

## Potentiometers

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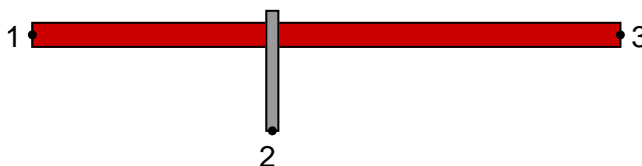
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Resources and methods for learning about these subjects (list a few here, in preparation for your research):

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### Question 1

Suppose a length of resistive material (such as *nichrome* wire) had three points of electrical contact: one at each end (points 1 and 3), plus a movable metal "wiper" making contact at some point between the two ends (point 2):



Describe what happens to the amount of electrical resistance between the following points, as the wiper is moved toward the left end of the resistive element (toward point 1)? State your answers in terms of "increase," "decrease," or "remains the same," and explain why each answer is so.

*Wiper moved toward point 1*



- Between points 1 and 2, resistance . . .
- Between points 2 and 3, resistance . . .
- Between points 1 and 3, resistance . . .

file 00213

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### Answer 1

As the wiper moves to the left (toward point 1):

- Between points 1 and 2, resistance *decreases*
- Between points 2 and 3, resistance *increases*
- Between points 1 and 3, resistance remains the same

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### Notes 1

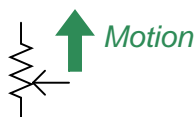
The purpose of this question is to get students to comprehend the function of a *potentiometer*, before they have ever seen one.

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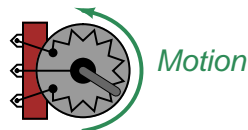
### Question 2

A very common misconception students have about potentiometers is the relationship between resistance and direction of wiper motion. For instance, it is common to hear a student say something like this, “Turning the potentiometer so the wiper moves *up* will increase the resistance of the potentiometer.”

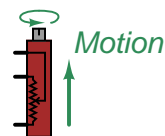
Schematic symbol



Internal view



Internal view



Explain why it does not really make sense to say something like this.  
file 03673

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### Answer 2

Moving a potentiometer wiper changes *two* resistances in complementary directions: one resistance will increase as the other will decrease.

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### Notes 2

Ask your students to identify which resistance (which two connection points on the potentiometer) increases and which decreases, and how they know this from the "internal views" of the potentiometers. This is a very important thing for your students to learn.

Year after year of teaching has revealed that a great many students have difficulty grasping this concept. This is especially true when they become accustomed to using a potentiometer as a rheostat and not as a voltage divider. The more you can make them think carefully about the operation of a potentiometer, the better!

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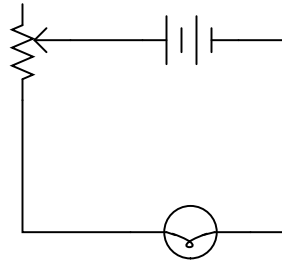
### Question 3

Draw a schematic diagram showing a potentiometer being used as a simple variable resistor for varying current to a light bulb. Also, designate which way the "wiper" should be moved to make the bulb glow brighter.

file 00324

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### Answer 3



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### Notes 3

Make note of the fact that only two of the potentiometer's three terminals need be used if a simple variable resistor is desired.

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#### Question 4

What is the difference between the following potentiometers, as indicated by their respective symbols?



file 00299

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#### Answer 4

The symbol on the left belongs to a standard, knob-adjustable potentiometer. The symbol on the right belongs to a "trimpot," which is a potentiometer adjustable only by a screwdriver, intended for non-routine adjustments.

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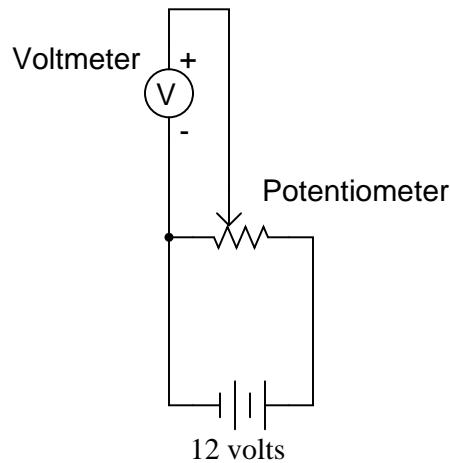
#### Notes 4

Ahhh, the joy of symbols! Do not be surprised if students are able to dredge up all kinds of electronic component symbols from symbol libraries you've never seen before.

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### Question 5

What would you expect the voltmeter in the following circuit to do when the potentiometer wiper is moved to the right?



What would you expect the voltmeter to register if the wiper were set precisely at the 50% (half-way) position?

file 00339

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### Answer 5

As the wiper is moved to the right, we should expect to see the voltmeter register an increasing voltage, ranging between 0 and 12 volts DC.

Follow-up question: a useful problem-solving method is to imagine multiple "test case" scenarios, sometimes referred to as *thought experiments*, for the purpose of identifying a trend. For instance, in this circuit you might imagine what the voltmeter would register with the wiper moved all the way to the left, and then with the wiper moved all the way to the right. Identify the voltmeter's readings in these two scenarios, and then explain why the analysis of "test cases" like these are useful in problem-solving.

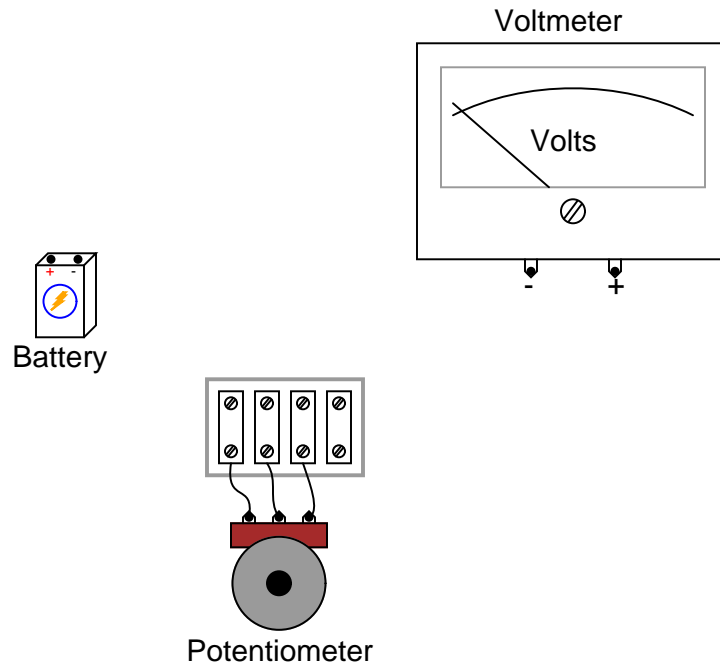
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### Notes 5

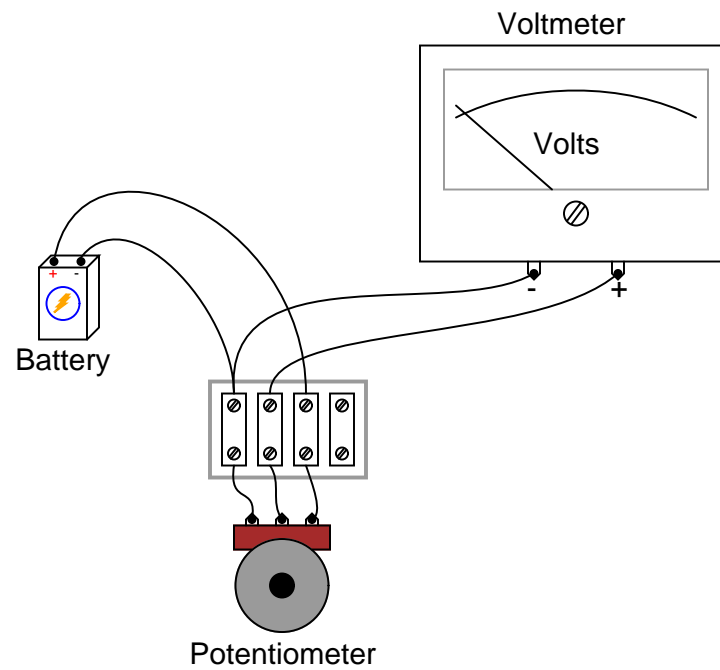
Ask your students to describe possible applications for a circuit like this. Where might we wish to utilize a potentiometer in such a way that it outputs a variable voltage, from a constant voltage source?

### Question 6

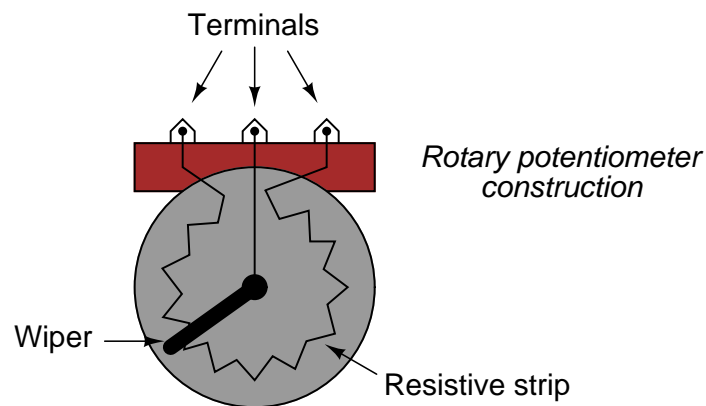
Connect the necessary wires in this illustration to make the potentiometer act as a variable voltage divider, providing a variable voltage to the voltmeter:



file 00322



Here's a hint for those unfamiliar with the internal construction of rotary potentiometers:



#### Notes 6

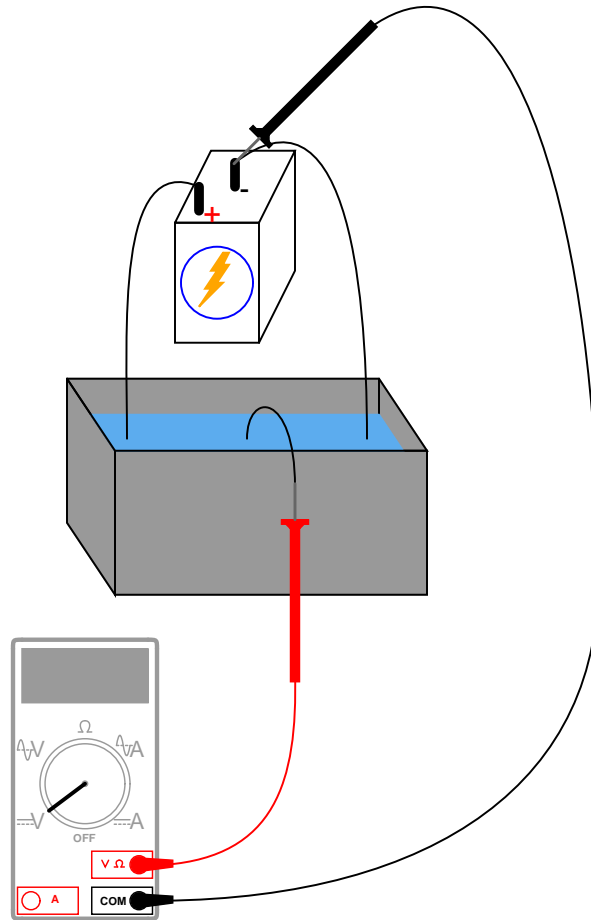
A good follow-up question to this would be to ask your students which way the potentiometer knob needs to be turned in order to *increase* the voltage applied to the meter.



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### Question 7

With a trough of water and three pieces of wire, you could make a *liquid potentiometer*:



Which way would you have to move the middle wire (the one touching the voltmeter's red test lead) in order to increase the voltmeter's reading?

file 03300

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### Answer 7

Move the wire to the left in order to make the voltmeter register a greater voltage.

Follow-up question: identify any advantages and disadvantages of such a "liquid pot" over standard potentiometers using solid pieces. Are there any potential safety hazards that occur to you as you look at the illustration of this liquid potentiometer?

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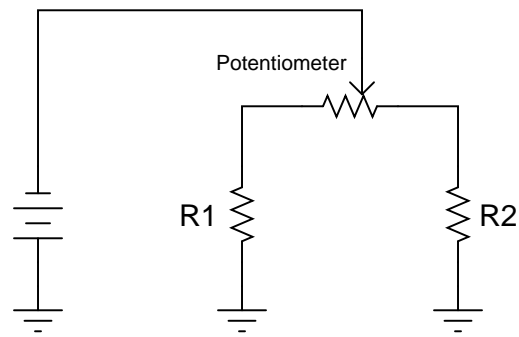
### Notes 7

Believe it or not, I have actually seen an application in industry where a "liquid rheostat" (not a potentiometer, but close) was used rather than a device made from solid parts. Very interesting. Very dangerous as well, since it was being used as part of a large motor speed control circuit, handling many amps of current at potentially deadly voltages! I do not know what maniac thought of building this contraption, but it was built and had been working for a number of years.

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### Question 8

Which way would you have to move the potentiometer wiper, to the left or to the right, in order to increase current through resistor R1?



file 01747

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### Answer 8

You would have to move the potentiometer wiper to the *left*.

Follow-up question: what would happen to the current through resistor R2 as you moved the wiper in that direction (closer to resistor R1)?

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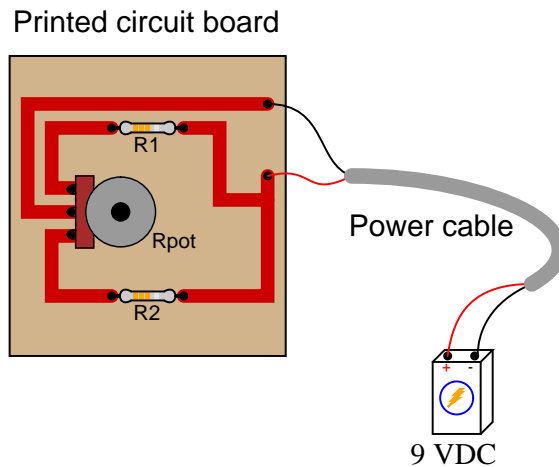
### Notes 8

This circuit is fairly self-explanatory.

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### Question 9

Which way would you have to twist the potentiometer shaft in order to increase current through resistor R1, clockwise or counter-clockwise? Explain your answer.



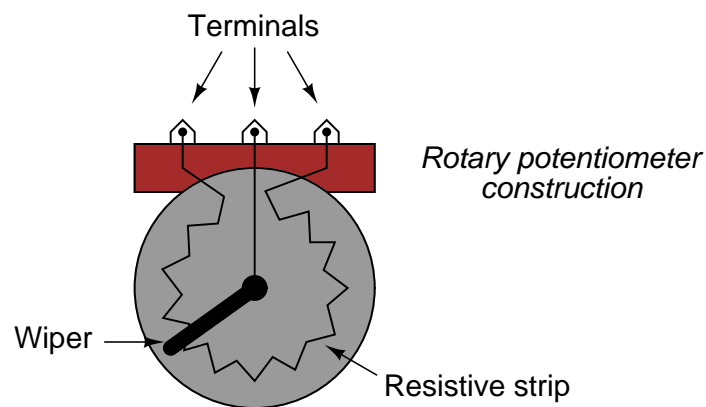
[file 01748](#)

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### Answer 9

You would have to twist the potentiometer shaft *counter-clockwise*.

Here's a hint for those unfamiliar with the internal construction of rotary potentiometers:



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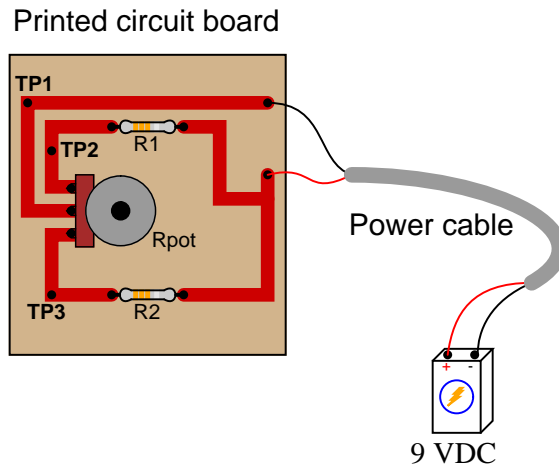
### Notes 9

This circuit is fairly self-explanatory, but getting the answer correct requires that you understand how a rotary potentiometer is constructed inside.

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### Question 10

This current divider circuit has a problem. The voltage between test points TP2 and TP1 varies with the potentiometer position, but the voltage between test points TP3 and TP1 remains at 0 volts no matter where the potentiometer is set:



Identify the most likely fault which would account for these measurements.  
[file 03943](#)

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### Answer 10

There is an "open" fault in resistor  $R_2$ , or somewhere in series with  $R_2$  (bad solder connection, open trace, etc.).

Follow-up question: identify which direction of potentiometer shaft motion (clockwise or counter-clockwise) should increase the voltage between test points TP2 and TP1.

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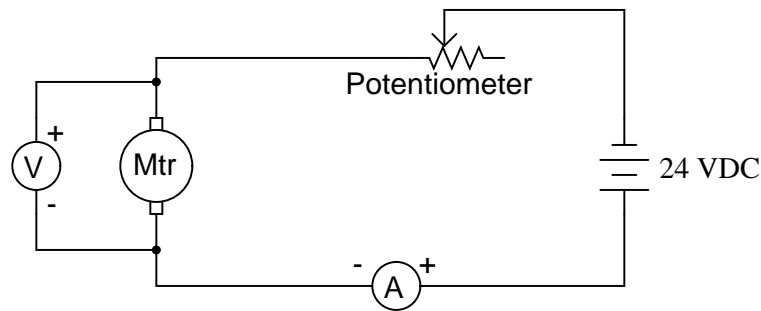
### Notes 10

Discuss with your students how they determined the identity of the fault. Also, be sure to discuss the follow-up question with them: how to determine the proper direction to turn the potentiometer shaft in order to increase  $V_{TP2-TP1}$ . It is important that your students realize how a 3/4 turn potentiometer works, and what to expect when the shaft is turned.

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### Question 11

A technician decides to use a potentiometer as a speed control for an electric motor. The potentiometer has a resistance rating of  $10\ \Omega$  and a power rating of 25 watts:



When operating the motor at a voltage of 16 volts and a current of 2 amps, though, smoke begins to pour out of the potentiometer, indicating that its power rating is being exceeded.

The technician is perplexed! According to his calculations, the potentiometer should be dissipating less than 25 watts of power. Why, then, is a potentiometer rated for 25 watts burning up under this condition?  
[file 00340](#)

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### Answer 11

The power rating of a potentiometer is based on the heat dispersing ability of the *entire* resistive element. The actual power dissipation rating of a potentiometer must be "de-rated" for wiper positions not utilizing the whole length of the resistive element.

Challenge question: based on the voltage and current values measured in this circuit (16 volts across the motor, 24 volts from the source, and 2 amps of current through it all), determine how badly the potentiometer is being overpowered. In other words, calculate the de-rated power rating of the potentiometer and compare that against the amount of power it is actually dissipating in this condition.

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### Notes 11

A very practical and important lesson, learned after watching students send many potentiometers to an early demise.

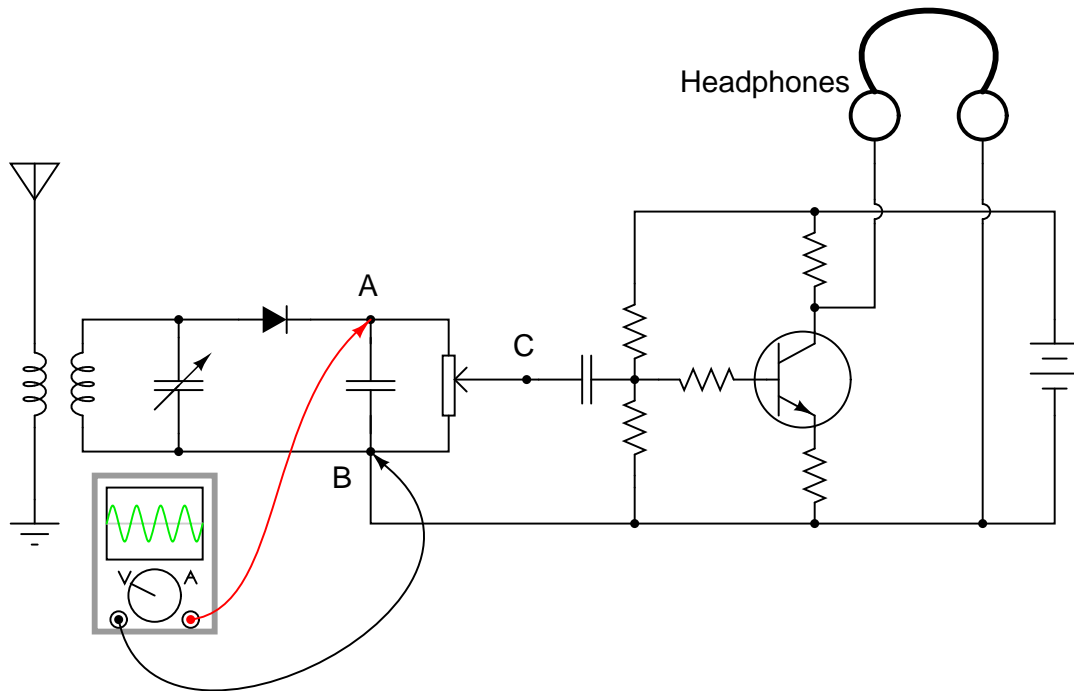
In order to answer the challenge question, students must determine the pot's setting as a percentage between 0% ( $0\ \Omega$ ) and 100% ( $10\ \Omega$ ), and use that setting to estimate power de-rating. It is safe to assume a linear power derating proportional to wiper position.

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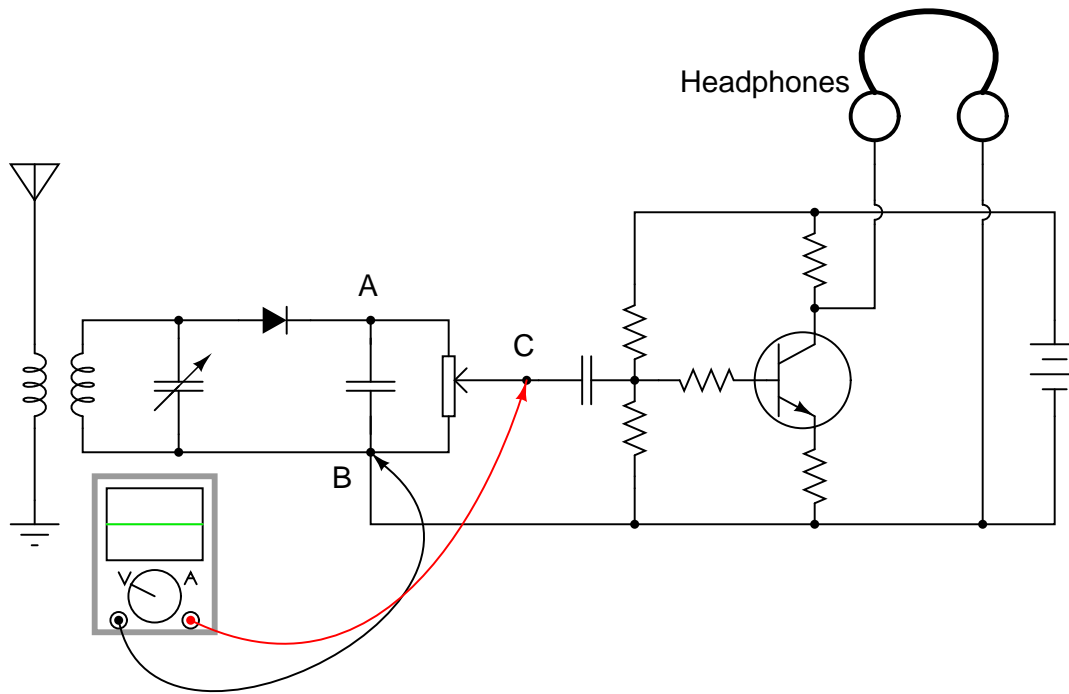
Question 12

A radio technician is troubleshooting a problem in a simple AM receiver, using a voltage-measuring device called an *oscilloscope*. An oscilloscope is nothing more than a graphical voltmeter, indicating the "wave shape" of voltages that change rapidly over time. The problem with this radio is that no sound at all is heard in the headphones.

When checking for a voltage signal between points A and B in the circuit, a strong signal is obtained:



However, when checking between points C and B in the circuit, no signal is measured:



What do these voltage measurements indicate about the nature of the problem in the receiver circuit? Is there a general troubleshooting rule that may be drawn from this example? If so, what is it?

If possible, identify the precise nature of the failure.

file 00341

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Answer 12

The fact that there is good signal before the potentiometer, and no signal afterward, indicates that the problem is somewhere between those two sets of signal measurement points (i.e. the potentiometer itself).

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Notes 12

Do not worry if your students have not studied inductors, capacitors, diodes, transistors, amplifiers, or radio theory yet. This problem focuses on the potentiometer's function, and that is all your students have to understand in order to determine an answer.

It is very important for electronics technicians to be able to isolate portions of circuits they do understand from portions they do not, and perform as much diagnostic work as they can based on what they know. For this reason, I believe it is a good practice to show beginning students problems such as this, where they are challenged to see beyond the complexity of the circuit, to focus only on those portions that matter. On the job, I was frequently challenged with troubleshooting large, complex systems that I had no hope of understanding the entirety of, but which I knew enough about to isolate the problem to sections I could repair proficiently.

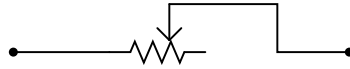
Ask your students to identify where, exactly, they think the potentiometer could have failed in order to cause this particular problem. Not just any fault within the potentiometer will result in the same loss of signal!

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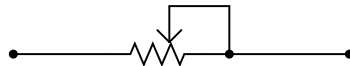
### Question 13

When potentiometers are used as variable resistors (*rheostats*), the unused terminal is often connected to the wiper terminal:

Potentiometer as rheostat  
(minimum necessary connections)



Potentiometer as rheostat  
(typical connection)



Explain what advantage is gained by connecting the wiper to the unused terminal. Why is the lower potentiometer connection scheme more commonly used than the upper?

[file 00343](#)

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### Answer 13

Here is a hint: suppose the potentiometer becomes worn with use, to the point where the wiper occasionally loses electrical contact with the resistive element. How would these two connection schemes compare, then?

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### Notes 13

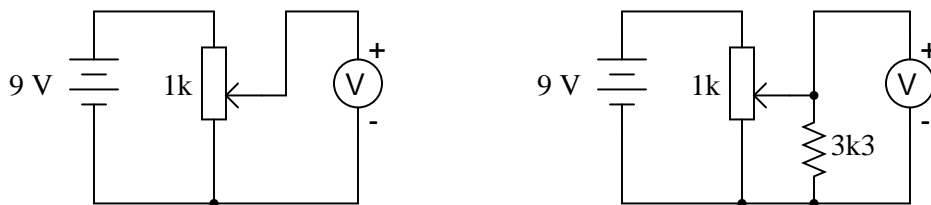
This is an example of "defensive engineering": designing something with eventual failure in mind, with the goal of minimizing the consequences of that inevitable failure. Whether your students go on to become engineers, or simply technicians, it is important for them to think past the immediate application and design issues, to consider what may happen as their system ages.



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### Question 14

Calculate the voltmeter voltage in each of these circuits, assuming the wiper position is 25% up from the bottom:



file 00342

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### Answer 14

Voltmeter in left-hand circuit = 2.25 volts

Voltmeter in right-hand circuit = 2.13 volts

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### Notes 14

Challenge your students to explain the significance of the reduced voltage from the potentiometer in the presence of a load (the 3.3 kΩ resistor). What impact could this effect have on a circuit we might build, where we expect the potentiometer to output a certain voltage corresponding to a specific wiper position?

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### Question 15

Suppose we were building a circuit that required an adjustable resistance with a range of  $1500\ \Omega$  to  $4500\ \Omega$ . The only potentiometer we have on hand is a  $10\ \text{k}\Omega$  unit. Of course, we could simply connect the potentiometer as-is and have an adjustable range of  $0\ \Omega$  to  $10,000\ \Omega$ , but that would be too "coarse" of an adjustment for our application.

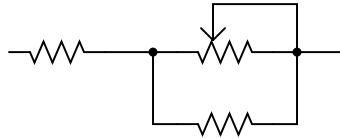
Explain how we could connect other resistors to this  $10\ \text{k}\Omega$  potentiometer in order to achieve the desired adjustable resistance range.

file 00470

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### Answer 15

I'll give you a hint:



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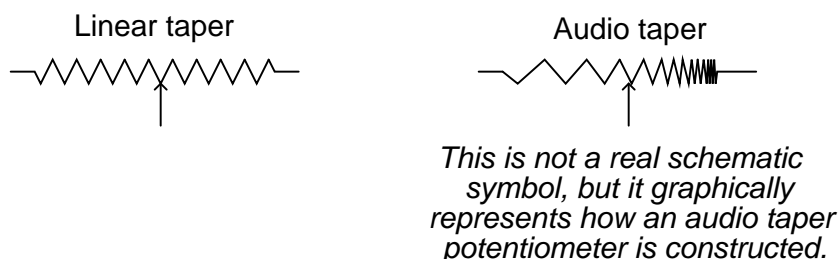
### Notes 15

Knowing how to limit the adjustable range of a potentiometer is a very useful skill when designing and building circuits where precision of adjustment is important. The only drawback to building such a sub-circuit is that the adjustment becomes nonlinear (i.e., setting the potentiometer to the half-way position does not result in the total resistance being 50% of the way between the lower and upper range values).

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### Question 16

Potentiometers are manufactured in two different "tapers": *linear* and *audio*. Linear taper potentiometers provide a direct, linear relationship between wiper position and resistance division, so that equal changes in wiper position result in equal changes in resistance. Audio taper potentiometers provide a non-linear (logarithmic, to be exact) relationship between wiper position and resistance division, so that the same amount of wiper motion at one end of its range gives a much greater change in resistance than at the other end of its range.



Suppose you have a potentiometer, but do not know whether it has a linear or audio taper. How could you determine this, using a meter?

[file 00338](#)

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### Answer 16

A linear taper potentiometer will exhibit resistance measurements between the wiper and the other two terminals, proportional to the wiper position.

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### Notes 16

Discuss with your students the purpose of an audio taper potentiometer: to provide logarithmically proportioned increases in audio power for volume control applications. This is necessary for a "proportional" response when turning the volume knob on an audio amplifier, since human hearing is not linear, but logarithmic in its detection of loudness. In order to generate a sound that the human ear perceives as twice as loud, ten times as much sound power is necessary.

A challenging question to ask your students is *which way* an audio taper potentiometer should be connected as a voltage divider in an audio amplifier circuit. Being that audio taper potentiometers are non-symmetrical, it truly matters which way they are connected!

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#### Question 17

Find one or two real potentiometers and bring them with you to class for discussion. Identify as much information as you can about your potentiometers prior to discussion:

- Resistance (ideal)
- Resistance (actual)
- Taper (linear or audio)
- Number of turns
- Power rating
- Type (carbon composition, wire-wound, etc.)

[file 01159](#)

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#### Answer 17

If possible, find a manufacturer's datasheet for your components (or at least a datasheet for a similar component) to discuss with your classmates.

Be prepared to *prove* the type of taper that your potentiometers have in class, by using a multimeter!

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#### Notes 17

The purpose of this question is to get students to kinesthetically interact with the subject matter. It may seem silly to have students engage in a "show and tell" exercise, but I have found that activities such as this greatly help some students. For those learners who are kinesthetic in nature, it is a great help to actually *touch* real components while they're learning about their function. Of course, this question also provides an excellent opportunity for them to practice interpreting component markings, use a multimeter, access datasheets, etc.

### **Don't just sit there! Build something!!**

Learning to mathematically analyze circuits requires much study and practice. Typically, students practice by working through lots of sample problems and checking their answers against those provided by the textbook or the instructor. While this is good, there is a much better way.

You will learn much more by actually *building and analyzing real circuits*, letting your test equipment provide the "answers" instead of a book or another person. For successful circuit-building exercises, follow these steps:

1. Carefully measure and record all component values prior to circuit construction.
2. Draw the schematic diagram for the circuit to be analyzed.
3. Carefully build this circuit on a breadboard or other convenient medium.
4. Check the accuracy of the circuit's construction, following each wire to each connection point, and verifying these elements one-by-one on the diagram.
5. Mathematically analyze the circuit, solving for all values of voltage, current, etc.
6. Carefully measure those quantities, to verify the accuracy of your analysis.
7. If there are any substantial errors (greater than a few percent), carefully check your circuit's construction against the diagram, then carefully re-calculate the values and re-measure.

Avoid very high and very low resistor values, to avoid measurement errors caused by meter "loading". I recommend resistors between 1 k $\Omega$  and 100 k $\Omega$ , unless, of course, the purpose of the circuit is to illustrate the effects of meter loading!

One way you can save time and reduce the possibility of error is to begin with a very simple circuit and incrementally add components to increase its complexity after each analysis, rather than building a whole new circuit for each practice problem. Another time-saving technique is to re-use the same components in a variety of different circuit configurations. This way, you won't have to measure any component's value more than once.

[file 00405](#)

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Answer 18

Let the electrons themselves give you the answers to your own "practice problems"!

It has been my experience that students require much practice with circuit analysis to become proficient. To this end, instructors usually provide their students with lots of practice problems to work through, and provide answers for students to check their work against. While this approach makes students proficient in circuit theory, it fails to fully educate them.

Students don't just need mathematical practice. They also need real, hands-on practice building circuits and using test equipment. So, I suggest the following alternative approach: students should *build* their own "practice problems" with real components, and try to mathematically predict the various voltage and current values. This way, the mathematical theory "comes alive," and students gain practical proficiency they wouldn't gain merely by solving equations.

Another reason for following this method of practice is to teach students *scientific method*: the process of testing a hypothesis (in this case, mathematical predictions) by performing a real experiment. Students will also develop real troubleshooting skills as they occasionally make circuit construction errors.

Spend a few moments of time with your class to review some of the "rules" for building circuits before they begin. Discuss these issues with your students in the same Socratic manner you would normally discuss the worksheet questions, rather than simply telling them what they should and should not do. I never cease to be amazed at how poorly students grasp instructions when presented in a typical lecture (instructor monologue) format!

A note to those instructors who may complain about the "wasted" time required to have students build real circuits instead of just mathematically analyzing theoretical circuits:

*What is the purpose of students taking your course?*

If your students will be working with real circuits, then they should learn on real circuits whenever possible. If your goal is to educate theoretical physicists, then stick with abstract analysis, by all means! But most of us plan for our students to do something in the real world with the education we give them. The "wasted" time spent building real circuits will pay huge dividends when it comes time for them to apply their knowledge to practical problems.

Furthermore, having students build their own practice problems teaches them how to perform *primary research*, thus empowering them to continue their electrical/electronics education autonomously.

In most sciences, realistic experiments are much more difficult and expensive to set up than electrical circuits. Nuclear physics, biology, geology, and chemistry professors would just love to be able to have their students apply advanced mathematics to real experiments posing no safety hazard and costing less than a textbook. They can't, but you can. Exploit the convenience inherent to your science, and *get those students of yours practicing their math on lots of real circuits!*