L1. Energy Consumption Monitoring with Energy Meters and Security Aspects

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Co-funded by the Erasmus+ Programme of the European Union

Consisting of

Coordinator:	Technical University of Sofia	Bulgaria
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	Software Company EOOD	Bulgaria

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Abbreviations

UPS	Uninterruptible Power Supply
HTTP	HyperText Transport Protocol
RFC	Request for Comments
URI	Unique Resource Identifier
UDP	User Datagram Protocol
VM	Virtual Machine
DC	Direct Current
I/O	Input Output
ASCII	American Standard Code for Information Interchange

1. Abbreviations

AC Alternating Current

DC Direct Current

IoT Internet of Things

VRx is the difference voltage between points V(n00x) and V(n00y), across Rz, in the diagram

PRz is the power absorbed by the resistor Rz

PwrSupl V is the output voltage generated by the voltage source as power supply. Here the selected voltage value is not related to the output current, and the parasitic components are not set. Symbol Names: VOLTAGE, BATTERY, Syntax: Vxxx n+ n- <voltage> [AC=<amplitude>] [Rser=<value>] [Cpar=<value>]

PwrSupl I is the output current generated by the power supply

PV1 is the output power generated by the power supply. An equation can be written P=VI.

1. Scope

3. Students will learn the interpretation and the evaluation of power quality's impact on the electrical installation and equipment. The analysis can be performed on a regular basis (for example, once per month) or ad hoc (when there is a problem caused by a potential power quality disturbance). Analysis is usually performed by skilled and experienced professionals, with specific competencies in power quality, electric installation, and equipment, who are capable of correlating power quality disturbances with equipment damage, malfunction, or electrical installation downtime. Because electrical and maintenance engineers in a facility plant are not always power quality experts and may have difficulties exploring and benefitting from power quality data, the current trend is to embed increasing analysis and expertise capabilities into power quality monitoring systems. Such systems can provide meaningful dashboards and appropriate widgets to analyze power quality problems. As next task they will then analyze some existing lists of measured values {Voltage (V), Current (A), Active power (W), Reactive power (var), Apparent power (VA), Power factor} and determine if power factor correction is necessary for an industrial application containing resistive and inductive loads.
4. This course explores
5. - Thorough and accurate documentation of laboratory work using a laboratory notebook;
6. - Thorough and accurate documentation of laboratory results using a laboratory report; and
7. - Functioning as an effective engineering team member.
8. - Electric charge, current, voltage, energy, and power.
9. - Training LtSpice default installation on laptops.
10. - Run the LtSpice executable and build a set of DC Schematics.
11. - Design of DC voltmeters, ammeters and power meters using LtSpice tools;
12. - Analysis of linear DC circuits using Ohm's law;
13. - Terminal characteristics of capacitors and inductors;
14. - Analysis of steady state linear AC circuits containing dependent and independent sources, resistors, capacitors, and inductors;
15. - DC and AC power calculations including power factor correction;
16. - Representing the step response as a sum of a transient and steady state response and a natural and forced response;
17. - Analysis, simulation, and experimental validation of DC circuits;
18. - Analysis and simulation of AC circuits;
19. - Use of virtual instrumentation such as voltmeters, ammeters, ohmmeters, signal generators, and oscilloscopes;

2. Training Prerequisites

- An intermediate knowledge of electrical design
- Familiarity with windows-based applications
- Working knowledge and understanding of electrical terminology, concepts and calculations, including an understanding of the relationships among current, voltage, power, and power factor in three-phase circuits.

LABORATORY 1: LTSpice/ Power Measurement

Materials need: Your own Laptop

Choose a team:

- Pick a team partner. Choose up to two people for a maximum group of three. Remember, you will likely have to work with this partner or persons for the rest of the this course.

- One laboratory report is needed for each group. Make sure you include all group members name on the front of the report.

- Step by step you will go through each lab section. Then choose any of the circuits you went through (unless specified) to prove concepts listed at the end of each section in your Proof of Concepts document.

- To support the proof of concept, answer any questions related to those concepts and provide mathematical calculation, simulation, and experimental data!

PART A0: LTSpice installation on own laptops:

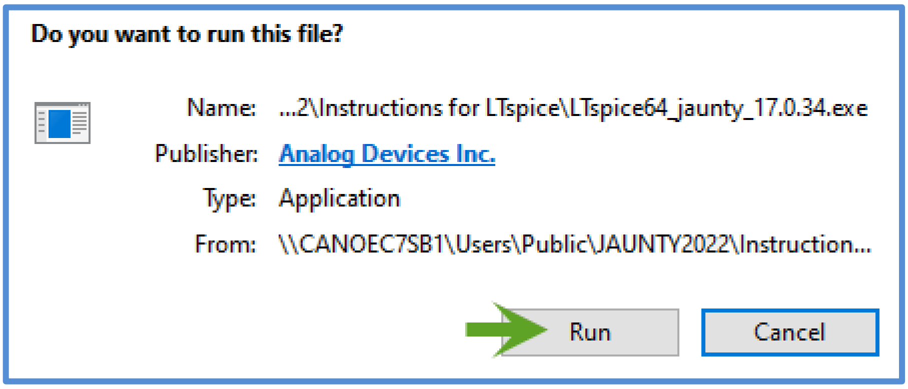
Software Full Name:	*Ltspice64_17.0.34*
Setup File Name:	Ltspice64_jaunty_17.0.34.exe
Full Setup Size:	59 291 304 bytes
Setup Type:	Offline Installer / Full Standalone Setup
Compatibility Architecture:	32 Bit (x86) / 64 Bit (x64)
Latest Version Release Added On:	18.03. 2022
Developers:	Analog Devices
System Requirements :	Before you start Intergraph SmartPlant Electrical 2015, make sure your PC meets minimum system requirements.
Operating System:	Windows 10
Memory (RAM):	4 GB of RAM required.
Hard Disk Space:	4 GB of free space required.
Processor:	Intel Pentium 6 or later.

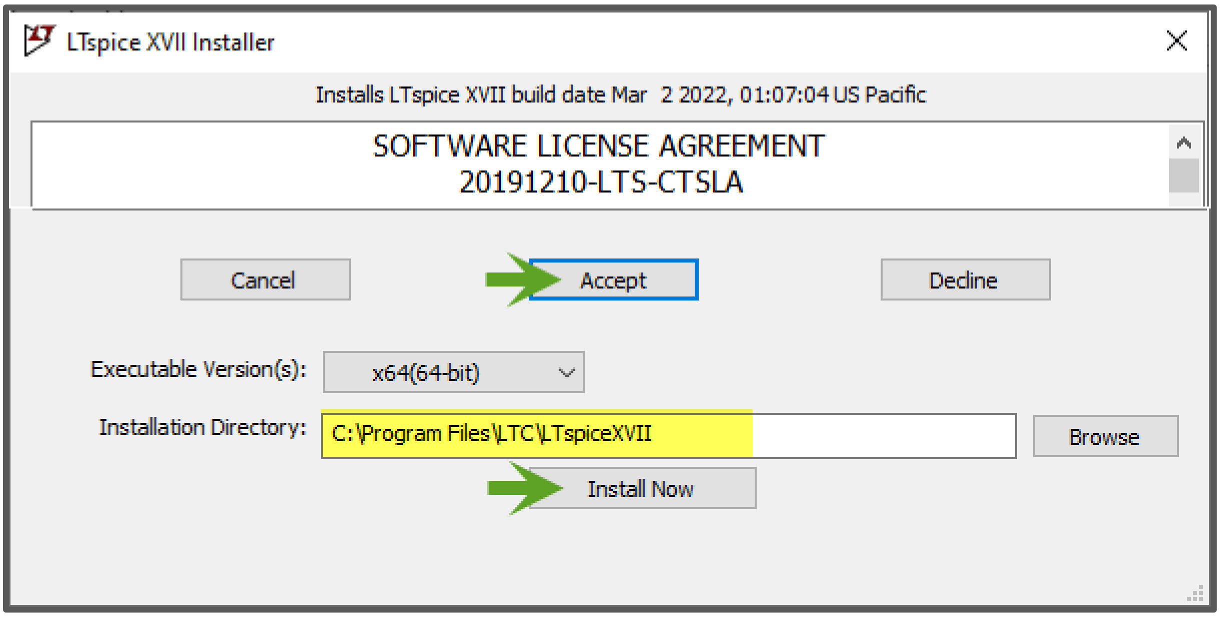
A0. 1. Use the link or find in the course:

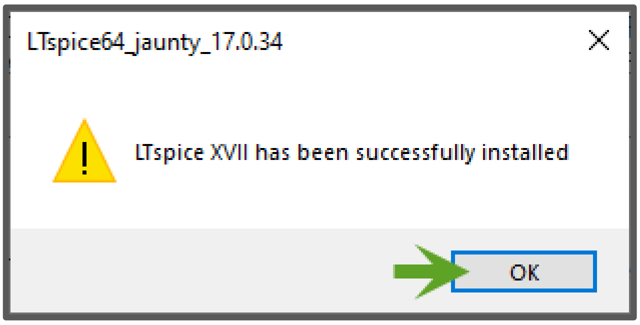
https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html

Or find (LTSpice Download) on the webpage under Resources. JAUNTY uses Version 17.0.34: *Ltspice64_jaunty_17.0.34.exe*

A0. 2. Run the executable and follow the default installation.







A0. 2. LTSPICE STARTING A NEW PROJECTS:

A0. 2. 1. Start “LTSpice XVII”

A0. 2. 2. Start a new Project under the File -> New Schematic

- Make sure your files are saved in a convenient directory. The root directory (C:\) or Desktop are probably not good choices. I would suggest creating a directory “C:\Circuits” and saving your work there.

- Pick an appropriate name (Laboratory_01 is a good choice)

A0. 2. 3. To place components:

- The first time you start, click Edit in the task bar. Here you’ll find symbols and their matching labels.

You can choose to go down the menu and click Component or simply use the Toolbar above the schematic frame from this point on OR

- There are shortcut keys for adding components as well.

KEYBOARD SHORTCUTS

Keyboard shortcuts are an alternate way to invoke one or more commands in Ltspice that would otherwise only be accessible by clicking through the menu or toolbar. You can view these shortcuts for the schematic editor by choosing:

Tools > Control Panel > Drafting Options and clicking Hot Keys.

Hot Keys can be reprogrammed by selecting a command and then pressing the key or key combination for the command. For example, you may want to reprogram the Undo, Redo and Duplicate (Copy) commands to a more traditional key combination. To remove a shortcut, select the command and press Delete.

Additional Hot Keys are also available for the Waveform Viewer, Symbol Editor and Netlist Editor.

Ltspice HotKeys				
	Schematic	**Symbol**	**Waveform**	**Netlist**
Modes	ESC – Exit Mode	ESC – Exit Mode		
	F3 – Draw Wire			
	F5 – Delete	F5 – Delete	F5 – Delete	
	F6 – Duplicate	F6 – Duplicate		
	F7 – Move	F7 – Move		
	F8 – Drag	F8 – Drag		
	F9 – Undo	F9 – Undo	F9 – Undo	F9 – Undo
	Shift+F9 – Redo	Shift+F9 – Redo	Shift+F9 – Redo	Shift+F9 – Redo
View	Ctrl+Z – Zoom Area	Ctrl+Z – Zoom Area	Ctrl+Z – Zoom Area	
	Ctrl+B – Zoom Back	Ctrl+B – Zoom Back	Ctrl+B – Zoom Back	
	Space – Zoom Fit		Ctrl+E – Zoom Extents	
	Ctrl+G – Toggle Grid		Ctrl+G – Toggle Grid	Ctrl+G – Goto Line #
	U – Mark Unncon. Pins	Ctrl+W – Attribute Window	'0' – Clear	
	A – Mark Text Anchors	Ctrl+A – Attribute Editor	Ctrl+A – Add Trace	
	Atl+Click – Power		Ctrl+Y – Vertical Autorange	Ctrl+R – Run Simulation
	Ctrl+Click – Attr. Edit		Ctrl+Click – Average	
	Ctrl+H – Halt Simulation		Ctrl+H – Halt Simulation	Ctrl+H – Halt Simulation

Place	**R – Resistor**	**R – Rectangle**
	C – Capacitor	**C – Circle**
	L – Inductor	**L – Line**
	D – Diode	**A – Arc**
	G – GND	
	S – Spice Directive	
	T – Text	**T – Text**
	F2 – Component	
	F4 – Label Net	
	Ctrl+E – Mirror	**Ctrl+E – Mirror**
	Ctrl+R – Rotate	**Ctrl+R – Rotate**

Suffix		**Suffix**		**Constants**	
		f	1e-15	E	2.7182818284590452354
T	1e12	p	1e-12	Pi	3.14159265358979323846
G	1e9	n	1e-9	K	1.3806503e-23
Meg	1e6	u	1e-6	Q	1.602176462e-19
K	1e3	M	1e-3	TRUE	1
		Mil	25.4e-6	FALSE	0

Simulator Directives – Dot Commands	
Command	**Short Description**
.AC	Perform a Small Signal AC Analysis
.BACKANNO	Annotate Subcircuit Pin Names on Port Currents
.DC	Perform a DC Source Sweep Analysis
.END	End of Netlist
.ENDS	End of Subcircuit Definition
.FOUR	Compute a Fourier Component
.FUNC	User Defined Functions
.FERRET	Download a File Given the URL

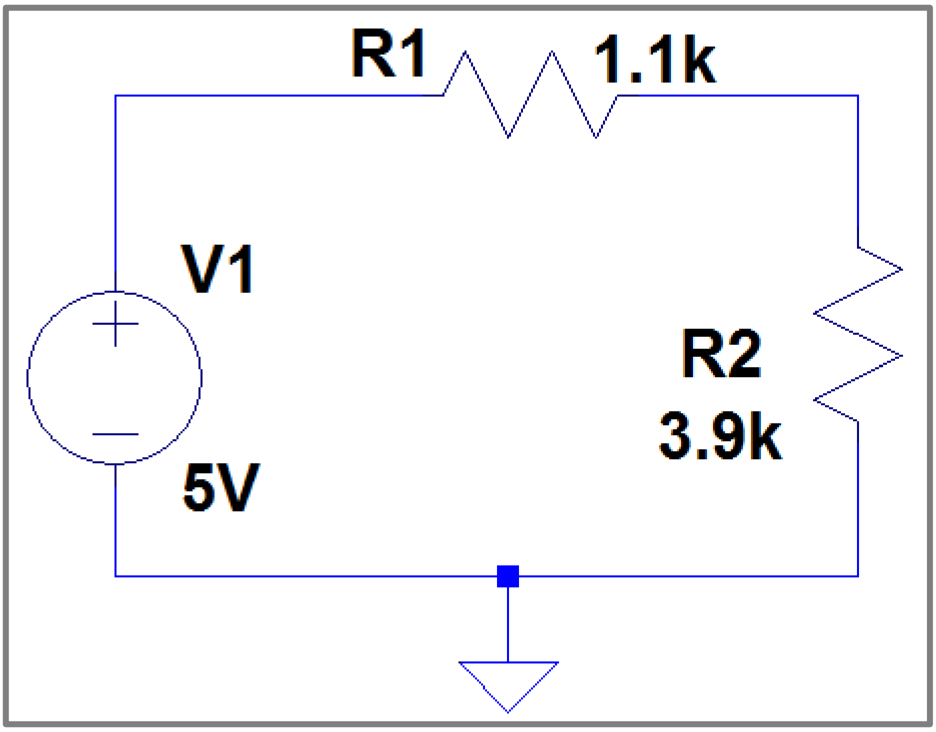
Command Line Switches	
Flag	**Short Description**
-ascii	Use ASCII .raw files. (Degrades performance!)
-b	Run in batch mode.
-big or -max	Start as a maximized window
-encrypt	Encrypt a model library
-FastAccess	Convert a binary .raw file to Fast Access Format
-netlist	Convert a schematic to a netlist
-nowine	Prevent use of WINE(Linux) workarounds

.GLOBAL	Declare Global Nodes
.IC	Set Initial Conditions
.INCLUDE	Include another File
.LIB	Include a Library
.LOADBIAS	Load a Previously Solved DC Solution
.MEASURE	Evaluate User-Defined Electrical Quantities
.MODEL	Define a SPICE Model
.NET	Compute Network Parameters in a .AC Analysis
.NODESET	Supply Hints for Initial DC Solution
.NOISE	Perform a Noise Analysis
.OP	Find the DC Operating Point
.OPTIONS	Set Simulator Options
.PARAM	User-Defined Parameters
.SAVE	Limit the Quantity of Saved Data
.SAVEBIAS	Save Operating Point to Disk
.STEP	Parameter Sweeps
.SUBCKT	Define a Subcircuit
.TEMP	Temperature Sweeps
.TF	Find the DC Small-Signal Transfer Function
.TRAN	Do a Nonlinear Transient Analysis
.WAVE	Write Selected Nodes to a .WAV file

-PCBnetlist	Convert a schematic to a PCB netlist
-registry	Store user preferences in the registry
-Run	Start simulating the schematic on open
-SOI	Allow MOSFET’s to have up to 7 nodes in subcircuit
-uninstall	Executes one step of the uninstallation process
-wine	Force use of WINE(Linux) workarounds

PART A – Introduction to DC Power Measurement in LTSpice.

A1: BIAS POINT MEASUREMENTS FOR RESISTIVE CIRCUITS



A1. 1. Create the circuit above in LTSpice and display the current, voltage and power values for the circuit like the next diagram below.

*Note: If you are confident that you can do this **without step-by-step instruction you can skip to A2.** Step-by-step instructions are below.*

A1. 2. Find and Add the Component (shortcut "F2"), by typing "voltage". Press "OK".

- A DC voltage source should follow your cursor.

- Left click to place. Press ESC to keep from duplicating. (If you make a mistake, you can press CTRL-V to cut the component).

- Move your cursor over the component. When a hand pointing left appears, right click, to edit the value of the DC voltage. Change the value to 5V.

A1. 3. Add resistors. (shortcut “R”). Press CTRL-R to rotate. Right click to place and ESC to keep from duplicating.

- They should be default labeled R1 and R2.

- Change values of R1 and R2 to 1.1k(1100Ω) and 3.9k (3900Ω) respectively by right clicking the component.

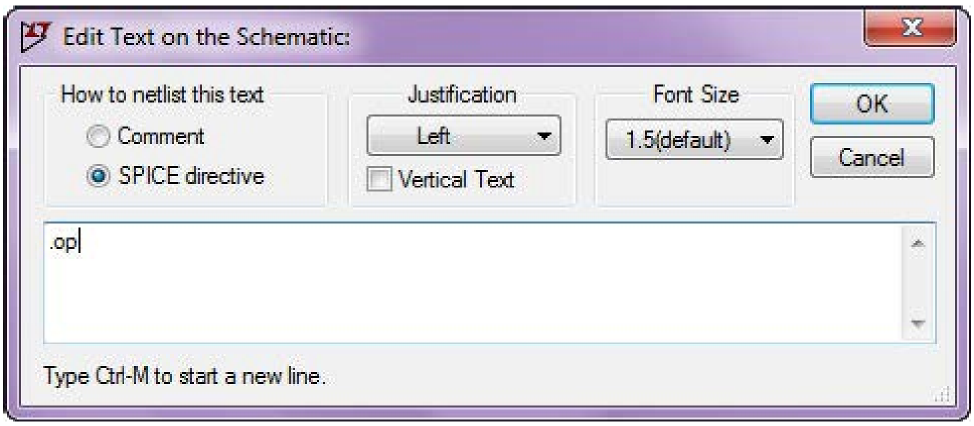
A1. 4. Connect the DC source and the two resistors in a closed loop by placing wire connections between each component. (shortcut “F3”) Click on one of the square boxes connected to a circuit component and then move the mouse and click on another square box to place a wire connection.

A1. 5. Add a ground connection. (shortcut “G”) You MUST use a ground in every circuit you simulate. Be sure to wire this as well.

A1. 6. Setting Operating Point DC Analysis

A1.6.1. To add operating point analysis (.op) you have a few options:

A1.6.1.1. Click “.op” in the tool bar on the far right and add text “.op” in the text box as shown below



A1.6.1.2. Press shortcut “t” on your keyboard then change radio button to “SPICE directive” then add text “.op” in the text box below it

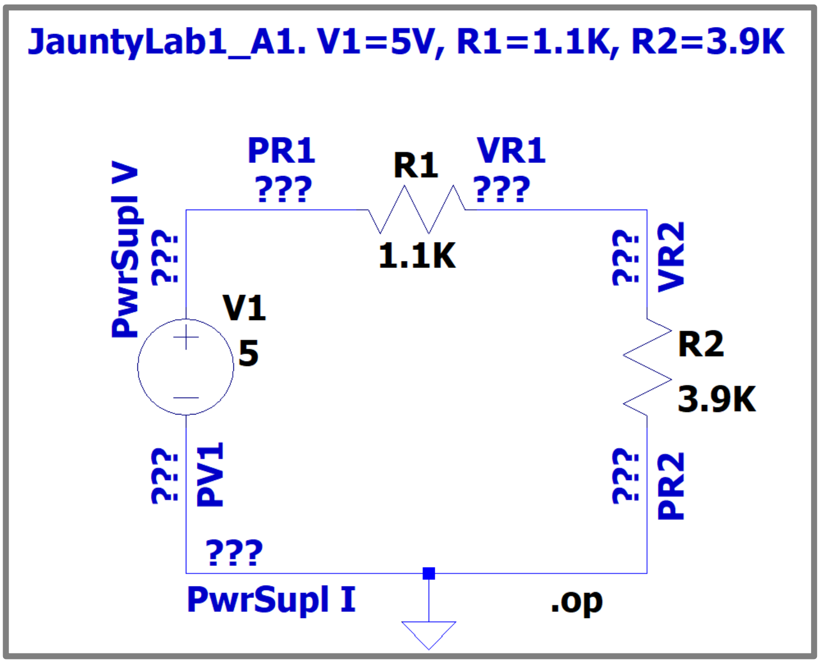
A1.6.1.3. Press “s” on your keyboard which automatically selects “SPICE directive” then add text “.op” in the text box below it.

A1.6.2. Place .op anywhere near the circuit

A1.6.3. Run the simulation. (Click the “Running person” in the toolbox.)

A1.6.4. Results will appear in a dialog box.

A1.6.5. Label the circuit with voltage, current, and power by placing operating point data labels. *The sample image below has unknown labels but gives an idea of what you need to show.*



- **VR1** is the difference voltage between points V(n001) and V(n002), across R1, in the diagram,

- **VR2** is the difference voltage between points V(n002) and GND, across R2, in the diagram,

- **PR1** is the power absorbed by the resistor R1,

- **PR2** is the power absorbed by the resistor R2,

- **PwrSupl V** is the output voltage generated by the voltage source as power supply. Here the selected voltage value is not related to the output current, and the parasitic components are not set.

Symbol Names: VOLTAGE, BATTERY

Syntax: Vxxx n+ n- <voltage> [AC=<amplitude>] [Rser=<value>] [Cpar=<value>]

This element sources a constant voltage between nodes n+ and n-. For AC analysis, the value of AC is used as the amplitude of the source at the analysis frequency. A parasitic series resistance and parallel capacitance can be defined. Voltage sources have historically been used as the current meters in SPICE and are used as current sensors for current-controlled elements. If Rser is specified, the voltage source can not be used as a sense element for F, H, or W elements. However, the current of any circuit element, including the voltage source, can be plotted.

- PwrSupl I is the output current generated by the power supply,

- PV1 is the output power generated by the power supply. An equation can be written P=VI.

A1.6.5.1. FOR VR2 voltage:

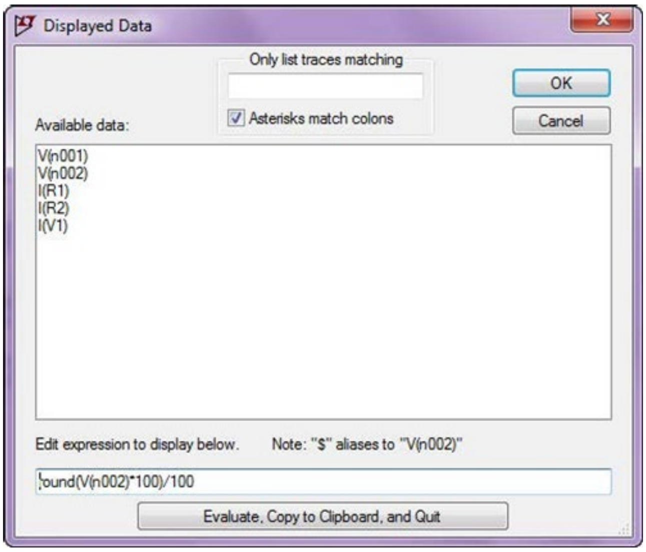
- Right click on the wire to the right of R1 (this is the voltage above R2, Vn002 to ground which is the voltage across R2, VR2).

- Right click to change the number of significant figures.

For two decimal places use: *round(**data label***100)/100* or here

*round(V(n002)*100)/100.*

For three significant figures multiply and divide by 1000. For four 10000 etc.



- Press ok and move the label anywhere convenient using the “Move” hand on the toolbar.

A1.6.5.2. FOR IR2 current

- Right click on the wire to the right of R1 again. It will show voltage but you will change it by right clicking on it and choosing I(R2) which will show in the text box

- Be sure to round this value to significant figures.

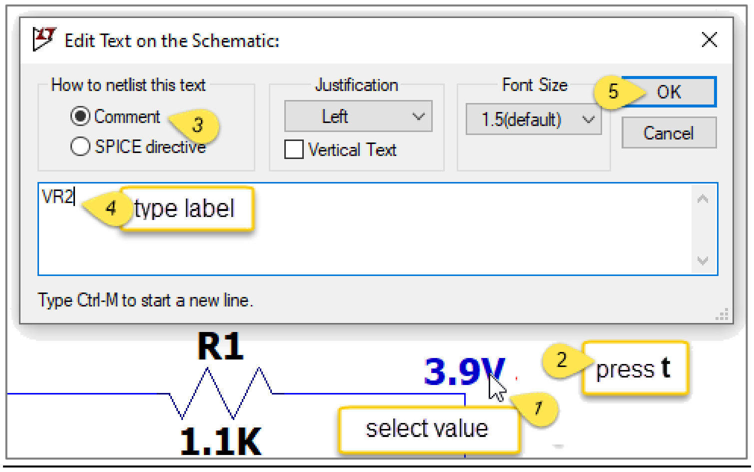
Note: LTSpice assumes conventional current flows from positive to negative terminal of the power supply (pointing down). Therefore, all resistors current will be labeled as negative in LTSpice. To make positive simply add a negative in front of I(R1) and I(R2).

A1.6.5.3. For PR2 power

- An equation can be written P=VI

with rounding to significant figures is included

*round(I(R2)*V(n002)*10000)/10000*



- Add text above all the numerical labels by pressing "t". The radio button should automatically be on "Comment". Type VR2 in the text box for example and place near the value in the figure.

Repeat this process for the voltage current and power for R1 and power for the voltage source in your figure.

Remember VR1 is the difference between points V(n001) and V(n002) in the diagram. Also remember power supplied must equal power absorbed by the resistors!

A2. Making Changes

A2.1. Change R1 to 22k and R2 to 42k. Rerun the simulation.

A2.1.1. Comment on the new voltage and current measurements. Are the results consistent with expectations? Why?

A2.1.2. Did the power levels go up, down or stay the same? Why?

A2.2. Replace the voltage source with a 5mA current source. (Component "current")

A2.2.1. What can you say about the current as R1 and R2 change?

A2.2.2. What happens to the power if both resistors are reduced back to their 1.5k and 3.2k values (from the 22k and 42k values)?

A2.2.3. Include a screen shot of your results in your report.

Part A: Proof of Concepts List

Prove Ohm's Law

Prove that power supplied must equal power absorbed (include polarity!) Prove how the placement of ground affects the circuit (or doesn't affect it)

Note: The word prove means <u>demonstrate</u> using simulation, mathematical calculation, and experimental results to show that a concept is valid. It is not a mathematical definition of a proof. If you find limitations to that concept, include it!

Please include screen shots of your results in your Proof of Concept Report.

Make sure they are easy to read, and simulation results are labelled.

Note for Part A, there isn't a built circuit to provide experimental results. You should still provide analytical hand calculations and discuss your results while answering any questions in the lab.

Voltage Divider as a Component (not just a calculation)

- Name three ways a voltage divider can be used in a circuit. (You can Google it!)

- Demonstrate one of those via simulation and DESCRIBE its purpose in a larger circuit. You CANNOT use the voltage divider for reducing a large total voltage in this example.

- Build the circuit and compare.

PART B – INTRODUCTION TO AC POWER MEASUREMENT IN LTSPICE

B0. 2. 1. Start a new Project under the File -> New Schematic

- Pick an appropriate name (Laboratory_01_ac is a good choice)

B0. 2. 2. To place components:

- The first time you start, click Edit in the task bar. Here you'll find symbols and their matching labels. You can choose to go down the menu and click Component or simply use the Toolbar above the schematic frame from this point on OR. There are shortcut keys for adding components as well.

B1: AC Measurements for Resistive Circuits

AC power enabled many other inventions key to industrialization, from the induction motor and gas discharge lamp ballasts to light dimmers and electric shavers. But part of the dark side of AC power is this notion of power factor. The voltage for DC power is constant, so there is ηo phase associated with it; AC power is (ideally) sinusoidal, with the voltage and current crossing O V at 100 times a second (twice per 50 Hz cycle). If the load (or even the power line) is slightly inductive or capacitive, the current will either lag or lead the voltage.

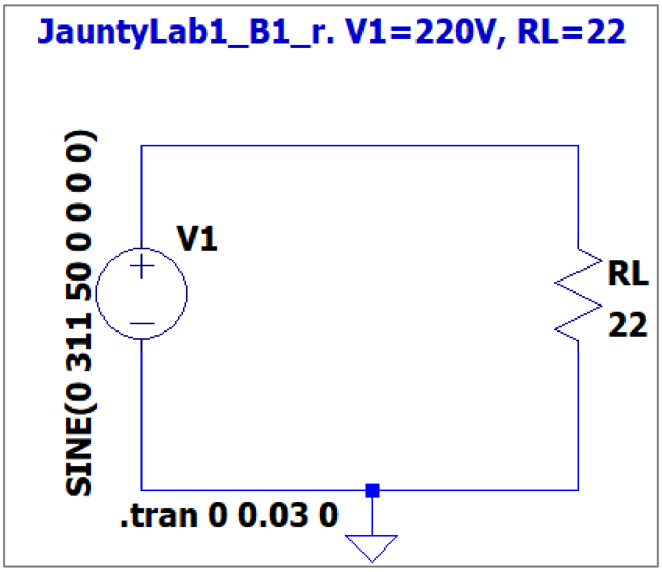


Fig. B1.1. Circuit for a single-phase AC power power analyse in resistive circuits

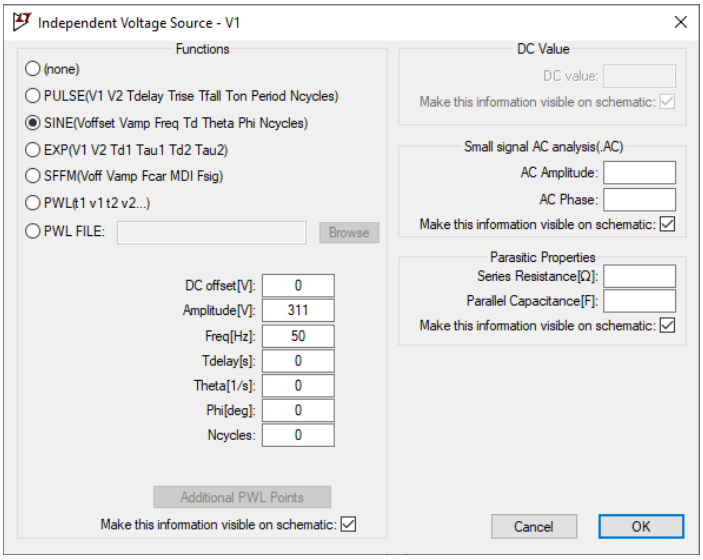
B1. 1. Create the circuit above in LTSpice and display the current, voltage and power values for the circuit like the next diagram below.

B1. 2. Find and Add the Component (shortcut "F2"), by typing "voltage". Press "OK".

- A DC voltage source should follow your cursor.

- Left click to place. Press ESC to keep from duplicating. (If you make a mistake, you can press CTRL-V to cut the component).

- Move your cursor over the component. When a hand pointing left appears, right click, to edit the value of the AC voltage. Change the value to:



Syntax: Vxxx n+ n- SINE(Voffset Vamp Freq Td Theta Phi Ncycles)

Time-dependent sine wave voltage source.

Name	*Description*	*Units*
Voffset	*DC offset*	*V*
Vamp	*Amplitude*	*V*
Freq	*Frequency*	*Hz*
Td	*Delay*	*sec*
Theta	*Damping factor*	*1/sec*
Phi	*Phase of sine wave*	*degrees*
Ncycles	*Number of cycles(Omit for free-running sine function)*	*cycles*

For times less than Td, the output voltage is given by

*Voffset+Vamp*sin(π*Phi/180)*

For times after Td, but before Ncycles have completed, the voltage is given by

*Voffset+Vamp*exp(-(time-Td)*Theta)*sin(2*π*Freq*(time-Td)+π*Phi/180)*

For times after Ncycles have completed, the voltage is the last voltage when Ncycles completed. Note Ncycles does not have to be an integer.

The damping factor, Theta, is the reciprocal of the decay time constant.

SINE(0 311 50 0 0 0 0)

***Vamp** = 220V*1.441=311V Amplitude*

B1. 3. Add resistors. (shortcut "R"). Press CTRL-R to rotate. Right click to place and ESC to keep from duplicating.

- It should be default labelled RL.

- Change values of RL to 22Ω respectively by right clicking the component. The value is often measured by some kitchen appliances.

B1. 4. Connect the AC source and the resistor RL in a closed loop by placing wire connections between each component. (shortcut "F3") Click on one of the square boxes connected to a circuit component and then move the mouse and click on another square box to place a wire connection.

B1. 5. Add a ground connection. (shortcut "G") You MUST use a ground in every circuit you simulate. Be sure to wire this as well.

B1. 6. Setting Operating Point AC Analysis and Simulation

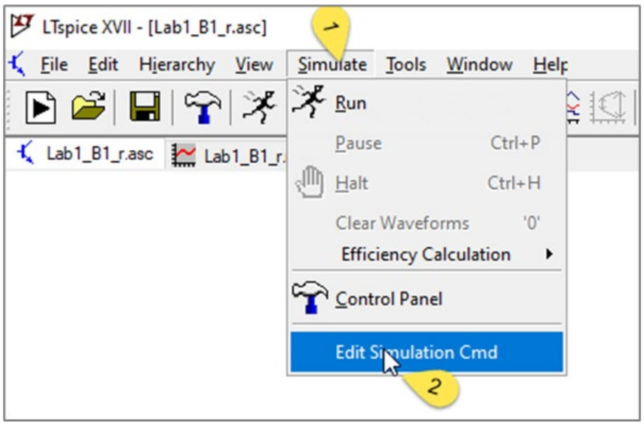
B1.6.1. To add operating point AC Analysis and Simulation (.tran) you have a few options.

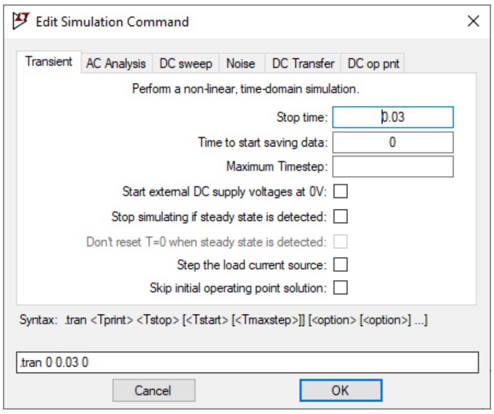
.TRAN -- Perform a Nonlinear Transient Analysis

Perform a transient analysis. This is the most direct simulation of a circuit. It basically computes what happens when the circuit is powered up. Test signals are often applied as independent sources.

Syntax: .TRAN <Tstep> <Tstop> [Tstart [dTmax]] [modifiers]
.TRAN <Tstop> [modifiers]

The first form is the traditional .tran SPICE command. Tstep is the plotting increment for the waveforms but is also used as an initial step-size guess. LTspice uses waveform compression, so this parameter is of little value and can be omitted or set to zero. Tstop is the duration of the simulation. Transient analyses always start at time equal to zero. However, if Tstart is specified, the waveform *data between zero and Tstart is not saved. This is a means of managing the size of waveform files by allowing startup transients to be ignored. The final parameter dTmax, is the maximum time step to take while integrating the circuit equations. If Tstart or dTmax is specified, Tstep must be specified. Several **modifiers** can be placed on the .tran line.*





B1.6.1.1. Click "Transient" in the toolbar on the far right and add text ".tran" in the text box as shown above. The value of the simulation period is set to 30ms, related to 50 Hz AC.

B1.6.2. Run the simulation. (Click the "Running person" in the toolbox.)

B1.6.3. Results will appear in a waveform below.

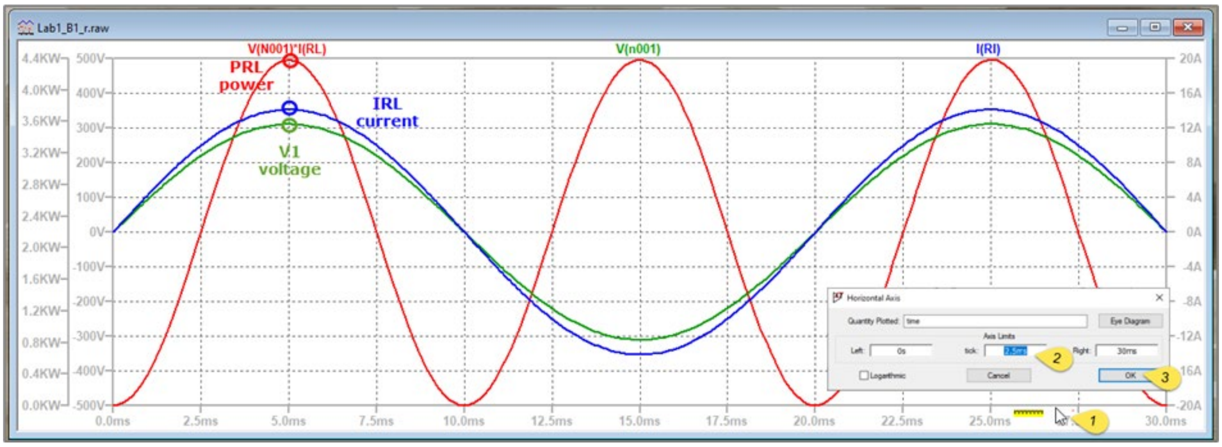
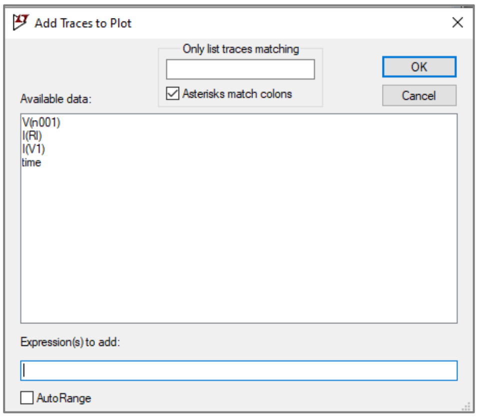
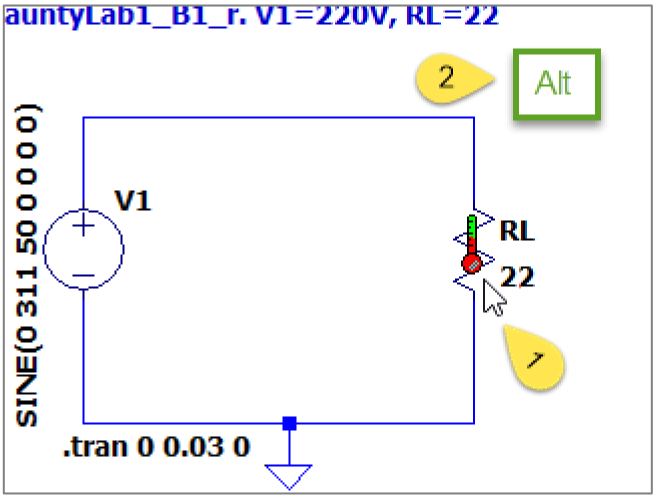


Fig. B1.6.3. Power in resistive AC circuits



B1.6.5. Here you can select voltage V(n001) and the current I(RL) traces select for a transient analysis.

B1.6.6. Next select power trace P=V(N001)*I(RL) for a power factor analysis. Select RL and press “Alt” key to activate power trace.



B1.6.7. In Control panel you can select colours and width for all the waveforms, background and grids.

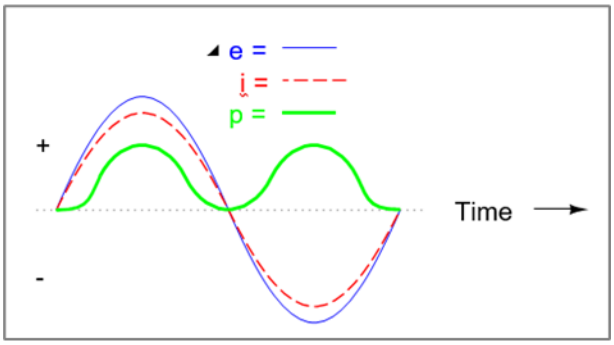
B1.7. Power in resistive AC circuits. Analysis.

Consider a circuit for a single-phase AC power system, where a 220 volt, 50 Hz AC voltage source is delivering power to a resistive load: Fig. B1.1. *Circuit for a single-phase AC power power analyse in resistive circuits.*

ZRL = 22 + j0 Ω or 22 Ω ∠ 0o

I(RL)= V(n001)/ ZRL=220/22=10A

In this example, the current to the load would be 10 amps, RMS. The power dissipated at the load would be 2200 watts. Because this load is purely resistive (no reactance), the current is in phase with the voltage, and calculations look like that in an equivalent DC circuit. If we were to plot the voltage, current, and power waveforms for this circuit, it would look like Fig. B1.6.3.



Current is in phase with voltage in a resistive circuit. Note that the waveform for power is always positive, never negative for this resistive circuit. This means that power is always being dissipated by the resistive load, and never returned to the source as it is with reactive loads. If the source were a mechanical generator, it would take 2200 watts worth of mechanical energy to turn the shaft.

Also note that the waveform for power is not at the same frequency as the voltage or current! Rather, its frequency is double that of either the voltage or current waveforms. This different frequency prohibits our expression of power in an AC circuit using the same complex (rectangular or polar) notation as used for voltage, current, and impedance, because this form of mathematical symbolism implies unchanging phase relationships. When frequencies are not the same, phase relationships constantly change.

As strange as it may seem, the best way to proceed with AC power calculations is to use scalar notation, and to handle any relevant phase relationships with trigonometry.

B1.7. Power in resistive AC circuits. Proving grounds.

B1.7.1 Measure the maximal electrical values of:

I(RL), V(n001) and the power P with the embedded tools in simulation window as shown on

Fig. B1.6.3. Power in resistive AC circuits. Explain the differences between RMS values and the real values.

B1.7.2 Measure the frequencies of:

I(RL), V(n001) and the power P

Explain the difference.

B1.7.3 Measure the phase shift of:

I(RL), V(n001)

Explain it.

Prove that power supplied must equal power absorbed (include polarity)

Note: The word prove means demonstrate using simulation, mathematical calculation, and experimental results to show that a concept is valid. It is not a mathematical definition of a proof. If you find limitations to that concept, include it!

Please include screen shots of your results in your Proof-of-Concept Report.

Make sure they are easy to read, and simulation results are labelled.

B2: AC Measurements for purely reactive (inductive) Circuits

AC power enabled many other inventions key to industrialization, from the induction motor and gas discharge lamp ballasts to light dimmers and electric shavers. But part of the dark side of AC power is this notion of power factor. The voltage for DC power is constant, so there is ɳo phase associated with it; AC power is (ideally) sinusoidal, with the voltage and current crossing O V at 100 times a second (twice per 50 Hz cycle). If the load (or even the power line) is slightly inductive or capacitive, the current will either lag or lead the voltage.

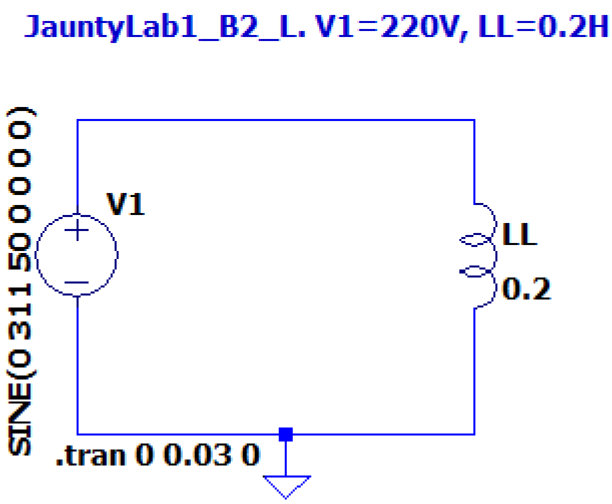


Fig. B2.1. Circuit for a single-phase AC power power analyse in purely reactive (inductive) circuits

B2. 1. Create the circuit above in LTSpice and display the current, voltage and power values for the circuit like the next diagram below.

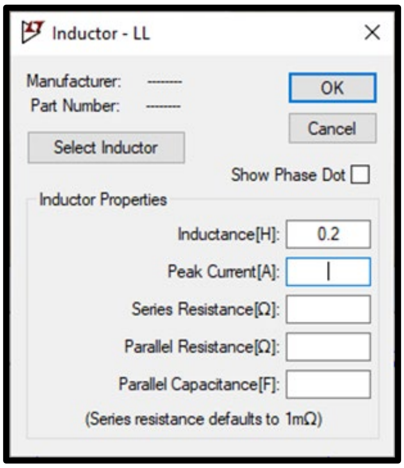
B1. 2. Find and Add the Component (shortcut “F2”), by typing “voltage”. Press “OK”.

- A AC voltage source should be the same as above.

B2. 3. Add resistors. (shortcut “L”). Press CTRL-R to rotate. Right click to place and ESC to keep from duplicating.

- It should be default labelled LL.

- Change values of LL to 0.2H respectively by right clicking the component.



B2. 4. Connect the AC source and the resistor RL in a closed loop by placing wire connections between each component. (shortcut "F3") Click on one of the square boxes connected to a circuit component and then move the mouse and click on another square box to place a wire connection.

B2. 5. Add a ground connection. (shortcut "G") You MUST use a ground in every circuit you simulate. Be sure to wire this as well.

B2. 6. Setting Operating Point AC Analysis and Simulation

B2.6.1. To add operating point AC Analysis and Simulation (.tran) you have to use the same steps as trained before.

B2.6.2. Run the simulation. (Click the "Running person" in the toolbox.)

B2.6.3. Results will appear in a waveform below.

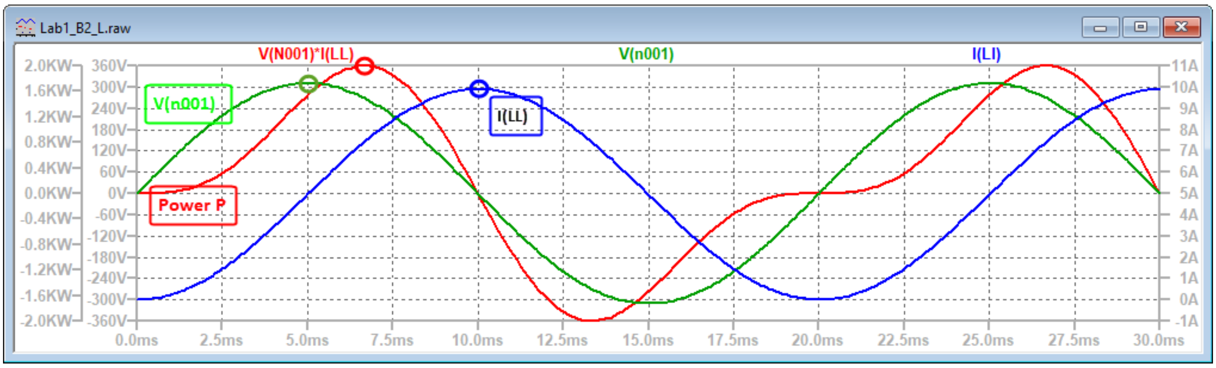


Fig. B2.6.3. Power in purely reactive (inductive) AC circuits

B2.6.5. Here you can select voltage V(n001) and the current I(LL) traces select for a transient analysis.

B2.6.6. Next select power trace P=V(N001)*I(LL) for a power factor analysis. Select LL and press “Alt” key to activate power trace.

B2.6.7. In Control panel you can select colours and width for all the waveforms, background and grids.

B1.7. Power in reactive AC circuits. Analysis.

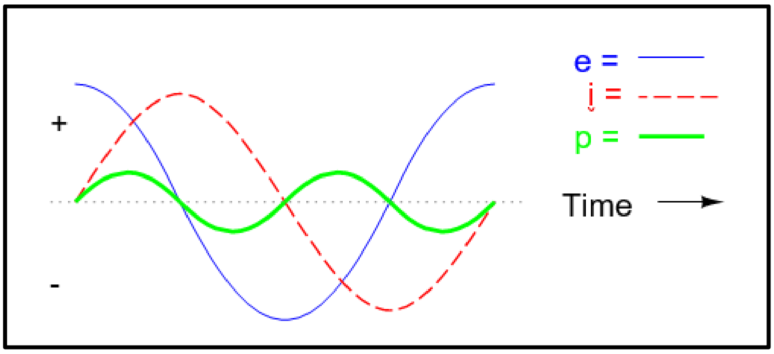
Consider a circuit for a single-phase AC power system, where a 220 volt, 50 Hz AC voltage source is delivering power to a reactive load: Fig. B2.1. *Circuit for a single-phase AC power analyse in reactive circuits.*

XL = 2¶fL= 63Ω

ZL = 0 + j63Ω or 63Ω ∠ 90o

I(RL)= V(n001)/ ZXL=220/63=3.5A

In this example, the current to the load would be 3.5A amps, RMS. The power dissipated at the load would be 2200 watts. Because this load is purely resistive (no reactance), the current is in phase with the voltage, and calculations look like that in an equivalent DC circuit. If we were to plot the voltage, current, and power waveforms for this circuit, it would look like Fig. B1.6.3.



Power is not dissipated in a purely reactive load. Though it is alternately absorbed from and returned to the source.

Note that the power alternates equally between cycles of positive and negative. This means that power is being alternately absorbed from and returned to the source. If the source were a mechanical generator, it would take (practically) no net mechanical energy to turn the shaft, because no power would be used by the load. The generator shaft would be easy to spin, and the inductor would not become warm as a resistor would.

Now, let’s consider an AC circuit with a load consisting of both inductance and resistance. Also note that the waveform for power is not at the same frequency as the voltage or current!

Rather, its frequency is double that of either the voltage or current waveforms. This different frequency prohibits our expression of power in an AC circuit using the same complex (rectangular or polar) notation as used for voltage, current, and impedance, because this form of mathematical symbolism implies unchanging phase relationships. When frequencies are not the same, phase relationships constantly change.

As with any reactive circuit, the power alternates between positive and negative instantaneous values over time. In a purely reactive circuit that alternation between positive and negative power is equally divided, resulting in a net power dissipation of zero. However, in circuits with mixed resistance and reactance like this one, the power waveform will still alternate between positive and negative, but the amount of positive power will exceed the amount of negative power. In other words, the combined inductive/resistive load will consume more power than it returns back to the source.

Looking at the waveform plot for power, it should be evident that the wave spends more time on the positive side of the centre line than on the negative, indicating that there is more power absorbed by the load than there is returned to the circuit. What little returning of power that occurs is due to the reactance; the imbalance of positive versus negative power is due to the resistance as it dissipates energy outside of the circuit (usually in the form of heat). If the source were a mechanical generator, the amount of mechanical energy needed to turn the shaft would be the amount of power averaged between the positive and negative power cycles.

Mathematically representing power in an AC circuit is a challenge, because the power wave isn't at the same frequency as voltage or current. Furthermore, the phase angle for power means something quite different from the phase angle for either voltage or current. Whereas the angle for voltage or current represents a relative shift in timing between two waves, the phase angle for power represents a ratio between power dissipated and power returned. Be-cause of this way in which AC power differs from AC voltage or current, it is actually easier to arrive at figures for power by calculating with scalar quantities of voltage, current, resistance, and reactance than it is to try to derive it from vector, or complex quantities of voltage, current, and impedance that we've worked with so far.

B2.7. Power in reactive AC circuits. Proving grounds.

B2.7.1 Measure the maximal electrical values of:

I(RL), V(n001) and the power P with the embedded tools in simulation window as shown on

Fig. B2.6.3. Power in purely reactive (inductive) AC circuits

Explain the differences between RMS values and the real values.

B2.7.2 Measure the frequencies of:

I(RL), V(n001) and the power P

Explain the difference.

B2.7.3 Measure the phase shift of:

I(RL), V(n001)

Explain it.

Prove that power supplied must equal power absorbed (include polarity)

Note: The word prove means demonstrate using simulation, mathematical calculation, and experimental results to show that a concept is valid. It is not a mathematical definition of a proof. If you find limitations to that concept, include it!

Please include screen shots of your results in your Proof-of-Concept Report.

Make sure they are easy to read, and simulation results are labelled.

B.3. POWER FACTOR. Concept Demonstration. Exam Questions

B.3.3 Power factor correction

When the need arises to correct for poor power factor in an AC power system, you probably won't have the luxury of knowing the load's exact inductance in henrys to use for your calculations. You may be fortunate enough to have an instrument called a *power factor meter* to tell you what the power factor is (a number between 0 and 1), and the apparent power (which can be figured by taking a voltmeter reading in volts and multiplying by an ammeter reading in amps). In less favorable circumstances you may have to use an oscilloscope to compare voltage and current waveforms, measuring phase shift in *degrees* and calculating power factor by the cosine of that phase shift.

Most likely, you will have access to a wattmeter for measuring true power, whose reading you can compare against a calculation of apparent power (from multiplying total voltage and total current measurements). From the values of true and apparent power, you can determine reactive power and power factor. Let's do an example problem to see how this works: (Figure B.3.3.1)

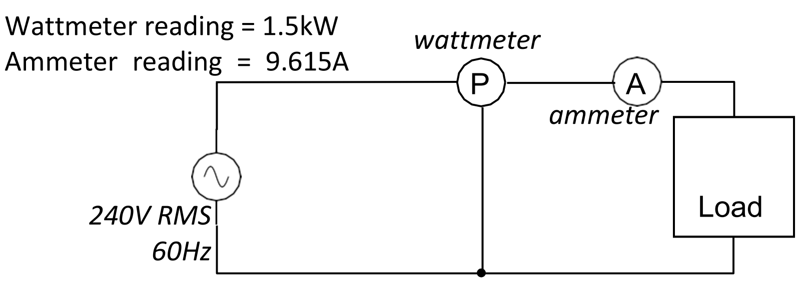


Figure B.3.3.1: Wattmeter reads true power, product of voltmeter and ammeter readings yields apparent power.

First, we need to calculate the apparent power in kVA. We can do this by multiplying load voltage by load current:

$S = I*E$

$S = (9.615A)*(240V)$, $S = 2.308$ kVA

As we can see, 2.308 kVA is a much larger figure than 1.5 kW, which tells us that the power factor in this circuit is rather poor (substantially less than 1). Now, we figure the power factor of this load by dividing the true power by the apparent power:

Power factor $=P/S$

Power factor = (1.5 kW)/2.308 kVA

Power factor =0.65

Using this value for power factor, we can draw a power triangle, and from that determine the reactive power of this load: (Figure B.3.3.2)

To determine the unknown (reactive power) triangle quantity, we use the Pythagorean Theorem “backwards,” given the length of the hypotenuse (apparent power) and the length of the adjacent side (true power):

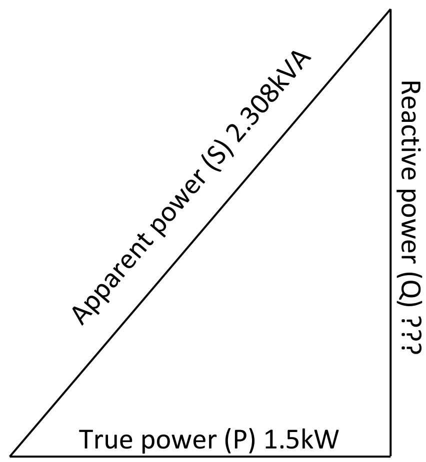


Figure B.3.3.2: Reactive power may be calculated from true power and apparent power.

$$\text{Reactive power} = \sqrt{(\text{Apparent power})^2 - (\text{True power})^2}$$

Q = 1.754 kVAR

If this load is an electric motor, or most any other industrial AC load, it will have a lagging (inductive) power factor, which means that we'll have to correct for it with a *capacitor* of appropriate size, wired in parallel. Now that we know the amount of reactive power (1.754 kVAR), we can calculate the size of capacitor needed to counteract its effects:

$Q = E^2/ X$

. . . solving for X . . .

$X = E^2/ Q$ where

$X_C = 1/ 2\pi fC$

$X = 240^2 / 1.754$ kVAR

. . . solving for C . . .

$X = 32.845\Omega$

$C = 1/ 2\pi fX$

$C = 80.761\mu F$ (*@60Hz, @32.845Ω*)

Rounding this answer off to 80 μF, we can place that size of capacitor in the circuit and calculate the results: (*Figure B.3.3.3)*

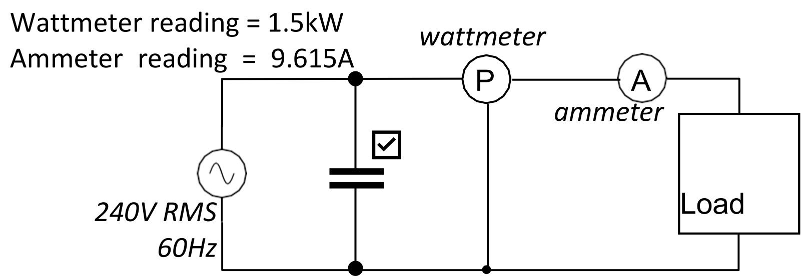


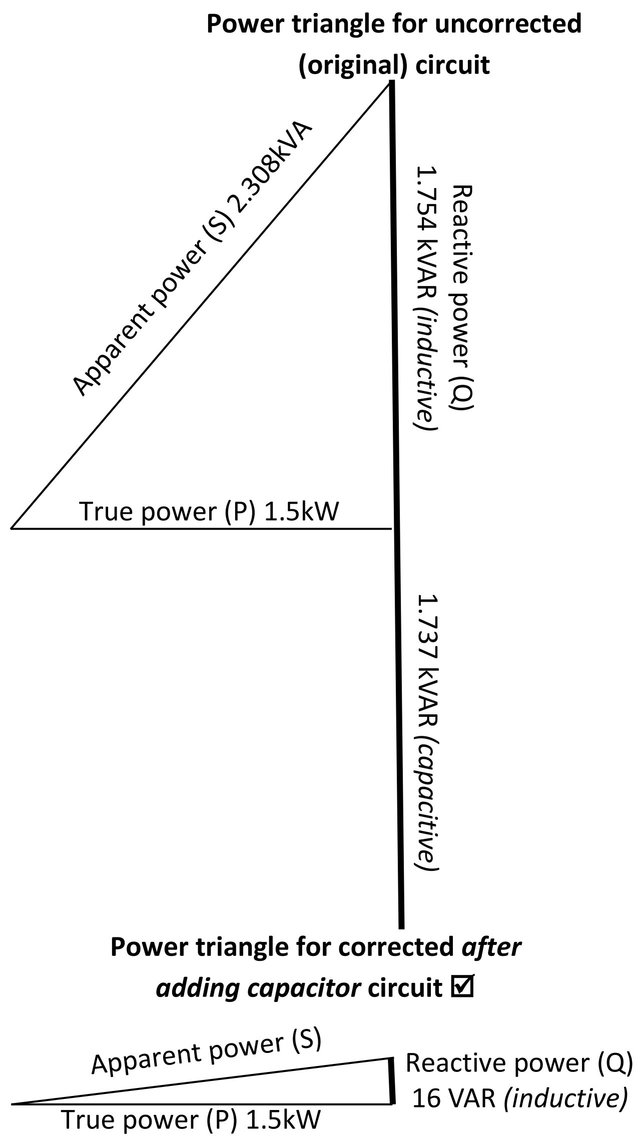
Figure B.3.3.3: Parallel capacitor corrects lagging (inductive) load.

An 80 μF capacitor will have a capacitive reactance of 33.157 Ω, giving a current of 7.238 amps, and a corresponding reactive power of 1.737 kVAR (for the capacitor *only*). Since the capacitor's current is 180° out of phase from the the load's inductive contribution to current draw, the capacitor's reactive power will directly subtract from the load's reactive power, resulting in:

Inductive kVAR - Capacitive kVAR = Total kVAR

1.754 kVAR - 1.737 kVAR = 16.519 VAR

This correction, of course, will not change the amount of true power consumed by the load, but it will result in a substantial reduction of apparent power, and of the total current drawn from the 240 Volt source*: (Figure B.3.3.4)*



Reactive power (Q)

16.519 VAR

Figure B.3.3.4: Power triangle before and after capacitor correction.

The new apparent power can be found from the true and new reactive power values, using the standard form of the Pythagorean Theorem:Type equation here.

Apparent power = √ (Reactive power)^2 - (True power)^2

Apparent power = 1.50009 kVA

This gives a corrected power factor of (1.5kW / 1.5009 kVA), or 0.99994, and a new total current of (1.50009 kVA / 240 Volts), or 6.25 amps, a substantial improvement over the uncorrected value of 9.615 amps! This lower total current will translate to less heat losses in the circuit wiring, meaning greater system efficiency (less power wasted).

Exam Questions. Basic electricity worksheet

References

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[2.] LTspice Tutorial ONLINE. **http://ltwiki.org/index.php?title=SPICE_and_LTspice_Courseware_and_Tutorials**

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[4.] Valeri MLADENOV, S. VLADOV, "ELECTRICAL ENGINEERING", ISBN: 978-954-9518-78-8

[5.] Ali Sheikholeslami, "ECE354: Electronic Circuits", Department of Electrical and Computer Engineering, University of Toronto

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Basic electricity worksheet. Sample.

Basic electricity worksheet

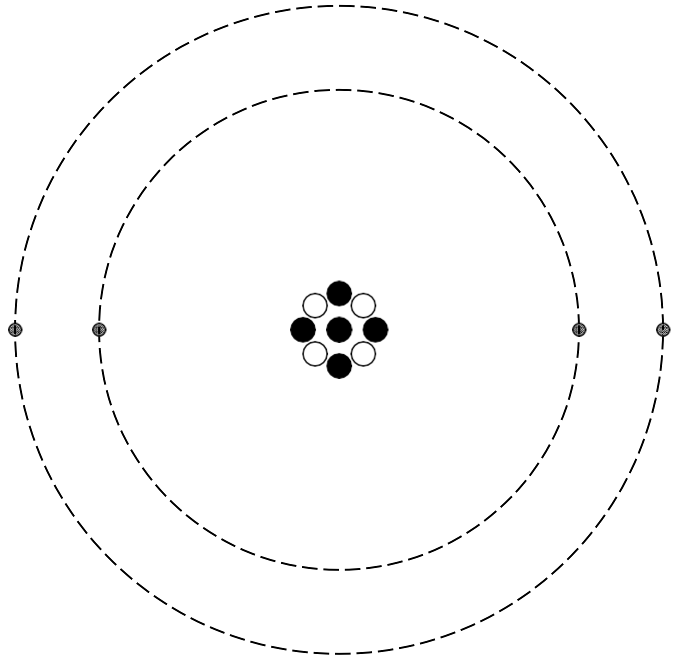
This worksheet covers the following concepts:

- Atomic structure.
- Basic electrical terms: *charge*, *voltage*, *current*, and *resistance*.
- Conductors and insulators.
- Direct current versus alternating current.
- Sources of electrical power.
- Very simple circuits.
- Determining electrical conductivity and continuity.
- Electrical schematic diagrams and component symbols.
- Switches.
- *Ground* connections in a circuit.
- Short circuits.
- Electromagnetism and electromagnetic induction.

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

Question 1

Shown here is a simplified representation of an *atom*: the smallest division of matter that may be isolated through physical or chemical methods.



Inside of each atom are several smaller bits of matter called *particles*. Identify the three different types of "elementary" particles inside an atom, their electrical properties, and their respective locations within the atom.

file 00110

Question 2

Different types of atoms are distinguished by different numbers of elementary particles within them. Determine the numbers of elementary particles within each of these types of atoms:

- Carbon
- Hydrogen
- Helium
- Aluminum

Hint: look up each of these elements on a *periodic table*. file 00111

Question

Of the three types of "elementary particles" constituting atoms, determine which type(s) influence the following properties of an element:

- The chemical identity of the atoms (whether it is an atom of *nitrogen*, *iron*, *silver*, or some other element).
- The mass of the atom.
- The electrical charge of the atom.
- Whether or not it is radioactive (spontaneous disintegration of the nucleus).

file 00112

Question 4

The Greek word for *amber* (fossilized resin) is *elektron*. Explain how this came to be the word describing a certain type of subatomic particle (electron).
file 00009

Question 5

What does it mean for an object to have an electric *charge*? Give an example of an object receiving an electric charge, and describe how that charged object might behave.
file 00044

Question 6

How many electrons are contained in one *coulomb* of charge?
file 00010

Question 7

What is happening when two objects are rubbed together and static electricity results?
file 00071

Question 8

It is much easier to electrically "charge" an atom than it is to alter its chemical identity (say, from lead into gold). What does this fact indicate about the relative mobility of the elementary particles within an atom?
file 00113

Question 9

Explain what the electrical terms *voltage*, *current*, and *resistance* mean, using your own words.
file 00008

Question 10

Describe what "electricity" is, in your own words.
file 00114

Question 11

What is the difference between materials classified as *conductors* versus those classified as *insulators*, in the electrical sense of these words?
file 00072

Question

Identify several substances that are good conductors of electricity, and several substances that are good insulators of electricity.

file 00073

Question 13

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

file 00017

Question 14

What is the difference between *DC* and *AC* electricity? Identify some common sources of each type of electricity.

file 00028

Question 15

Suppose you are building a cabin far away from electric power service, but you desire to have electricity available to energize light bulbs, a radio, a computer, and other useful devices. Determine at least three different ways you could generate electrical power to supply the electric power needs at this cabin.

file 00003

Question 16

Where does the electricity come from that powers your home, or your school, or the streetlights along roads, or the many business establishments in your city? You will find that there are many different sources and types of sources of electrical power. In each case, try to determine where the *ultimate* source of that energy is.

For example, in a hydroelectric dam, the electricity is generated when falling water spins a turbine, which turns an electromechanical generator. But what continually drives the water to its "uphill" location so that the process is continuous? What is the *ultimate* source of energy that is being harnessed by the dam?

file 00024

Question 17

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 18

Draw an electrical schematic diagram of a circuit where a battery provides electrical energy to a light bulb.

file 00007

Question

Most electrical wire is covered in a rubber or plastic coating called *insulation*. What is the purpose of having this "insulation" covering the metal wire?

file 00018

Question 20

In the early days of electrical wiring, wires used to be insulated with *cotton*. This is no longer accepted practice. Explain why.

file 00019

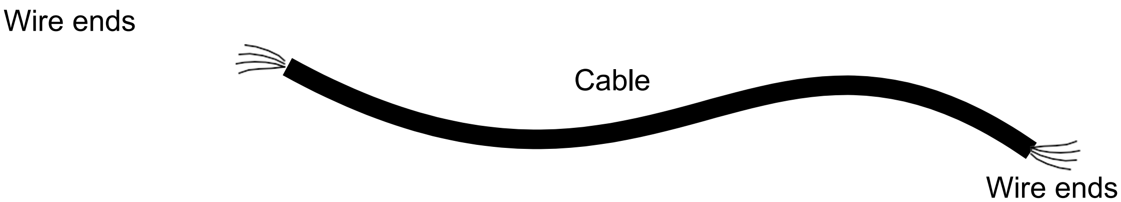
Question 21

How could a battery, a light bulb, and some lengths of metal wire be used as a *conductivity tester*, to test the ability of different objects to conduct electricity?

file 00011

Question 22

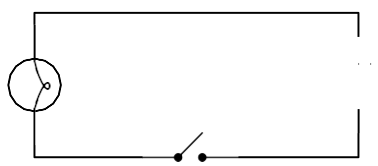
Suppose we had a long length of electrical *cable* (flexible tubing containing multiple wires) that we suspected had some broken wires in it. Design a simple testing circuit that could be used to check each of the cable's wires individually.



file 00012

Question 23

What is the purpose of the *switch* shown in this schematic diagram?

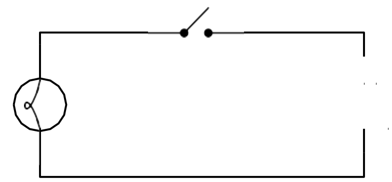


file 00013

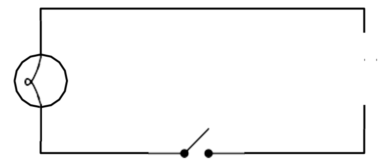
Question

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



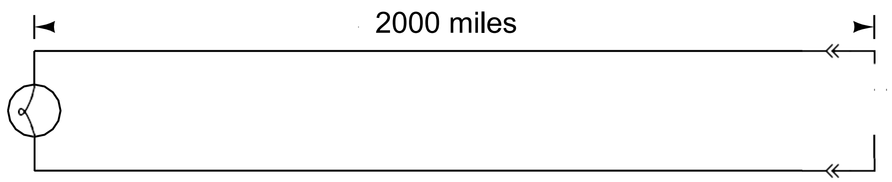
Switch on positive side of circuit



file 00014

Question 25

How long will it take for the light bulb to receive electrical power once the battery is connected to the rest of the circuit?



file 00116

Question 26

A 22-gauge metal wire three feet in length contains approximately 28.96×10^{21} "free" electrons within its volume. Suppose this wire is placed in an electric circuit conducting a current equal to 6.25×10^{18} electrons per second. That is, if you were able to choose a spot along the length of this wire and were able to count electrons as they drifted by that spot, you would tally 6,250,000,000,000,000,000 electrons passing by each second. (This is a reasonable rate for electric current in a wire of this size.)
Calculate the average velocity of electrons through this wire. file 00117

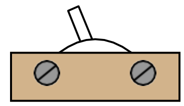
Question 27

Does this switch (in the closed state) have a low resistance or a high resistance between its terminals?

file 00027

Question

How might you use a meter (or a conductivity/continuity tester) to determine whether this electrical switch is in the *open* or *closed* state?



file 00065

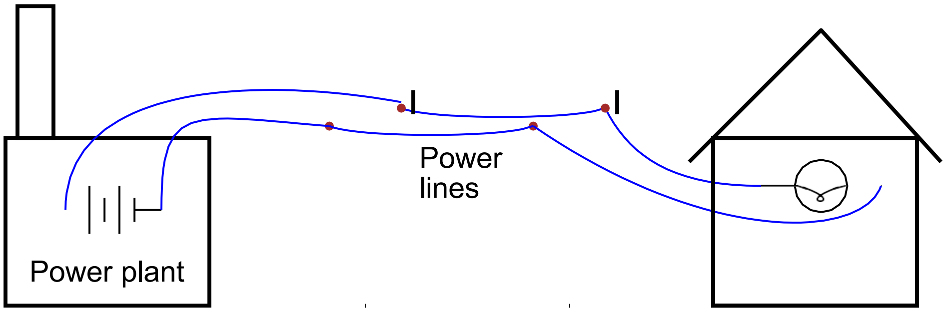
Question 29

What do the symbols with the question marks next to them refer to? In the circuit shown, would the light bulb be energized?

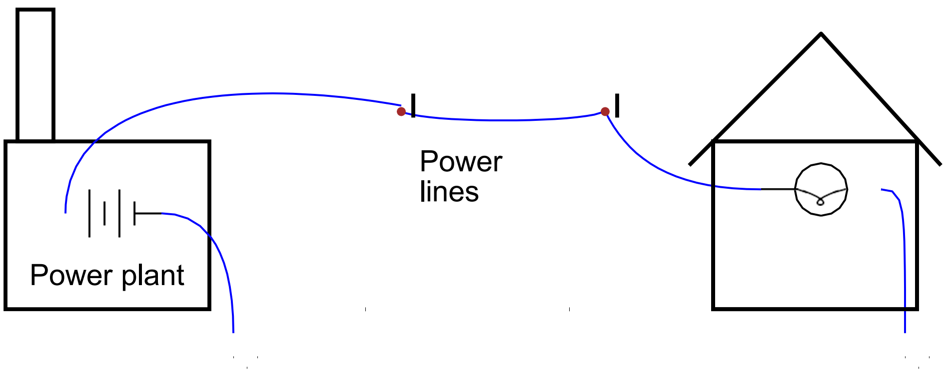
file 00022

Question

Shown here is a simplified representation of an electrical power plant and a house, with the source of electricity shown as a battery, and the only electrical "load" in the house being a single light bulb:



Why would anyone use two wires to conduct electricity from a power plant to a house, as shown, when they could simply use one wire and a pair of *ground* connections, like this?



file 00075

Question 31

What, exactly, is a *short circuit*? What does it mean if a circuit becomes *shorted*? How does this differ from an *open* circuit?

file 00026

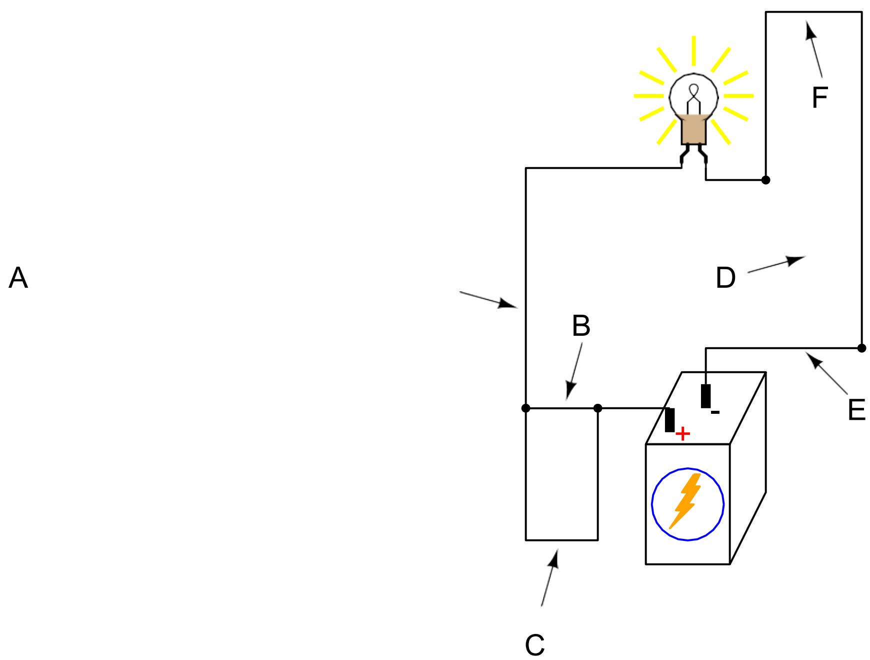
Question 32

What would have to happen in this circuit for it to become *shorted*? In other words, determine how to make a *short circuit* using the components shown here:

file 00074

Question

Determine if the light bulb will de-energize for each of the following breaks in the circuit. Consider just one break at a time:



- Choose one option for each point:
- A: de-energize / no effect
- B: de-energize / no effect
- C: de-energize / no effect
- D: de-energize / no effect
- E: de-energize / no effect
- F: de-energize / no effect

file 00002

Question 34

When lightning strikes, nearby magnetic compass needles may be seen to jerk in response to the electrical discharge. No compass needle deflection results during the accumulation of electrostatic charge preceding the lightning bolt, but only when the bolt actually strikes. What does this phenomenon indicate about voltage, current, and magnetism?

file 00077

Question 35

Just as electricity may be harnessed to produce magnetism, magnetism may also be harnessed to produce electricity. The latter process is known as *electromagnetic induction*. Design a simple experiment to explore the phenomenon of electromagnetic induction.

file 00078

Question

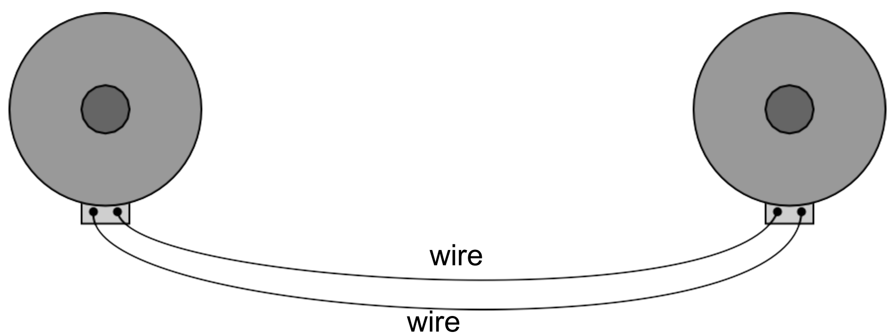
A large audio speaker may serve to demonstrate both the principles of *electromagnetism* and of *electromagnetic induction*. Explain how this may be done.

file 00079

Question 37

What do you think might happen if someone were to gently tap on the cone of one of these speakers? What would the other speaker do? In terms of electromagnetism and electromagnetic induction, explain what is happening.

Speaker #1 Speaker #2

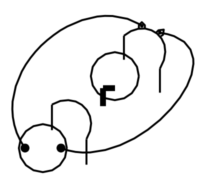


file 00080

Question 38

Suppose someone mechanically couples an electric motor to an electric generator, then electrically couples the two devices together in an effort to make a perpetual-motion machine:

Motor

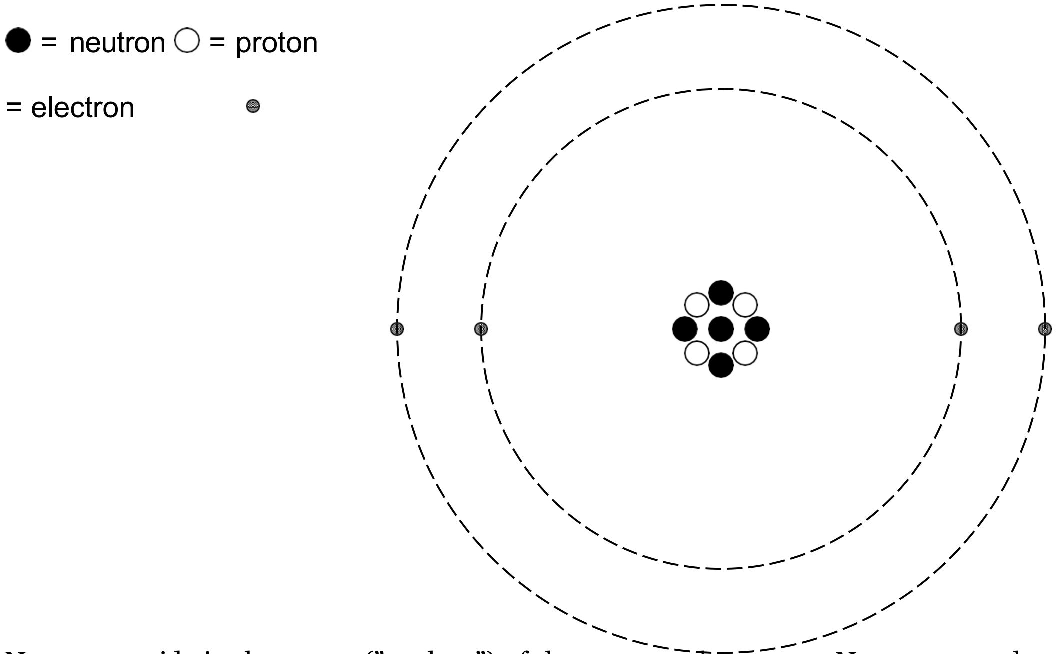


Generator

Why won't this assembly spin forever, once started?

file 00041

Answer 1



Neutrons reside in the center ("nucleus") of the atom, as do protons. Neutrons are electrically neutral (no charge), while protons have a positive electrical charge. Electrons, which reside outside the nucleus, have negative electrical charges.

Answer 2

Each atom of carbon is guaranteed to contain 6 protons. Unless the atom is electrically charged, it will contain 6 electrons as well to balance the charge of the protons. Most carbon atoms contain 6 neutrons, but some may contain more or less than 6.

Each atom of hydrogen is guaranteed to contain 1 proton. Unless the atom is electrically charged, it will contain 1 electron as well to balance the charge of the one proton. Most hydrogen atoms contain no neutrons, but some contain either one or two neutrons.

Each atom of helium is guaranteed to contain 2 protons. Unless the atom is electrically charged, it will contain 2 electrons as well to balance the charge of the protons. Most helium atoms contain 2 neutrons, but some may contain more or less than 2.

Each atom of aluminum is guaranteed to contain 13 protons. Unless the atom is electrically charged, it will contain 13 electrons as well to balance the charge of the protons. Most aluminum atoms contain 14 neutrons, but some may contain more or less than 14.

While you're researching the numbers of particles inside each of these atom types, you may come across these terms: *atomic number* and *atomic mass* (sometimes called *atomic weight*). Be prepared to discuss what these two terms mean.

Answer

- The chemical identity of the atoms: protons.
- The mass of the atom: neutrons and protons, and to a much lesser extent, electrons.
- The electrical charge of the atom: electrons and protons (whether or not the numbers are equal).
- Whether or not it is radioactive: neutrons, although one might also say protons in some cases, as there are no known "stable" (non-radioactive) isotopes of certain elements, the identity of an element being determined strictly by the number of protons.

Answer 4

When a piece of amber is rubbed with a cloth, a static electric charge develops on both objects. Early experimenters postulated the existence of an invisible fluid that was transferred between the amber and the cloth. Later, it was discovered that tiny sub-atomic particles constituted this "fluid," and the name *electron* was given to them.

Answer 5

For an object to be electrically *charged*, it must have either a surplus or a deficit of electrons among its atoms. A common example of electrically charging objects is rubbing latex balloons against wool clothing, or brushing your hair with a plastic comb. The consequences of these electric charges are very easy to perceive!

Answer 6

There are 6.25×10^{18} electrons in one *coulomb* of charge. What would this appear as without the use of scientific notation? Write this same figure using the most appropriate metric prefix.

Answer 7

When certain combinations of materials are rubbed together, the rubbing action transfer electrons from the atoms of one material to the atoms of the other. This imbalance of electrons leaves the former material with a *positive* charge and the latter with a *negative* charge.

Answer 8

Electrons are much easier to remove from or add to an atom than protons are. The reason for this is also the solution to the paradox of why protons bind together tightly in the nucleus of an atom despite their identical electrical charges.

Answer 9

Voltage: electrical "pressure" between two different points or locations.
Current: the flow of electrons.
Resistance: opposition, or "friction," to the flow of electrons.

Answer 10

If you're having difficulty formulating a definition for "electricity," a simple definition of "electric current" will suffice. What I'm looking for here is a description of how an electric current may exist within a solid material such as a metal wire.

Answer 11

Electrical "conductors" offer easy passage of electric current through them, while electrical "insulators" do not. The fundamental difference between an electrical "conductor" and an electrical "insulator" is how readily electrons may drift away from their respective atoms.
For an illustration of electron mobility within a metallic substance, research the terms *electron gas* and *"sea of electrons"* in a chemistry reference book.

Answer

It is very easy to research (and test!) whether or not various substances are either conductors or insulators of electricity. I leave this task in your very capable hands.

Answer 13

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

Answer 14

DC is an acronym meaning *Direct Current*: that is, electrical current that moves in one direction only. *AC* is an acronym meaning *Alternating Current*: that is, electrical current that periodically reverses direction ("alternates").
Electrochemical batteries generate DC, as do solar cells. Microphones generate AC when sensing sound waves (vibrations of air molecules). There are many, many other sources of DC and AC electricity than what I have mentioned here!

Answer 15

There are several different devices capable of producing electrical power for this cabin of yours:

- Engine-driven generator
- Solar cell
- Thermopile
- Windmill

For each of these devices, what is its operating principle, and where does it obtain its energy from?

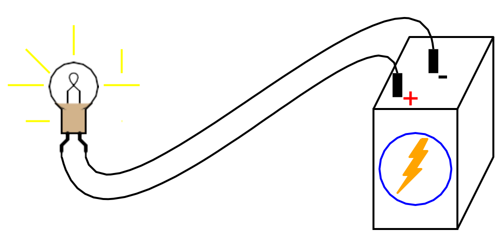
Answer 16

Some sources of electrical power:

- Hydroelectric dams
- Nuclear power plants
- Coal and oil fired power plants
- Natural gas fired power plants
- Wood fired power plants
- Geothermal power plants
- Solar power plants
- Tidal/wave power plants
- Windmills

Answer 17

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



Answer

This schematic diagram is not the only valid way to show a battery powering a light bulb:

Other orientations of the components within the diagram are permissible. What matters, though, is for there to be a single, continuous path for electric current from the battery, to the light bulb, and back to the other terminal of the battery.

Answer 19

The purpose of *insulation* covering the metal part of an electrical wire is to prevent accidental contact with other conductors of electricity, which might result in an unintentional electric current through those other conductors.

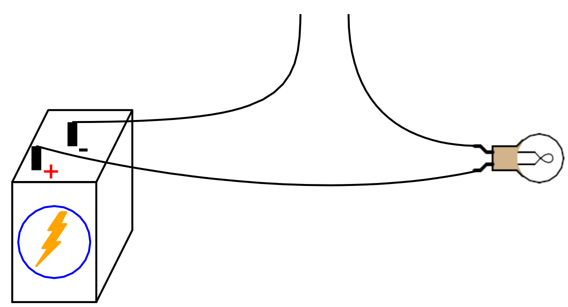
Answer 20

Cotton, like many natural fibers, is an electrical insulator . . . until it becomes wet!

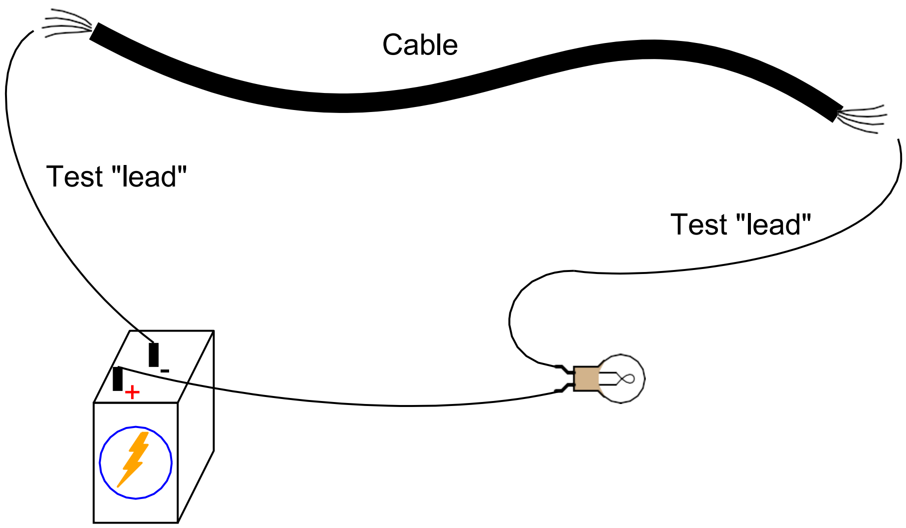
Answer 21

The following circuit would function as a simple continuity tester. Simply place the open wire ends in contact with the object to be tested, and the light bulb will indicate whether or not the object conducts electricity to any substantial degree:

Touch the wire ends to a substance to check for electrical conductivity



Answer



Answer 23

This device is known as a *switch*, and its purpose in this circuit is to establish or interrupt the electrical continuity of the circuit in order to control the light bulb.

Answer 24

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 25

Approximately 11 milliseconds (0.0107 seconds).

Answer 26

Average electron velocity = 0.000647 feet per second, or 6.47×10^{-4} ft/s. This is very slow: only 0.00777 inches per second, or 0.197 millimeters per second!

Answer 27

A closed switch is supposed to have *low* resistance between its terminals.

Answer 28

Most multimeters have a "resistance" measurement range ("Ohms scale") that may be used to check continuity. Either using a meter or a conductivity/continuity tester, measure between the two screw terminals of this switch: if the resistance is low (good conductivity), then the switch is *closed*. If the measured resistance is infinite (no conductivity), then the switch is *open*.

Answer 29

These are *ground* symbols, and they can either refer to connections made to a common conductor (such as the metal chassis of an automobile or circuit enclosure), or the actual earth (usually via metal rods driven into the dirt).

Answer

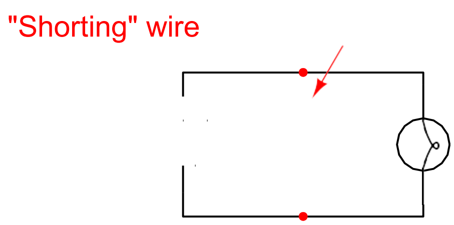
This is not a practical solution, even though it would only require half the number of wires to distribute electrical power from the power plant to each house! The reason this is not practical is because the earth (dirt) is not a good enough conductor of electricity. Wires made of metal conduct electricity far more efficiently, which results in more electrical power delivered to the end user.

Answer 31

A *short circuit* is a circuit having very little resistance, permitting large amounts of current. If a circuit becomes *shorted*, it means that a path for current formerly possessing substantial resistance has been bypassed by a path having negligible (almost zero) resistance.

Conversely, an *open circuit* is one where there is a break preventing any current from going through at all.

Answer 32



Answer 33

- A: de-energize
- B: no effect
- C: no effect
- D: no effect
- E: de-energize
- F: no effect

Answer 34

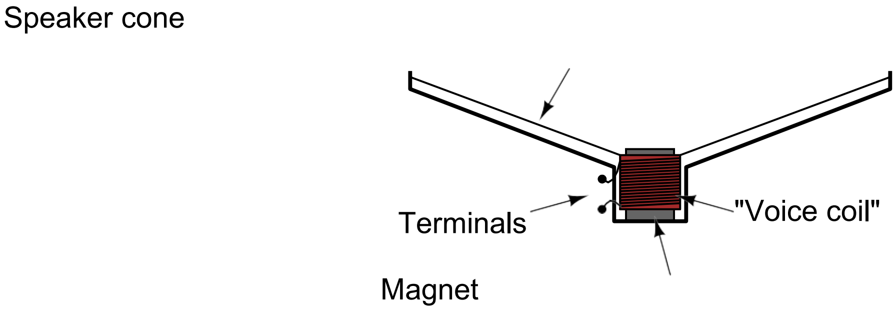
The presence of an electric current will produce a magnetic field, but the mere presence of a voltage will not. For more detail on the historical background of this scientific discovery, research the work of Hans Christian Oersted in the early 1820's.

Answer 35

Perhaps the easiest way to demonstrate electromagnetic induction is to build a simple circuit formed from a coil of wire and a sensitive electrical meter (a digital meter is preferred for this experiment), then move a magnet past the wire coil. You should notice a direct correlation between the position of the magnet relative to the coil over time, and the amount of voltage or current indicated by the meter.

Answer

I won’t tell you how to set up or do the experiment, but I will show you an illustration of a typical audio speaker:



The ”voice coil” is attached to the flexible speaker cone, and is free to move along the long axis of the magnet. The magnet is stationary, being solidly anchored to the metal frame of the speaker, and is centered in the middle of the voice coil.
This experiment is most impressive when a physically large (i.e. ”woofer”) speaker is used.

Follow-up question: identify some possible points of failure in a speaker which would prevent it from operating properly.

Answer 37

Try this experiment yourself, using a long pair of wires to separate the two speakers from each other by a significant distance. Listen and feel the speaker on your end while someone else taps on the other speaker, then trade roles.

Answer 38

This will not work because neither the motor nor the generator is 100% efficient.

Notes 1

Most, if not all, students will be familiar with the "solar system" model of an atom, from primary and secondary science education. In reality, though, this model of atomic structure is not that accurate. As far as anyone knows, the actual physical layout of an atom is much, much weirder than this!

A question that might come up in discussion is the definition of "charge." I'm not sure if it is possible to fundamentally define what "charge" is. Of course, we may discuss "positive" and "negative" charges in operational terms: that like charges repel and opposite charges attract. However, this does not really tell us *what* charge actually is. This philosophical quandary is common in science: to be able to describe what something is in terms of its behavior but not its identity or nature.

Notes 2

Be sure to ask your students what definitions they found for "atomic number" and "atomic mass".

It is highly recommended that students seek out periodic tables to help them with their research on this question. The ordering of elements on a periodic table may provoke a few additional questions such as, "Why are the different elements arranged like this?" This may build to a very interesting discussion on basic chemistry, so be prepared to engage in such an interaction on these subjects if necessary.

Notes 3

It never ceases to fascinate me how many of the basic properties of elements is determined by a simple integer count of particles within each atom's nucleus.

In the answer, I introduce the word *isotope*. Let students research what this term means. Don't simply tell them!

Notes 4

This question provides a good opportunity to discuss the history of electricity, and how its understanding and mastery has dramatically changed peoples' lives. Be sure to ask questions about Benjamin Franklin and the modeling of electricity as a *fluid*. Scientific discovery is often assisted by models, but may also be hindered by them as well. Franklin's model of electricity as a fluid has done both (conventional versus electron flow notation)!

Notes 5

This question naturally leads to a discussion on atomic theory. Encourage your students to discuss and explore simple models of the atom, and how they serve to explain electricity in terms of electron placement and motion.

Notes 6

A little math review here: using scientific notation to denote very large (or very small) numbers.

Notes 7

The terms "positive" and "negative" seem backward in relation to the modern concept of electrons as charge carriers. Be sure to discuss the historical aspect of this terminology (Benjamin Franklin's conjecture), and the subsequent designation of an electron's individual charge as "negative."

Notes 8

Discuss with your students the importance of this fact: that electrons may be added to or taken from an atom rather easily, but that protons (and neutrons for that matter) are very tightly "bound" within an atom. What might atoms behave like if their protons were not so tightly bound as they are?

We know what happens to the electrons of some atoms when substances are rubbed together. What might happen to those substances if protons were not as tightly bound together as they are?

Notes

While it is easy enough for students to look up definitions for these words from any number of references, it is important that they be able to cast them into their own words. Remembering a definition is not the same as really understanding it, and if a student is unable to describe the meaning of a term using their own words then they definitely do not understand it! It is also helpful to encourage students to give real-life examples of these terms.

Notes 10

This question is not as easy to answer as it may first appear. Certainly, electric current is defined as the "flow" of electrons, but how do electrons "flow" through a solid material such as copper? How does *anything* flow through a solid material, for that matter?

Many scientific disciplines challenge our "common sense" ideas of reality, including the seemingly solid nature of certain substances. One of the liberating aspects of scientific investigation is that it frees us from the limitations of direct sense perception. Through structured experimentation and rigorous thinking, we are able to "see" things that might otherwise be impossible to see. We certainly cannot see electrons with our eyes, but we can detect their presence with special equipment, measure their motion by inference from other effects, and prove empirically that they do in fact exist.

In this regard, scientific method is a tool for the expansion of human ability. Your students will begin to experience the thrill of "working with the invisible" as they explore electricity and electric circuits. It is your task as an instructor to foster and encourage this sense of wonder in your students' work.

Notes 11

It is important to realize that electrical "conductors" and "insulators" are not the same as thermal "conductors" and "insulators." Materials that are insulators in the electrical sense may be fair conductors of heat (certain silicone gels used as heat-transfer fluids for heat sinks, for instance). Materials that are conductors in the electrical sense may be fair insulators in the thermal sense (conductive plastics, for example).

Notes 12

If students have access to simple multimeters, they may perform conductivity tests on various substances with them. This is a fun and interesting classroom activity!

Notes 13

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 14

Discuss a bit of the history of AC versus DC in early power systems. In the early days of electric power in the United States of America, there was a heated debate between the use of DC versus AC. Thomas Edison championed DC, while George Westinghouse and Nikola Tesla advocated AC.

It might be worthwhile to mention that almost all the electric power in the world is generated and distributed as AC (Alternating Current), and not as DC (in other words, Thomas Edison lost the AC/DC battle!). Depending on the level of the class you are teaching, this may or may not be a good time to explain *why* most power systems use AC. Either way, your students will probably ask why, so you should be prepared to address this question in some way (or have them report any findings of their own!).

Notes

For each of these electric power ”sources,” there is a more fundamental source of energy. People often mistakenly think of generator devices as magic sources of energy, where they are really nothing more than energy *converters*: transforming energy from one form to another.

Notes 16

A great point of conversation here is that almost all ”sources” of energy have a common origin. The different ”sources” are merely variant expressions of the same true source (with exceptions, of course!).

Notes 17

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 18

Impress upon the students the importance of learning to ”communicate” in the language of schematic diagrams. The symbols and conventions learned here are international, and not limited to use in the United States.

Notes 19

Not only is this question practical from the standpoint of understanding circuit function, but also from the perspective of electrical safety. Why is it important for wires to be insulated? Are overhead power lines insulated like the wires used in classroom projects? Why or why not? How were electrical wires insulated before the advent of modern plastics technology?

Notes 20

This question affords the opportunity to discuss electrical safety with regard to clothing (often made of cotton). Does dry clothing offer insulation to electricity like the old-style cotton wire insulation? Can cotton clothing be trusted to insulate you safely from hazardous voltage?

Notes 21

Not only is this question an opportunity to solve a problem, but it lends itself well to simple and safe experimentation. Encourage students to build their own conductivity testers and test various substances with them.

Notes 22

A significant portion of electrical/electronic circuit problems are caused by nothing more complex than broken wire connections, or faults along the length of wires. Testing cables for wire breaks is a very practical exercise. The same technique may be used to ”map” wires from one end of a cable to the other, in the event that the wires are not color-coded or otherwise made identifiable.

Notes

Beginning students often find the terminology for switches confusing, because the words *open* and *closed* sound similar to the terminology used for doors, but do not mean quite the same thing when used in reference to a switch! In order to help avoid confusion, ask the students how they may think of these terms in a way that is consistent with their meaning in the context of an electrical switch.

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 24

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 25

Electricity is fast: the effects of electron motion travel at approximately the speed of light (186,000 miles per second). Actual average electron velocity, on the other hand, is very, very slow. A convenient analogy I've used to illustrate how electrons may move slowly yet have rapid effect is that of a closed-loop hydraulic system. When the valve is opened, fluid motion throughout the system is immediate (actually, the motion progresses at the speed of sound through the fluid – very fast!), yet the actual velocity of fluid motion is much slower.

Incidentally, the double-chevron symbols indicate an electrical connector pair (plug and jack; male and female).

Notes

Despite the rapid progression of the *effects* of electron motion throughout a circuit (i.e. approximately the speed of light), the actual electron velocity is extremely slow by comparison.
Base figures used in this calculation are as follows:

- Number of free electrons per cubic meter of metal (an example taken from Encyclopedia Brittanica 15th edition, 1983, volume 6, page 551) = 10^{29} electrons per m^3. The metal type was not specified.
- 22 gauge wire has a diameter of 0.025 inches.

Questions like this may be challenging to students without a strong math or science background. One problem-solving strategy I have found very useful is to simplify the terms of a problem until a solution becomes obvious, then use that simplified example to establish a pattern (equation) for obtaining a solution given *any* initial parameters. For instance, what would be the average electron velocity if the current were 28.96×10^{21} electrons per second, the same figure as the number of free electrons residing in the wire? Obviously, the flow velocity would be one wire length per second, or 3 feet per second. Now, alter the current rate so that it is something closer to the one given in the problem (6.25×10^{18}), but yet still simple enough to calculate mentally. Say, half the first rate: 14.48×10^{21} electrons per second. Obviously, with a flow rate half as much, the velocity will be half as well: 1.5 feet per second instead of 3 feet per second. A few iterations of this technique should reveal a pattern for solution:

$$v = 3\frac{I}{Q}$$

Where,
v = Average electron velocity (feet per second)
I = Electric current (electrons per second)
Q = Number of electrons contained in wire

It is also very helpful to have knowledgeable students demonstrate their solution techniques in front of the class so that others may learn novel methods of problem-solving.

Notes 27

Ask the students what it would mean if a closed switch actually measured having high resistance between its terminals. Knowing what the measurements of any electrical component *ought to be* is a very important skill for troubleshooting.

Notes 28

This is another question which lends itself well to experimentation. A vitally important skill for students to develop is how to use their test equipment to diagnose the states of individual components.
An inexpensive source of simple (SPST) switches is a hardware store: use the same type of switch that is used in household light control. These switches are very inexpensive, rugged, and come with heavy- duty screw terminals for wire attachment. When used in small battery-powered projects, they are nearly indestructible!

Notes 29

Ask the students about the relative conductivities of metal chassis versus dirt (earth ground). Is a current pathway formed by two metal chassis grounds equivalent to a current pathway formed by two earth grounds? Why or why not? What conditions may affect these relative conductivities?

Notes 30

Discuss the fact that although the earth (dirt) is a poor conductor of electricity, it may still be able to conduct levels of current lethal to the human body! The amount of current necessary to light up a household light bulb is typically far in excess of values lethal for the human body.

Notes 31

Discuss with your students some of the potential hazards of short circuits. It will then be apparent why a "short circuit" is a bad thing. Ask students if they can think of any realistic circumstance that could lead to a short-circuit developing.

I have noticed over several years of teaching electronics that the terms "short" or "short-circuit" are often used by new students as generic labels for *any* type of circuit fault, rather than the specific condition just described. This is a habit that must be corrected, if students are to communicate intelligently with others in the profession. To say that a component "is shorted" means a very definite thing: it is not a generic term for any type of circuit fault.

Notes 32

In real life, of course, short circuits are usually things to be avoided. Discuss with your students *why* short circuits are generally undesirable, and what role wire insulation plays in preventing them.

Notes 33

This question is an important one in the students' process of learning troubleshooting. Emphasize the importance of inductive thinking: deriving general principles from specific instances. What does the behavior of this circuit tell us about *electrical continuity*?

Notes 34

The discovery of electromagnetism was nothing short of revolutionary in Oersted's time. It paved the way for the development of electric motors, among other useful electrical devices.

Notes 35

Many students improperly assume that electromagnetic induction may take place in the presence of *static* magnetic fields. This is not true. The simple experimental setup described in the "Answer" section for this question is sufficient to dispel that myth, and to illuminate students' understanding of this principle. Incidentally, this activity is a great way to get students started thinking in calculus terms: relating one variable to the *rate of change over time* of another variable.

Notes 36

Since not everyone has ready access to a large speaker for this kind of experiment, it may help to have one or two "woofer" speakers located in the classroom for students to experiment with during this phase of the discussion. Any time you can encourage students to set up impromptu experiments in class for the purpose of exploring fundamental principles, it is a Good Thing.

Notes 37

Not only does this experiment illustrate the dual principles of electromagnetism and electromagnetic induction, but it also demonstrates how easy it is to set up a simple sound-powered audio telephony system. It is highly recommended to have an identical pair of "woofer" speakers located in the classroom for this experiment, as well as a long length of twin-wire cable (an old piece of extension cord wire works well for this purpose, with alligator-clip "jumper" wires to make the connections).

The easy answer to this question is ”the Law of Conservation of Energy (or the Second Law of Thermodynamics) forbids it,” but citing such a ”Law” really doesn’t explain *why* perpetual motion machines are doomed to failure. It is important for students to realize that reality is not *bound* to the physical ”Laws” scientists set; rather, what we call ”Laws” are actually just *descriptions* of regularities seen in nature. It is important to emphasize critical thinking in a question like this, for it is no more intellectually mature to deny the possibility of an event based on dogmatic adherence to a Law than it is to naively believe that anything is possible.

Notes