Physics ii

PHYSICS II ELECTRICITY, MAGNETISM, SOUND, AND LIGHT SERIES CIRCUIT In this unit you'll begin learning how to analyze circuits. Circuit analysis means looking at a schematic diagram for a circuit and computing the voltage, current, or power for any component in that circuit. Closely related to the task of circuit analysis is the task of troubleshooting, which means figuring out what is wrong in a circuit that is not working correctly. Analyzing and troubleshooting go hand in hand; when a circuit is not working correctly, the easiest way to figure out what's wrong is usually to measure voltages in the circuit and compare those measured values to the values that the voltages should have (which you compute by analyzing the circuit). The rest of this course will concentrate on analyzing and troubleshooting resistive circuits (circuits that contain only resistors in addition to power supplies). In later courses you'll learn how to analyze and troubleshoot circuits that contain other components, such as capacitors, inductors, diodes, and transistors. This unit covers just about everything you could ever want to know about the simplest type of circuit, which is called a series resistive circuit.   Some of the things you'll learn here apply only to series resistive circuits, but other things apply to any kind of circuit. For instance, the rule called Kirchhoff's Voltage Law applies to all circuits, and is therefore a very important general rule of circuit analysis. First read entirely this article and attend short classroom discussion then work through the Self-Test questions below.   Some Definitions * First, we'll define some terms, it will be useful for us first to define the terms series connection and series path. And even before we define those terms, we'll define what we mean by saying that two components are connected to each other. * Defining these terms carefully will be a big help later when we get to more complicated series-parallel

circuits. Connected Components * Two components are said to have be connected to each other when there is a path of zero resistance joining a terminal of one component to a terminal of the other component. * Basically, this means that either the components are connected directly to each other, or there's a conductor (such as a wire, or a trace on a circuit board) that connects them together. * Examples: In the circuit shown below, * VS is connected to R1 at one point; * R2 and R3 are connected to each other at two points; * VS and R2 are not connected to each other. Series Connection * Now that we've defined what we mean by saying that two components are connected to each other, we can define what we mean by a series connection. * Two components are connected in series if they are connected to each other at exactly one point and no other component is connected to that point. * Notice that there are two halves to this definition, both of which must be met in order to have a series connection. 1. First, the components must be directly or indirectly connected at exactly one point, no more and no less. 2. Second, no other component can be connected to that point where the other two components meet. * The most common mistake that students make here is to remember the first half of the definition but forget about the second half. For example, in the circuit shown below, R1 and R2 are connected to each other at exactly one point, but the voltage source is also connected to that same point. Therefore, R1 and R2 are not connected in series. Series-Connected Components Have the Same Current * The most important property of series connections is that the current is the same in every series-connected component. * Example: In the circuit shown below, VS and R1 are connected in series, so we know that the current through VS must be the same as the current through R1. But R1 and R3 are not

connected in series, so we cannot assume that the current through R1 is equal to the current through R3. Series Path * Now that we've defined what we mean by a series connection, we can define what we mean by a series path. * A series path is a group of connected components in which each connection is a series connection. * As noted above, components connected in series have the same current. Therefore, all of the components in a series path must have the same current as each other Series Circuit * Now that we've defined what we mean by a series path, we can define what we mean by a series circuit. * A series circuit is a (complete) circuit that consists exclusively of one series path. In other words, it's a complete circuit in which every connection is a series connection. * As noted above, components connected in series have the same current as each other. Therefore, all of the components in a series circuit must have the same current as each other. * " A series circuit provides only one path for current between two points so that the current is the same through each series component." Current in a Series Circuit * We've already said this once or twice, but it's so important that we'll repeat it: the current is the same everywhere in a series circuit. * So, for example, in the series circuit shown below, if you measure or compute the current through any one of the components, then you immediately know the current through each of the other components. All of the components have the same current. * By the way, this is true for all series circuits, not just series resistive circuits. In the circuit shown below, if we replaced R2 with a diode, inductor, or other component, we would still be able to say that that component has the same current as R1, R3, and the voltage source. Total Series Resistance * The total resistance of resistors connected in series is simply equal to the sum of the individual resistance

values. * Example: if a 1. 2 kΩ resistor is connected in series with a 4. 7 kΩ resistor, then the total resistance is 5. 9 kΩ. * We'll use the symbol RT to stand for total resistance. So for the case above, we could write RT = 5. 9 kΩ. * The general formula for finding the total resistance of resistors connected in series is RT = R1 + R2 + R3 + ... + Rn Analyzing Series Resistive Circuits * We now know enough to be able to find currents and voltage drops in a series resistive circuit. There are four basic steps. 1. Find the total resistance by adding all of the individual resistances: RT = R1 + R2 + R3 + ... + Rn 2. Apply Ohm's law in the form I = V ÷ R to the entire circuit. In words, the total current produced by the voltage source is equal to the source voltage divided by the total resistance. In symbols, IT = VS ÷ RT 3. Recall that in a series circuit, every component has the same current. Therefore, each resistor's current is equal to the total current. In symbols, IT = I1 = I2 = I3 = ... = In 4. Use Ohm's law in the form V = I × R to find the voltage drop across each resistance. In symbols, V1 = I1 × R1 V2 = I2× R2 V3 = I3 × R3 and so on for each of the resistors. * These four steps do not apply to all circuits. In particular, Steps 1 and 3 do not work for circuits that aren't series circuits. (But Steps 2 and 4 do work for all resistive circuits.) An Example Consider the series circuit shown below: * We want to determine the current through each resistor and the voltage across each resistor. * Our analysis of this circuit has four steps: 1. Add the resistor values together to find the total resistance RT. RT | = R1 + R2 | | = 100 Ω + 200 Ω | | = 300 Ω | 2. Use Ohm's law on the entire circuit to find the circuit's total current IT: IT | = VS ÷ RT | | = 12 V ÷ 300 Ω | | = 40 mA | 3. Recall that since this is a series circuit, current is the same everywhere. Therefore, each resistor receives the total current: I1 | = IT | | = 40 mA | 4.

and I2 | = IT | | = 40 mA | 5. Use Ohm's law on each resistor to find the voltage drops V1 and V2 across the resistors: V1 | = I1 Ã— R1 | | = 40 mA Ã— 100 Î© | | = 4 V | 6. and V2 | = I2 Ã— R2 | | = 40 mA Ã— 200 Î© | | = 8 V | Current Direction and Voltage Polarity * When we analyze a circuit to figure out the current, we're interested not only in the current's magnitude (or size), but also in its direction. * For example, in the series circuit shown below, the current has a magnitude of 1. 93 mA. What is the current's direction? The current's direction is clockwise around the circuit, because current comes out of the voltage source's positive terminal (represented by the longer line in the symbol for a voltage source) and goes into the voltage source's negative terminal. * Also, when we analyze a circuit to figure out a particular voltage, we're interested not only in the voltage's magnitude (or size), but also in its polarity. Polarity means which end of the voltage is positive and which end is negative. Here's how to figure out the polarity of the voltage across a resistor: 1. The end of a resistor into which current enters is the positive end; 2. The end of a resistor from which current leaves is the negative end. * For example, in the circuit shown above, we've determined that current flows clockwise around the circuit, which means that it flows into the left-hand end of R1 and out of the right-hand end of R1. Therefore, the polarity of R1's voltage is: positive on the left-hand end, and negative on the right-hand end. * The diagram below uses + and - signs to show the polarity of each voltage in the circuit we've been discussing: * Notice an important difference between voltage sources and resistors: 1. Current flows out of a voltage source's positive end and into its negative end. 2. Current flows into a resistor's positive end and out of its negative end. Voltage Drops and Voltage Rises * Some circuit-analysis techniques

(including one called Kirchhoff's Voltage Law that we'll introduce soon) require you to take an imaginary journey around a circuit, keeping track of the voltage changes as you travel. * As you mentally move through the circuit, if you pass through a component from its âˆ' end to its + end, we'll call that a voltage rise. * On the other hand, if you mentally pass through a component from its + end to its âˆ' end, we'll call that a voltage drop. * Example: In the circuit shown below, suppose you decide to " travel" around the circuit in a clockwise direction. Then you'll encounter voltage drops as you pass through R1, R2, and R3, and you'll encounter a voltage rise as you pass through the voltage source. * But, continuing the same example, suppose you now decide to " travel" around the circuit in a counter-clockwise direction. Then you'll encounter voltage rises as you pass through R1, R2, and R3, and you'll encounter a voltage drop as you pass through the voltage source. * So a particular voltage can be considered as either a voltage drop or a voltage rise, depending on the direction of your imaginary trip around the circuit. Voltage Sources in Series * Sometimes you'll encounter a circuit with two or more voltage sources connected in series. * A common example is a flashlight. As you probably know, most flashlights require two batteries. Each battery is a voltage source, and when you load the batteries into the flashlight, they go in end-to-end, so they're connected in series. * It's pretty easy to analyze voltage sources connected in series. You just have to be careful to notice whether the voltage sources are trying to drive current in the same direction or in opposite directions. We call these two cases series-aiding voltage sources and series-opposing voltage sources. Series-Aiding Voltage Sources * If two series-connected voltage sources are connected so as to produce current in the same direction, they are said to be series-aiding.

* The net effect on the circuit is the same as that of a single source whose voltage equals the sum of the two voltage sources. * Example: in the circuit shown below, VS1 and VS2 are both connected so as to push current in a clockwise direction around the circuit. Therefore, they are series-aiding, and they combine to have the same effect as a 22-V source. Series-Opposing Voltage Sources * When two series-connected sources are connected so as to produce current in opposite directions, they are said to be series-opposing. * The net effect on the circuit is the same as that of a single source equal in magnitude to the difference between the source voltages and having the same polarity as the larger of the two. * Example: in the circuit shown below, VS1 tries to push current in a clockwise direction around the circuit, but VS2 tries to push current in a counter-clockwise direction. Therefore, they are series-opposing, and they combine to have the same effect as a 2-V source with the polarity of VS1 (pushing current clockwise around the circuit). Double-Subscript Notation for Voltages * You may be familiar with the concept of the voltage across a resistor or other component. When we wish to refer to the voltage across a particular resistor, we usually use a notation such as V1, which means the voltage across resistor R1. In this notation, we write a capital V with a single number as a subscript: this number is the number of the resistor whose voltage we're talking about. * Sometimes, when we want to talk about a voltage between two points in a circuit, we'll use a different notation, which has a capital V with two letters as a subscript, such as VAB. * In such cases, the points A and B would be labeled in the circuit 's schematic diagram to identify them, as in the diagram below. * VAB means the voltage between points A and B, with point A regarded as + and point B regarded as âˆ'. In other words, it's the voltage

that you would measure with a voltmeter if you placed the meter's positive (red) lead at point A and the meter's negative (black) lead at point B. * On the other hand, VBA means the voltage between points A and B, but with B regarded as + and A regarded as âˆ'. In other words, it's the voltage that you would measure with a voltmeter if you placed the meter's positive (red) lead at point B and the meter's negative (black) lead at point A. * So in any given circuit, VAB and VBA will have the same magnitude, but one of them will have a negative sign and the other will not. For example, in the circuit shown above, VAB = âˆ'12 V and VBA = 12 V. Kirchhoff's Voltage Law * Kirchhoff's Voltage Law says that the sum of the voltage drops around any closed loop in a circuit equals the sum of the voltage rises around that loop. * We use the abbreviation KVL as a shorthand way of referring to Kirchhoff's Voltage Law. KVL in Series Resistive Circuits * When applied to a complete series resistive circuit with a single voltage source, KVL says that if you add the voltages across all of the resistors, the sum must be equal to the value of the source voltage. * For example, consider the circuit shown below, which shows the polarities of the voltages across the source and across the resistors. * If we " travel" clockwise around the circuit, then voltages V1, V2, and V3 are voltage drops, and voltage VS is a voltage rise. Since KVL says that the sum of the voltage drops must equal the sum of the voltage rises, we know that V1 + V2 + V3 = VS * On the other hand, if we " travel" counter-clockwise around the circuit, then voltages V1, V2, and V3 are voltage rises, and voltage VS is a voltage drop. Since KVL says that the sum of the voltage drops must equal the sum of the voltage rises, we know that VS = V1 + V2 + V3 * Either way, we reach the same conclusion: the sum of the resistor voltages is equal to the source voltage. So in the circuit shown

above, we know that if we add together the voltages across the three resistors, we'll get a sum of 10 V. KVL in Other Circuits * KVL is a general rule that applies in all circuits, not just series circuits and not just circuits containing resistors. In more complicated circuits, it can get tricky to apply KVL correctly, but when applied correctly it is a powerful tool. We'll see this in later units. Voltage Divider * A string of series resistors is often called a voltage divider because the total voltage across the entire string is divided among the various resistors in direct proportion to the resistance of each one. * For example, if you have two resistors in series and one resistor is twice as large as the other one (for example, suppose that one is 20 kÎ© and the other is 10 kÎ©), then there will be twice as much voltage across the larger resistor as there is across the smaller one. * On the other hand, if one of the series resistors is three times as large as the other one (say, 30 kÎ© and 10 kÎ©), then there will be three times as much voltage across the larger resistor as there is across the smaller one. The Voltage-Divider Rule * The voltage-divider rule is a shortcut rule that you can use to find the voltage drop across a resistor in a series circuit. * The rule says that the voltage across any resistance in a series circuit is equal to the ratio of that resistance to the circuit's total resistance, multiplied by the source voltage. * In equation form, this rule is expressed as: Vx = (Rx Ã· RT) Ã— VS * Here x is a variable representing the number of the resistor that you're interested in. * For instance, if you're trying to find the voltage across resistor R1, you would replace x with 1 to get: V1 = (R1 Ã· RT) Ã— VS * On the other hand, applying the rule to resistor R4 in a series circuit gives us: V4 = (R4 Ã· RT) Ã— VS * Of course, you can also find these voltage drops using the procedure we used earlier: first find total resistance, then use Ohm's law to find the current, and

then use Ohm's law to find the voltage drop that you're interested in. Doing it this way will give you the same answer that you get by using the voltage-divider rule. Potentiometer as a Voltage Divider * A potentiometer is a type of variable resistor with three terminals, represented by the following schematic symbol: * When you adjust a potentiometer you are moving the middle terminal (called the wiper terminal) toward one end or the other of the resistor. The resistance between the two end terminals stays constant, but the resistance between the wiper and either end terminal will change as you adjust the potentiometer. * In effect, what you have here is an adjustable voltage divider. In other words, it's like having two resistors in series whose total resistance is constant, but you can adjust the relative sizes of the individual resistors by moving the wiper in one direction or the other. Power in a Series Circuit * The three formulas for computing the power dissipated in a resistor are: $P = I2 Ã— R$ $P = V Ã— I$ $P = V2 Ã· R$ * Recall that in each of these equations, R is the resistor's resistance, V is the voltage across the resistor, and I is the current through the resistor. * These formulas let you find a resistor's power in any kind of circuit, including a series resistive circuit. But you need to be a little careful. The most common mistake that students make when using these formulas is to use the wrong value for V. In particular, students often mistakenly use the value of the source voltage when they should use the value of a single resistor's voltage. * In the circuit shown below, for example, the source voltage (VS) equals 12 V, and R1's voltage (V1) equals 4 V. Here's one correct way to find the power dissipated in R1: $P1 = V12 Ã· R1 = (4 V)2 Ã· 100 Î© = 160 mW$ Correct answer! Many students would incorrectly use the source voltage instead, which gives the wrong answer: $P1 = VS2 Ã· R1 = (12 V)2 Ã· 100 Î©$

= 1. 44 W   Incorrect answer! Total Circuit Power * We've been talking about the power dissipated in a single resistor. Not surprisingly, we use the symbol P1 for the power dissipated in resistor R1, and the symbol P2 for the power dissipated in resistor R2, and so on. We can also talk about the total power dissipated in an entire circuit, for which we use the symbol PT. * Here are two ways to compute total power in a resistive circuit. You'll get the same answer either way: 1. You can find the power for each resistor, and then add these powers: PT = P1 + P2 + P3 + … + Pn 2. Or you can apply any one of the power formulas to the entire circuit: PT = IT2 Ã— RT PT = VS Ã— IT PT = VS2 Ã· RT These are the same power formulas from above, except that now we're applying them to the entire circuit, instead of to a single resistor. Voltage Relative to Ground * Earlier in this unit you learned about the double-subscript notation that we use to talk about a voltage between two points in a circuit. For instance, if we have points labeled A and B in a circuit, we use the symbol VAB to refer to the voltage between those two points. As mentioned earlier, this is the voltage that you would measure with a voltmeter by placing the meter's positive (red) lead at point A and the meter's negative (black) lead at point B. * In many cases, we're interested in knowing the voltage at a point in a circuit relative to the circuit's ground. In such cases we use a notation that has a capital V with one letter as a subscript, such as VA. This is the voltage at point A relative to ground, which simply means the voltage that you would measure with a voltmeter by placing the meter's positive (red) lead at point A and the meter's negative (black) lead at the circuit's ground point. Troubleshooting * Troubleshooting a non-working circuit means finding the problem that is preventing the circuit from working correctly. * The two most common types of problems

are open circuits and short circuits. Open Circuit * An open circuit, or " open," is a break in a circuit path. * For example, when a light bulb burns out, it causes an open. A resistor or other component can also fail by becoming open. This can happen, for instance, if too much current passes through a resistor, causing it to " burn out." * A circuit containing an open is said to be an open circuit, or to be open-circuited. Current Through an Open * The most important thing to remember about opens is that no current can flow through an open. * Therefore, no current can flow anywhere in a series circuit containing an open. * Since no current flows through an open, you can think of the open as having infinite resistance (R = âˆž). Voltage Across an Open * A common mistake is to believe that since the current through an open is zero, the voltage across the open must also be zero. * Usually, an open will not have a voltage drop of 0 V. In fact, in a series circuit that contains an open, the entire source voltage will appear across the open, and no voltage will appear across any of the other resistors. * So if you measure the voltage between any two points in a series circuit containing an open, you'll measure 0 V if the two points are on the same side of the open, but you'll measure the entire source voltage if the points are on opposite sides of the open. * For example, suppose R3 is open in the circuit shown below. Then there will be 0 V across R1, across R2, and across R4. Also, Vab = 0 V. But there will be 9 V across R3. Also, Vac = 9 V, and Vbc = 9 V. Short Circuit * A short circuit, or " short," is a path of zero resistance connecting two points in a circuit that are not supposed to be connected. * For example, a wire clipping or a loose lump of solder can accidentally touch the leads of two resistors, thereby connecting those resistors to each other. Voltage Across a Short * Since a short has zero resistance, the voltage across it must

be zero. This follows from Ohm's law, V = I Ã— R. Current Through a Short * A component is said to be short-circuited, or " shorted out," when there is a short circuit connected across it. No current flows through a short-circuited component. Instead, current is diverted through the short itself. * For example, suppose that in the circuit shown below there is a short between points a and b, perhaps caused by a loose wire clipping that connects these two points. Then R2 is short-circuited. No current will flow through R2; instead, current will follow the path of zero resistance through the short itself (the wire clipping). * A short in a series circuit reduces the circuit's total resistance, causing more current to flow out of the voltage source. * For example, in the circuit shown above, if R2 is short-circuited by a wire clipping that connects points a and b, then R2's resistance disappears from the circuit, and the circuit's total resistance is equal to R1 + R3 + R4. Typical Causes of Opens and Shorts * The following animated lesson shows some of the real-world conditions that typically cause shorts or opens in circuits. It's got some good practical examples, so be sure no to skip it. Review * This lesson has covered several important topics, including: * series connections and series paths * series circuits * voltage drops and voltage rises * voltage sources in series * Kirchhoff's Voltage Law (KVL) * voltage dividers and the voltage-divider rule * power in series circuits * open circuits and short circuits. * To finish the lesson, take this self-test to check your understanding of these topics. Congratulations! You've completed the lesson for this module.