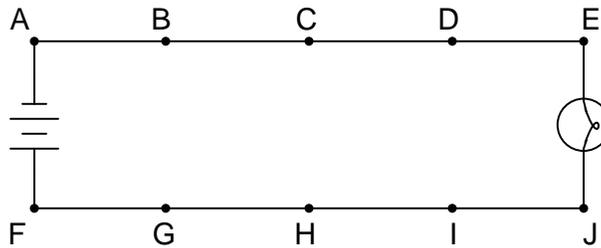


Using a voltmeter, a technician measures 0 volts between the points C and H. The result of this single measurement indicates which half of the circuit there is a definite problem in. What would you recommend as the *next* voltmeter measurement to take in troubleshooting the circuit, following the same "divide in half" strategy?

[file 00125](#)

Question 41

Suppose this battery and light bulb circuit failed to work:



Using nothing but a voltmeter, a technician measures voltage between the following sets of points:

- Between A and C: 0 volts
- Between D and G: 12 volts
- Between E and J: 0 volts
- Between B and E: 12 volts

From these voltage measurements, what can you tell about the condition of the battery, wiring, and light bulb? Be as specific as you can.

Challenge question: identify which of the four measurement are unnecessary in determining the precise location of the fault in this circuit.

[file 00121](#)

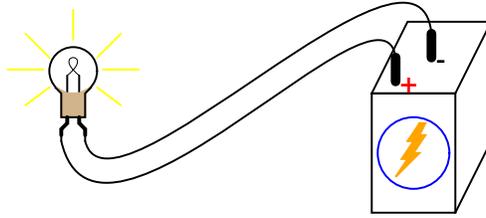
Answers

Answer 1

An electrical *circuit* is any continuous path for electrons to flow away from a source of electrical potential (voltage) and back again.

Answer 2

This is the simplest option, but not the only one.



Answer 3

Let the electrons show you the answers to these questions!

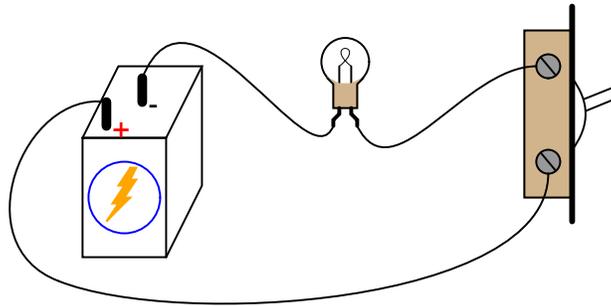
Answer 4

The choice of switch locations shown in the two alternate diagrams makes no difference at all. In either case, the switch exerts the same control over the light bulb.

Answer 5

The choice of battery "polarity" in a simple light bulb circuit makes no difference at all. In either case, the light bulb will energize when the switch is closed.

Answer 6



Follow-up question: suppose the circuit were built like this but the light bulb did not turn on when the switch was closed. Identify at least five specific things that could be wrong with the circuit to cause the light not to turn on when it should.

Answer 7

I could simply give you the answer, but this problem is so easy to simulate in real life that I'd rather let you try it yourself!

Follow-up question: what does this tell you about the nature of voltage, and how it is measured?

Answer 8

The voltmeter will register -6 volts.

What do you suppose will happen if the voltmeter is of the *analog* style (with a moving "needle" rather than a numerical display)?

Answer 9

- Voltmeter A = 0 volts
 - Voltmeter B = 6 volts
 - Voltmeter C = 6 volts
 - Voltmeter D = 0 volts
-

Answer 10

- Voltmeter A = 6 volts
 - Voltmeter B = 0 volts
 - Voltmeter C = 6 volts
 - Voltmeter D = 0 volts
-

Answer 11

Due to the ammeter's very low resistance, it will "draw" a lot of current from the voltage source. In effect, the ammeter will form a short circuit with the voltage source, potentially damaging the meter and/or the source.

In applications where the voltage source possesses very little internal resistance of its own, the current surge resulting from such a short-circuit may be huge. Very large surges of electric current are capable of heating wires to the point where their insulation bursts into flames, as well as causing super-heated blasts of *plasma* (electrically ionized gas) to form at any point of electrical contact where there is a spark. Either of these high-temperature conditions are hazardous to the person holding the meter and test leads!

Answer 12

The bulb is not lit, and the two ammeters both register 0 amperes of current.

Answer 13

The bulb is lit, and the two ammeters register equal amounts of current.

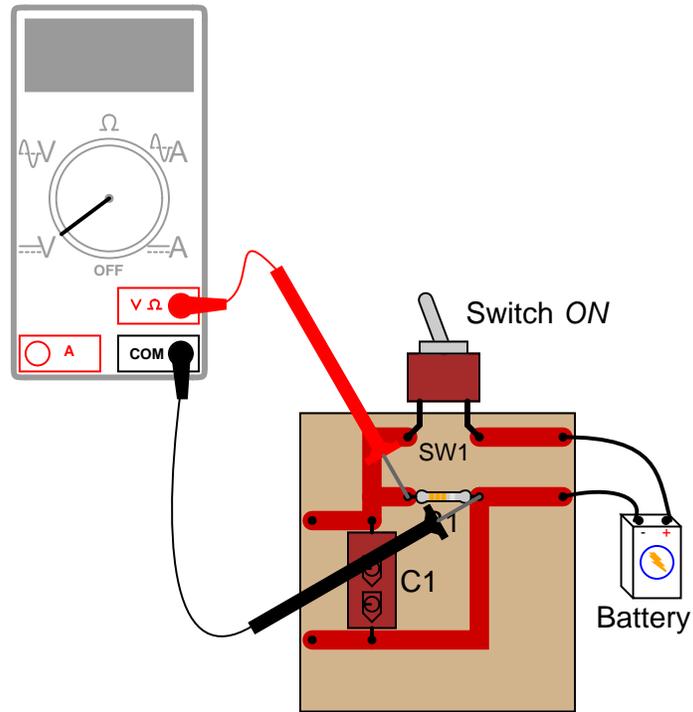
Answer 14

The bulb is lit, but ammeter "A" registers much more current than ammeter "B".

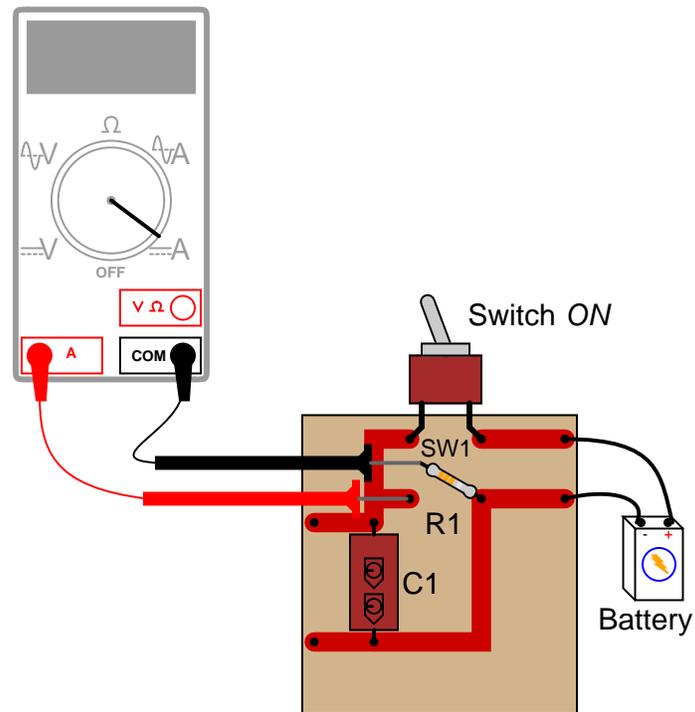
Answer 15

Ohmmeters always contain a battery or some other internal source of electrical power so that the component under test may be supplied with a small amount of current, in order to measure how hard it is for current to go through.

If the light bulb were burnt open, the ohmmeter would register an extremely large (infinite) amount of resistance.

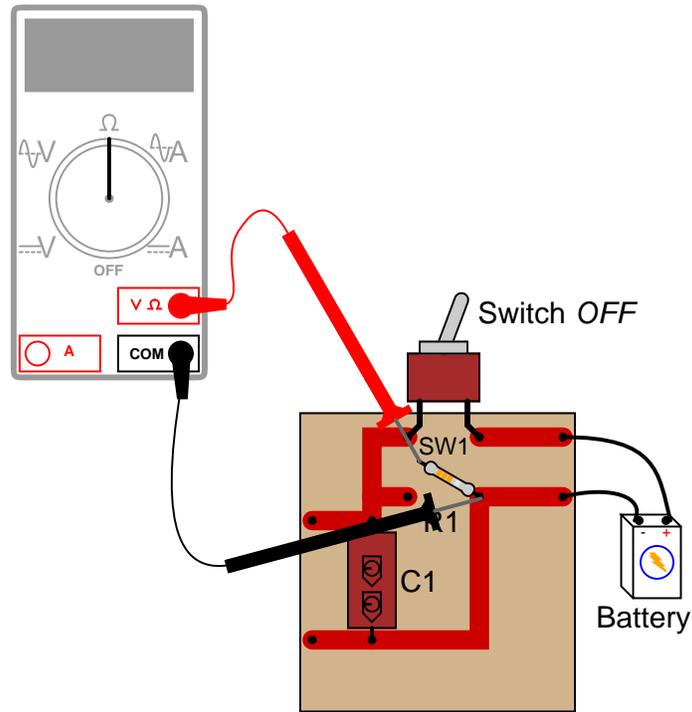


The test lead connections (to the circuit) shown are not the only correct answer. It is possible to touch the test leads to different points on the PCB and still measure the voltage across the resistor (component labeled R1). What are some alternative points on the PCB where the voltage across R1 could be measured?

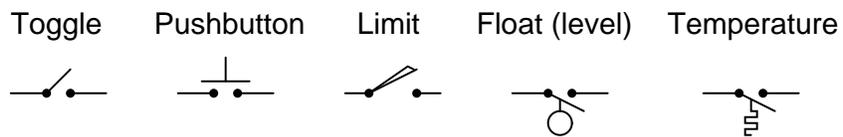
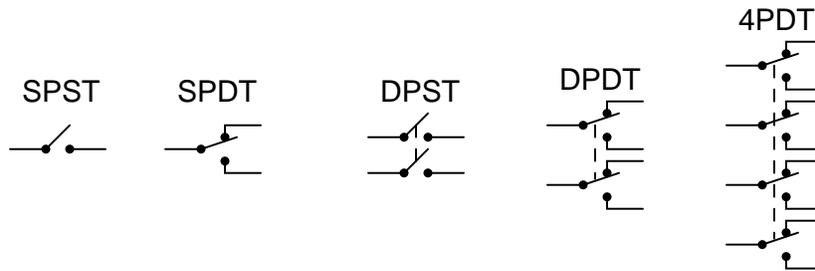


In order to measure current through resistor R1, one of its leads must be de-soldered from the circuit board so that the meter may be connected directly in-line (in *series*) with it.

The meter would create a short-circuit with the battery. Determine what damage this short-circuit might cause, to all components involved.



Disconnect the power supply from the circuit board (only one wire need be disconnected), and then use an ohmmeter to measure continuity across the switch terminals when in the "ON" position and when in the "OFF" position. Incidentally, this is not the only way to check the switch's continuity, but it is the most direct.



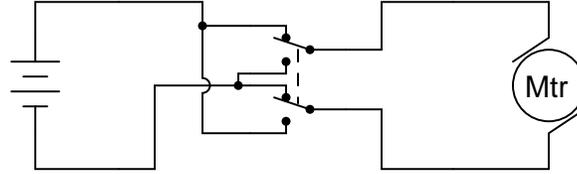
Answer 23

This is a *selector* switch of the *break-before-make* variety.

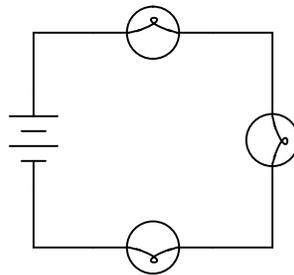
Answer 24

For the light bulb to be energized, both switches must either be in the "up" position, or in the "down" position.

Answer 25



Answer 26



Answer 27

The three light bulbs would glow dimly.

Answer 28

The current through each of the lights bulbs is guaranteed to be equal. The voltage across each of the light bulbs, in this particular case (with identical bulbs), happens to be equal.

Answer 29

The purpose of a *resistor* is to provide a precise amount of electrical resistance in a circuit. Here is an illustration of a small (1/8 or 1/4 watt) resistor:



It is also good to know that the zig-zag symbol shown in the question is not the only symbol used to represent resistors. Another common resistor symbol is shown here:



Answer 30

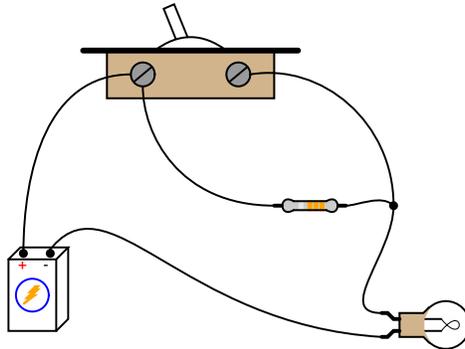
Alternative symbols for a resistor



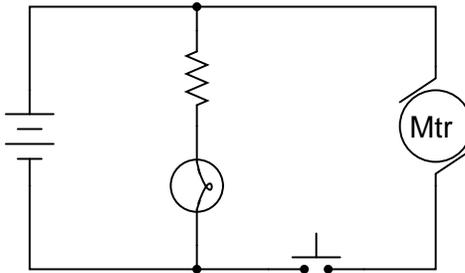
Answer 31

When the switch is closed, the light bulb will receive full voltage from the battery. When the switch is open, the light bulb will receive less voltage (and correspondingly, less current).

Answer 32



Answer 33



Answer 34

You should expect to measure full battery voltage with one test lead of your voltmeter touching any of the points along the top wire of the circuit (points A through E), and with the other test lead touching any of the points along the bottom wire of the circuit (points F through J).

Answer 35

You should not measure any significant voltage between any of the test points along the upper wire (A to B, A to C, A to D, etc.), nor between any of the test points along the lower wire (F to G, F to H, F to I, etc.). As a general rule, points in a circuit that are *electrically common* to each other should never have voltage between them.

Answer 36

There are several strategies which may be employed to find the location of the problem in this circuit. One popular technique is to "divide the circuit in half" by testing for voltage between points C and H first. The presence or absence of voltage between these two points will indicate whether the problem lies between those points and the battery, or between those points and the light bulb (assuming there is but a *single* problem in the circuit – a large assumption!).

Answer 37

Based on this one measurement, we are able to determine that the battery is outputting full voltage, and that the circuit wiring is continuous from the negative battery terminal to point C, and from the positive battery terminal to point H. The fault is an "open" somewhere to the right of points C and H – possibly more than one.

Answer 38

To "divide the circuit in half" again, measure voltage between points D and I.

Answer 39

Based on this one measurement, we are able to determine that there is definitely a problem in the circuit somewhere on the left-hand side (from points C and H, left). The exact nature of the problem is unknown, but there is definitely a problem of some nature in that half of the circuit.

There may or may not be a problem on the right-hand side of the circuit, as well. Given this single voltage measurement, we simply cannot tell.

Answer 40

To "divide the circuit in half" again, measure voltage between points B and G.

Answer 41

Based on these measurements, we are able to determine that the battery's voltage is 12 volts, that the light bulb has good continuity, and that there is a single break in the circuit between points D and E.

Challenge answer: the two "0 volt" measurements are unnecessary in determining the location of the fault in this circuit.

Notes 1

Although definitions are easy enough to research and repeat, it is important that students learn to cast these concepts into their own words. Asking students to give practical examples of "circuits" and "non-circuits" is one way to ensure deeper investigation of the concepts than mere term memorization.

The word "circuit," in vernacular usage, often refers to *anything* electrical. Of course, this is not true in the technical sense of the term. Students will come to realize that many terms they learn and use in an electricity or electronics course are actually mis-used in common speech. The word "short" is another example: technically it refers to a specific type of circuit fault. Commonly, though, people use it to refer to *any* type of electrical problem.

Notes 2

This question gives students a good opportunity to discuss the basic concept of a circuit. It is very easy to build, safe, and should be assembled by each student individually in class. Also, emphasize how simple circuits like this may be assembled at home as part of the "research" portion of the worksheet. To research answers for worksheet questions does not necessarily mean the information has to come from a book! Encourage experimentation when the conditions are known to be safe.

Have students brainstorm all the important concepts learned in making this simple circuit. What general principles may be derived from this particular exercise?

Notes 3

I find that 6-volt "lantern" batteries work well for an experiment such as this, along with either 6 or 12 volt miniature light bulbs. Sometimes the over-rated light bulbs (12 volt rated lamp powered by a 6 volt battery) work better for showing students the glowing filament. The filament of an incandescent light bulb at full brightness is difficult to distinguish.

Please avoid using LED's or any polarity-sensitive devices until your students are ready to explore polarity!

Notes 4

This is a difficult concept for some students to master. Make sure they all understand the nature of electrical current and the importance of continuity *throughout* the entire circuit. Perhaps the best way for students to master this concept is to actually build working battery-switch-lamp circuits. Remind them that their "research" of these worksheet questions is not limited to book reading. It is not only valid, but *preferable* for them to experiment on their own, so long as the voltages are low enough that no shock hazard exists.

One analogy to use for the switch's function that makes sense with the schematic is a drawbridge: when the bridge is down (closed), cars may cross; when the bridge is up (open), cars cannot.

Notes 5

It should be noted that not all electrical loads are "non-polarized" like an incandescent light bulb. Some electrical components, such as *light-emitting diodes*, are polarity sensitive, and will function only if current goes through them in the proper direction.

Notes 6

One of the more difficult skills for students to develop is the ability to translate a nice, neat schematic diagram into a messy, real-world circuit, and visa-versa. Developing this skill requires lots of practice.

In case students have not learned battery symbol convention yet, please point out to them the "+" and "-" polarity marks, and note which side of the battery is which.

One analogy to use for the switch's function that makes sense with the schematic is a drawbridge: when the bridge is down (closed), cars may cross; when the bridge is up (open), cars cannot.

Notes 7

This question affords an excellent opportunity to discuss another foundational concept of electricity: that *voltage is always measured between two points*.

Notes 8

Ask the students how an analog (moving pointer) style of voltmeter would respond in this situation. This question lends itself very well to simple experimentation in the classroom, even during discussion time.

Notes 9

Students often find the terms "open" and "closed" to be confusing with reference to electrical switches, because they sound opposite to the function of a door (i.e. you can only go through an open door, but electricity can only go through a closed switch!). The words actually make sense, though, if you look at the schematic symbol for an electrical switch as a door mounted "sideways" in the circuit. At least visually, then, "open" and "closed" will have common references.

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I have found that the concept of *electrically common points* is most helpful when students first learn to relate voltage drop with continuity (breaks or non-breaks) in a circuit.

To be able to immediately relate the expected voltage drop between two points with the electrical continuity between those points is a very important foundational skill in electrical troubleshooting. Without mastery of this skill, students will have great difficulty detecting and correcting faults in circuits caused by poor connections and broken wires, which constitute a fair portion of realistic circuit failures.

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Notes 11

An important point to discuss is how electrical safety encompasses more than just shock hazard. In particular, *arc blasts* caused by high-current "faults" such as this may be just as dangerous as electric shock. At the very least, placing an ammeter directly across the terminals of a voltage source will likely result in the ammeter's fuse being blown.

In some cases, ammeter fuses are more expensive than one might think. Safety-rated ammeters often use expensive fast-action fuses with significant current interruption ratings. In the case of the Fluke 187 and 189 multimeters, these fuses cost around \$8 each (American dollars, 2004)!

Notes 12

It is vitally important for students to understand the significance of continuity throughout the entire circuit, not just at one or more points in the circuit.

Notes 13

This is a good question to engage students' thinking on meter properties. A voltmeter does not function the same as an ammeter, and the two different types of meters will impact circuits differently when connected! Incidentally, ammeters tend to get you into more trouble than voltmeters when troubleshooting circuits, which is why students should be encouraged to use a voltmeter whenever possible rather than an ammeter. Of course, clamp-on ammeters are not as unsafe as ammeters requiring direct connection with circuit conductors.

Notes 14

Exactly what ammeter "B" will register (aside from its indication being less than ammeter "A"), is an interesting question.

Notes 15

Unlike voltmeters or ammeters, ohmmeters *must* contain their own power sources. An implication of this fact is that ohmmeters must never be used to measure the resistance of an energized component. Discuss this important caveat with your students, being sure to ask them to explain why connecting an ohmmeter to an energized component might give erroneous measurements (if it doesn't destroy the meter first!).

In regard to the ohmmeter reading for an open bulb, I have found that many math-weak students have a difficult time grasping the differentiating zero from infinity. They recognize both as being extreme conditions (nothing versus everything), but many make the mistake of regarding "infinity" as identical to zero. Quite to the contrary, "infinity" means *bigger than big, and huger than huge*. Do not be surprised if one or more of your students harbor this same misconception, and be ready to address it!

Notes 16

Many multimeters use "international" symbols to label DC and AC selector switch positions. It is important for students to understand what these symbols mean.

The test lead connections (to the circuit) shown are not the only correct answer. It is possible to touch the test leads to different points on the PCB and still measure the voltage across the resistor (R1). However, if there are poor connections on the circuit board (between component leads and copper traces), measuring voltage at points on the circuit board other than directly across the component in question may give misleading measurements. Discuss this with your students.

Notes 17

Many multimeters use "international" symbols to label DC and AC selector switch positions. It is important for students to understand what these symbols mean.

As you can see in this answer, measuring current through components is generally more difficult than measuring voltage across components, and involves greater risk because the meter must conduct the component's full current (which in some cases may be significant). For this reason, technicians need to learn troubleshooting techniques prioritizing voltage measurements over current measurements.

Notes 18

Even though it might not appear that the meter is "shorting" the battery in this example, it most certainly is. In asking students to determine the resulting damage from such an action, it is important for them to trace the path of "fault current" through the circuit. Those components within the path of fault current are in risk of damage, while those components not within the path of fault current are not at risk.

Notes 19

It is very important that students understand component resistance cannot be measured when the component is energized! In cases such as this, it is necessary to disconnect the component from the rest of the circuit so that only *its* resistance (and not any other components' resistance) is measured. In other cases, though, it may be acceptable to leave the component in place to take a resistance measurement.

Notes 20

Challenge your students to think of other methods which could be used to check the switch's continuity. There is often more than one way to perform a certain check of component function, if you are knowledgeable in electrical theory and creative in your use of test equipment!

Notes 21

Switches come in all types and sizes, and it is important for students to recognize certain common switch types, both by name and by schematic symbol.

Notes 22

Students will probably want to know how the temperature switch actually works. Be prepared to explain how bi-metallic elements may be used to actuate small mechanisms like switches, or challenge the students to research this on their own.

Notes 23

Selector switches are very, very common in electrical and electronic circuits, for selecting different machine functions.

Notes 24

This wiring arrangement ("three-way" switches) is commonly used in residential lighting, for controlling a light bulb in a hallway with switches at either end. Once students relate this circuit to personal experience, it usually makes a lot more sense to them.

Notes 25

DPDT switches are often used as polarity-reversal devices. No doubt your students will see (or build!) this switch arrangement some time in their careers.

Notes 26

One of the more difficult skills for students to develop is the ability to translate the layout of a real-world circuit into a neat schematic diagram. Developing this skill requires lots of practice.

It is very worthwhile for students to discuss how they solve problems such as these with each other. For those students who have trouble visualizing shapes, a simple hint or "trick" to use when translating schematics to illustrations or visa-versa may be invaluable.

Notes 27

Here, the important principle of voltage "drops" in a series circuit is highlighted. This question serves to further define, in practical ways, what the term "series" really means.

Notes 28

Here, the important principles of voltage and current in a series circuit are highlighted. This question serves to further define, in practical ways, what the term "series" really means.

An important lesson of this question is the distinction between measurements which are *guaranteed* to be equal versus measurements which just *happen* to be equal for a given selection of components.

Notes 29

Students may (properly) ask, "Why is there such a thing as a component whose sole purpose is to *impede* the flow of electrons?" While resistors may seem rather pointless at first, they end up being extremely valuable electrical/electronic components. If asked, you may cite several uses of resistors in circuits:

- To limit maximum circuit current to a safe value.
- To "split" a voltage into proportions.
- To "scale" meter movements, for precise measurement of current and voltage.
- To provide a non-shorting path to discharge static electricity.

Notes 30

It might be a good idea to occasionally draw schematic diagrams for your students using the "other" resistor symbol, just so they are not taken by surprise when they see this symbol in real schematics. Just be sure to remain consistent in your symbolism within each diagram: never mix the two different symbols within the same schematic!

Notes 31

This is another opportunity to review the meanings of "open" and "closed" with regard to switches. Again, students new to electricity often exhibit confusion over these terms, because in the context of doors they hold opposite meanings.

Notes 32

One of the more difficult skills for students to develop is the ability to translate a nice, neat schematic diagram into a messy, real-world circuit, and visa-versa. Developing this skill requires lots of practice.

It is very worthwhile for students to discuss how they solve problems such as these with each other. For those students who have trouble visualizing shapes, a simple hint or "trick" to use when translating schematics to illustrations or visa-versa may be invaluable.

Notes 33

This type of question is one that lends itself well to students drawing their answers on the board in front of class. The skill of transferring a real circuit into a cleanly-drawn schematic is one that some students struggle mightily with, but it is important. Those students will want to know what technique(s) may be used to make the transfer. Students who are more spatially adept will probably have a couple of different ways to approach a problem such as this. Allow them to explain to the rest of the class their technique(s) for tracing the real circuit's wiring into a schematic diagram.

Giving students the opportunity to teach their peers is a powerful instructional method, and should be encouraged at all times!

Notes 34

This circuit provides an excellent opportunity to discuss the concept of "electrically common" points. Any points in a circuit directly connected together with wire are considered "electrically common" to each other: a voltage measurement referenced at any one of those points should be identical if referenced any of the other points as well.

Notes 35

The answer uses a concept which I've found to be very helpful in understanding electrical circuits: the idea of points in a circuit being *electrically common* to each other. Simply put, this means the points are connected together by conductors of negligible resistance. Having nearly 0 ohms of resistance between points assures insignificant voltage drop, even for large currents.

Conversely, if significant voltage is measured between points in a circuit, you can be assured that those points are *not* electrically common to each other. Engage your students in a discussion of electrical commonality and expected voltage drops:

- If voltage is measured between two points in a circuit, are those two points electrically common to each other? Why or why not?
- If no voltage is measured between two points in a circuit, are those two points electrically common to each other? Why or why not?

Notes 36

A circuit like this is very easy to construct, and makes for an excellent classroom demonstration piece. I've used such a circuit, constructed on a piece of pegboard 2 feet by 4 feet, with metal screws acting as test points, for students to develop their troubleshooting skills in front of the class where everyone may observe and learn together.

It has been my experience that students who experience difficulty troubleshooting circuits in general usually experience difficulty troubleshooting this simple circuit in particular. Although the circuit itself couldn't be simpler, the fundamental concept of *voltage* as a quantity measurable only between 2 points is confusing for many. Spending lots of time learning to troubleshoot a circuit such as this will be greatly beneficial in the future!

Notes 37

Some measurements given definite answers, while others only indefinite answers. In this particular question, the single voltage measurement tells us definite things about the left-hand side of the circuit, but little about the right-hand side. It is very important for students to develop the logical skill of distinguishing *necessary* conclusions from *possible* conclusions in troubleshooting scenarios. A skill like this takes time and practice to develop, so be sure to spend adequate time throughout the course with your students honing it!

Notes 38

Some troubleshooters refer to this strategy as "divide and conquer," because it divides the possibilities of fault location by a factor of 2 with each step. Make sure your students understand that being able to immediately determine which part of a system is *not* faulted is a valuable time-saver.

Notes 39

There are times when a voltmeter indication of 0 volts is just as informative concerning a circuit fault as a non-zero measurement. In this case, the measurement tells us that a definite problem exists in one half of the circuit.

Notes 40

Some troubleshooters refer to this strategy as "divide and conquer," because it divides the possibilities of fault location by a factor of 2 with each step.

It is important to realize in situations such as this that no determination of faultlessness in the circuit has been made yet. By measuring 0 volts between points C and H, we know there is a definite problem in the left half of the circuit, but we have by no means "cleared" the right half of the circuit of any fault. For all we know, there may be faults in *both* halves of the circuit! Only further investigation will reveal the truth.

Scenarios such as this are excellent for group discussion, encouraging students to think critically about the data and to apply their practical knowledge of electricity to a realistic problem.