Lesson Answer Keys

Lesson 3
Your First Circuit

This exercise provides consistent results regardless of the actual voltage put to the circuit. Why is the voltage from a power source that says "9 volts" not exactly 9 volts?

A. Reasons for the difference if you are using a battery.

- A new alkaline battery will give a different value than a new "general-purpose" battery.

- The general-purpose battery has a shelf life of six to eight months. It loses voltage as it sits on the shelf.

- An alkaline battery has a shelf life of over two years. During that time, the voltage remains very high.

B. Reasons for the difference if you are using a wall adapter.

- If it is a "regulated" power supply, it will provide 9 volts almost exactly.

- If it is an "unregulated" wall adapter, it will provide between 9 volts and nearly 13 volts, depending on the amount of strain put on it.

4. A new 9-volt battery will provide between 9.3 volts and 9.6 volts. If the voltage is below 5 volts, get a fresh battery.

5. The voltage used across the diode from TP-A to TP-B should be .7 volts to .8 volts. The voltage used across the LED (TP-C to TP-D) should be between 1.9 volts and 2.3 volts. The differences of voltage across the LED can be caused by:

- The color of the LED

- The brightness of the LED

- The size of the LED

   Add voltages of 6, 7, and 8 together. Compare them to the original battery voltage. They should be very close.

Lesson 4
Reading Resistors

Remember to look at the corner of your auto-ranging multimeter's readout for the different letters. "k" represents 1,000 and "M" represents 1,000,000.

1. You need to measure your own resistors. Then check to see if they are within 5 percent of the marked value.

2. A resistor marked brown-black-red-gold can have a maximum value of 1,050 ohms and minimum of 950 ohms.

3. Everyone will have different readings, but they should be between 100k ohms and 1M ohms. Why would the resistance decrease when you are asked an embarrassing question? Extra sweat! The salts let the electrons move more easily.

4. (a) 10k ohms = 10,000 ohms (b) 1k ohms = 1,000 ohms (c) .47k ohms = 470 ohms (d) 47k ohms = 47,000 ohms

Lesson 5
The Effect Resistors Have on a Circuit

These values represent my own measurements using stable 9.0 volts.

Your answers should follow a similar pattern, but the voltages will be different, depending on the strength of your battery. See Table A1-1.

Lesson 6
The Potentiometer

3. Results here will vary from pencil to pencil, person to person.

   a. About 100,000 ohms

   b. Measurement changes proportionate to distance

4. Outer legs. This will change proportionately to how much you move the knob. The tolerance on carbon ring potentiometers is normally 20 percent, so the measurement could be as high as 120,000 ohms (120k ohms) or as low as 80,000 ohms (80k ohms).

   a. The measurement between the two outer legs will be between 85k ohms and 115k ohms.

   b. This measurement will not change as you adjust the knob.

   c. Should be about half the measurement between the outer legs.

   d. Yes, it will change in direct proportion to the amount you have moved the knob.

      Less distance means less carbon clay mixture. Less carbon clay mixture means less resistance.

6. The same is occurring here as what was charted in Table L5-1.

7. If the potentiometer's resistance is set to zero ohms, there would be nothing to eat the extra voltage. The LED would be hit with much more voltage than it could handle and would burn out.

TABLE A1-1	This Relates to Table L5-1			
Resistance	V_{total}	V_{drop} Across Resistor	V_{drop} Across LED	Relative Brightness
100 ohm	9.00 v	5.8 v	3.20 v	Bright
470 ohm	9.00 v	6.85 v	2.15 v	Normal
2,200 ohm	9.00 v	7.08 v	1.92 v	Less
10,000 ohm	9.00 v	7.17 v	1.83 v	Dim
47,000 ohm	9.00 v	7.23 v	1.77 v	Dimmer
220,000 ohm	9.00 v	7.28 v	1.72 v	Barely on (view in closet)

Lesson 7
Light-Dependent Resistors

1. In the light, the LDR will have a resistance as low as 1,000 ohms.

2. A good dark lid will get the resistance of the LDR to at least 100,000 ohms. In a dark room, using a flashlight to see the multimeter readouts, it will easily pass 1,000,000 ohms.

3. These are the directions. And you should do them. Note that the darkness increases the resistance. The LED should become dimmer. The brighter the light, the easier it is for electrons to move. And the less resistance the LDR provides. Conversely, the less light (darker), the harder it is for electrons to move. The resistance has increased.

4. You would need direct sunlight to get the resistance of the LDR to even think of going below 400 ohms.

5. The brightest condition would mean that the LDR has the LEAST resistance. The LEAST resistance uses the LEAST voltage. The condition presented in "D" goes first. "C" is last because the LDR is using the most voltage. That coincides with the darkest condition that creates the most resistance.

Lesson 8
Capacitors and Push Buttons

2. Yes, you have to build it. When you push the plunger of the push button, the cap fills. Then when you disconnect from the voltage by releasing the plunger, the cap acts like a reservoir. What happens to the brightness of the LED as the cap drains? I can't tell you everything.

3. How to remove these without damaging the count?

   c. The cap should measure close to full voltage. The LED should light and go dim, just as if the push button had just been pushed and released.

4. The value of the capacitor relates directly to the amount of energy stored.

   a.

TABLE A1-2	Corresponds to Table L8-1
Capacitor Value	**Time**
1,000 μF	About five to six seconds
470 μF	Couple of seconds
100 μF	Less than a second
10 μF	Turns off softly
1 μF	Snaps off

   b. Less capacitance means less energy stored.

5. Capacitors store electrical potential (voltage and current).

6. The LED fades when you push and hold the plunger. Remember, the action of the PBNC is opposite that of the PBNO.

Lesson 9
Introducing Transistors

1. The transistor is the basic electronic switch.

2. Absolutely not. The TO-92 package is just a package. See Appendix A.

3. With the flat face towards you and legs down, left to right, Enjoy British Columbia. Whenever I think of this silly cue, it reminds me of Monty Python's Lumberjack Song (look up the reference).

4. For the TO-92 package, the center leg is the base.

5. a) Direction of the current flow, pointing towards ground. b) It is always drawn on the emitter side.

6. Read the number. If you really want to be impressed, this website cross-references 40,000 types of transistors: www.ee.washington.edu/circuit_archive/parts/cross.html and enter **2n3906**.

7. The pressure is in the system, whether the valve is on or off.

8. The capacitor is providing both voltage and current (power) to the transistor.

9. V+ to diode, to transistor (collector => emitter), to resistor, then LED.

10. You have got to do the work on this yourself.

    a. The answers will vary widely from one system to the next, depending on the voltage available.

    b. The 100 μF cap will hold the LED on 8 to 10 times longer than the 10 μF cap.

    c. The 1000 μF cap will hold the LED on nearly 10 times longer than the 100 μF cap.

11. Capacitor

Lesson 10
The PNP Transistor

1. The notation Q1 and Q2 is used in North America to represent Transistor 1 and Transistor 2.

2. Direction of current flow

3. Emitter

4. Ideally, the answer is that the LED would burn out. The reality is such that this transistor actually provides enough resistance to keep the LED from getting too much power.

5. Changing 10 μF to 100 μF

    a. Now it should be very close to 10 times longer.

    b. Ten times more capacitance will ideally hold the transistor's valving action 10 times longer.

6. Do it. The capacitor can't drain through the transistor but does drain through R1. Now it drains much slower.

7. b. Smaller size drain means water emplies slower. This slows total RC action.

8. Refer to Figure L12-7.

9. Refer to Figure L12-7.

Lesson 12
Your First Project: The Automatic Night Light

1. Think of water in a small creek. A flow of electrons is like the current of water. Water follows the easiest path downhill, the path of least resistance. Electrons do the same.

2. The voltage at the test point would be very close to zero volts because under good light, the LDR has very little resistance. So the current flows directly to ground.

3. Refer to Figure A1-1. The TP voltage would be close to V+. In good darkness, the LDR will have over 1M ohms. It's easier for the current to move through 22,000 ohms rather than 1,000,000 ohms. They move to the transistor.

6. The voltage at the test point will be very high. Done properly, it would be the same as measuring right at V+. Most of the current will move through the LDR, because it only has 1,000 ohms or less, compared to R1 at 22,000 ohms. The LEDs might even turn on a bit because (using the water analogy) some of the current is splashing through R1 and turning on Q1 a bit.
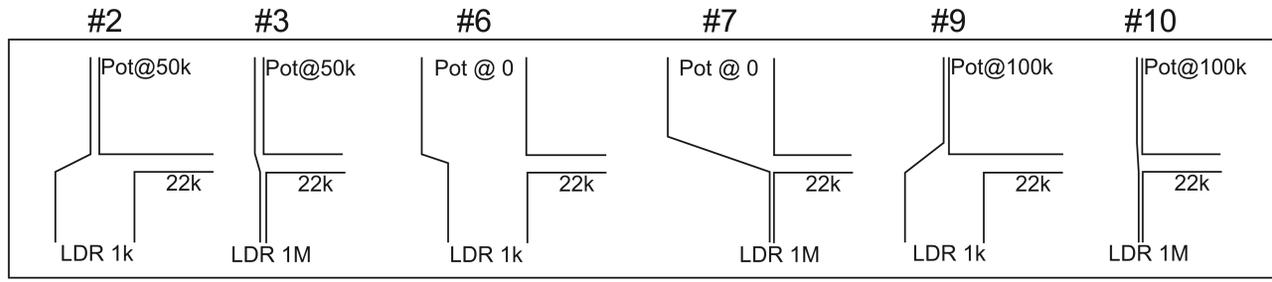
| #2 | #3 | #6 | #7 | #9 | #10 |

Figure A1-1

7. The voltage at the test point will be V+. The LEDs will turn on fully even in dim light. You will find it difficult to adjust them to an off setting even in dim light.

9. Your measurement at TP will be close to zero volts, because under good light, the LDR has very little resistance. It is so much easier for the current (electrons) to flow through 1,000 ohms than it is to move through 22,000 ohms. So most of the current flows directly to ground.

10. Your night light responds less quickly. The measurement at the test point will be less than your readings from #3, but still will be fairly close to V+. See Figure L12-7.

Lesson 13
Specialized Transistors: The SCR

1. False! Remember that transistors are widely available in many types of packages. See Appendix A. Each package represents a change in ability to handle different power requirements (Power = Current × Voltage).

2. All transistors are identified by code numbers. Basic transistor numbers begin with 2N–. Diode numbers all start with 1N–. SCRs used here are identified by the code C106.

3. To reset the SCR, all power has to be removed from the component.

4. V+, D1, R1, PBNC, ground

5. V+, D1, R1, D2, gate

6. Same as #4

7. V+, D1, R2, through closed PB contacts, gate

8. The foil tape is like the PBNC. The voltage follows the easiest path to ground, which is the path through the foil tape. If the foil breaks, the voltage takes the next easiest path and moves through D2. This triggers the G (gate) leg of the SCR.

9. Consider that if a door normally remains open, Figure A1-2 displays the type of device could you design to turn the alarm on when it closed.
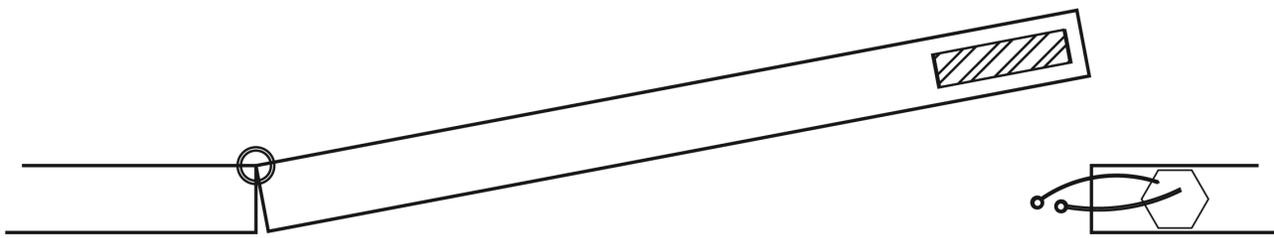

Figure A1-2

Lesson 15
A Spoiled Billionaire

Think about it. Sometimes it really is lots of work for digital to imitate what naturally happens in analog.

- $2^8 = 8$ bits per pixel, which allows for 256 colors available for each pixel.

- $2^{24} = 24$ bits per pixel. That allows each pixel to potentially be any of 16,777,216 colors.

- $2^{32} = 32$ bits per pixel. That allows for 4,294,967,296 colors available for each pixel.

1. Various answers and opinions.
2. Digital to Analog (Table A1-3)
3. Analog to Digital (Table A1-4)

TABLE A1-3	Digital Counting is a Fairly Simple Concept						
	64	**32**	**16**	**8**	**4**	**2**	**1**
1	O	1	O	1	1	O	O
128	0+	32+	0+	8+	4+	0+	0 = 172
O	1	1	O	O	1	1	O
O	64+	32+	0+	0+	4+	2+	0 = 102
1	O	O	1	O	O	1	1
128	0+	0+	16+	0+	0+	2+	1 = 147
O	O	1	1	O	O	O	1
O	0+	2+	16+	0+	0+	0+	1 = 49

TABLE A1-4	If the Next Power of 2 Can Be Subtracted, Add the Digital Notation "1"						
241	241	113	49	17	1	1	1	1
	−128	−64	−32	−16	−8	−4	−2	−1
	113	49	17	1	<0	<0	<0	0
	YES	YES	YES	YES	no	no	no	YES
	1	1	1	1	O	O	O	1
27	27	27	27	27	11	3	3	1
	−128	−64	−32	−16	−8	−4	−2	−1
	<0	<0	<0	11	3	<0	1	0
	no	no	no	YES	YES	no	YES	YES
	O	O	O	1	1	O	1	1
191	191	63	63	31	15	7	3	1
	−128	−64	−32	−16	−8	−4	−2	−1
	63	<0	31	15	7	3	1	0
	YES	no	YES	YES	YES	YES	YES	YES
	1	O	1	1	1	1	1	1
192	192	64	O	O	O	O	O	O
	−128	−64	−32	−16	−8	−4	−2	−1
	64	0	<0	<0	<0	<0	<0	<0
	YES	YES	no	no	no	no	no	no
	1	1	O	O	O	O	O	O

TABLE A1-5	These Clearly Show the Layout of the 9-Bit Binary; the Count from 0 to 511 Is a Total of 512 Numbers								
1	1	1	1	1	1	1	1	1	= 11111111
256+	128+	64+	32+	16+	8+	4+	2+	1	= 511

4. The 8-bit sequence counts from "0" to "255." This is a total of 256 digits. The pattern for binary counting should be very clear. Each extra bit "switch" doubles the count. The following clearly shows the layout of the 9-bit binary. See Table A1-5.

Lesson 16
The Basic Digital Logic Gates

Build the prototype of each logic gate.*

1. Inputs here are represented by the action of your finger.

2. The processors here are the push buttons. They process the power flow.

3. The outputs in these demonstration circuits are the LED.

4. The voltage for the output comes from the power supply. The inputs don't supply the power. They act as switches and just redirect the power.

5. The unpushed push button represents a "LOW" input.

6. The action of pushing the plunger of the push button represents a "HIGH" input.

7. If you said "push buttons" here, you need to do more than look at the pictures.

8. The inputs are represented here as similar to the base of a transistor. (Do remember that this is a simplified analogy. The input is actually a fairly sophisticated circuit discussed in "The Voltage Comparator" in Lesson 55.)

* Doing the prototyping work is just as important as the questions themselves.

Lesson 17
Integrated Circuits: CMOS ICs

1. DIP = dual inline package and SIP = single inline package

2. From 3 to 15 volts—Too much can and will burn out the chips and other components.

3. The six precautions are listed on page 73.

4. So draw it if you want to.

5. The number 4011 should be prominent. But be aware that the writing varies from chip to chip. It is discussed in detail later. Note Figure L39-3.

6. Questions 6 through 9 refer to Figure L17-4.

7. Figure L17-4.

8. Figure L17-4.

9. Figure L17-4.

10. With the notch to the left, pin 1 is at the bottom left.

11. At the least, the processor would not work properly. At worst, you could burn out the chip.

12. This is very true. Most frequently, integrated circuits and other components are destroyed as a result of bad wiring.

13. Read all of this. Why is this question even being asked? Our introduction to digital electronics relies on logic gate chips like the 4011 IC (a dual input, quad NAND gate). Many ICs use analog and digital inputs to manage information and signals. Only a fraction of IC processors deal with logic gates. Too often, people immediately think that all ICs are logic gates. Recognize that this is not true.

Lesson 21
Test Point 3—Introducing the Resistor/Capacitor Circuit

> **NOTE** Enter your information onto Table L22-2.

1. Wait! Let the circuit sit for at least two minutes before you take this measurement. This is because even when the LED is off, the capacitor is still draining, and will continue to do so until it reaches 0.0 volts. The "AT REST" voltage at Test Point 3 (TP3) is ideally 0.0 volts.

2. You have to keep the plunger down so that pin 11 provides a steady high (V+) output. Your measure of voltage should be nearly full voltage.

3. Specifically, the diode will use .8 volts. So if your power supply is providing 9.5 volts, your reading will be 8.7 volts. $9.5 - .8 = 8.7$. This goes way back to Lesson 3. The regular diode always uses about .8 volts.

4. Have the DMM red probe touching TP3 when you release the plunger. It will begin draining immediately.

5. The output LED should remain on for 8 to 10 seconds after you release the plunger.

6. Watch carefully. The inputs to the second gate (TP3) will sense the change from a high to a low input as the capacitor's draining voltage crosses the "half of V+" mark.

7. This may vary, depending on a number of factors. Resistor/capacitor circuits are analog at heart. The timing does not draw a perfectly straight line. There is a decrease in the rate of draining as the voltage approaches zero.

8. The capacitor is similar to a sink that gets filled with water. The resistor acts like a drain.

9. The larger the sink, the longer it takes to drain. Also, the smaller the drain hole, the slower it drains.

10. Consider that you originally had a 10MΩ resistor acting as a drain. By doubling the resistance to 20MΩ you have effectively decreased the size of the drain by half. Now think of your kitchen sink. You decrease the size of the hole in the drain. The size of the sink is the same. Logically then, it follows that the capacitor will hold the same amount but drain at half the speed as before.

11. Think about it!! Any input over half of V+ to any input pin is seen as Hi. As voltage in C1 drains, crossing the halfway point of V+, the input is now seen as Lo.

12. Think here, too. A pattern should be emerging. The time should last twice that of the 10MΩ resistor.

13. Make sure you changed R2 back to 10MΩ and changed the capacitor to 10 μF. If your original LED's output was timed at 10 seconds, it should be almost exactly 100 seconds now. Most capacitors have a tolerance (range of accuracy) of plus or minus 10 percent. So a 10 μF capacitor might be as small as 9 μF or as big as 11 μF. A sink 10 times larger will naturally take 10 times longer to drain.

14. The main reason to use this rough formula now is because there are too many variables to consider.

    - Because the inputs here are analog.
    - Because the diode between TP2 and TP3 affects the voltage provided to the RC timer.

TABLE A1-6	How to Predict Timing				
RC values	1μF@10MΩ	1μF@20MΩ	10μF@1MΩ	10μF@2.2MΩ	10μF@4.7MΩ
Expected	10 seconds	20 seconds	10 seconds	22 seconds	47 seconds
Real (approximate)	8 seconds	16 seconds	8 seconds	18 seconds	38 seconds

16. Okay. What's the pattern? If you are still having trouble explaining, review questions 10, 13, and 14.

Lesson 22
Test Point 4—The Inputs Are Switches

1. Look carefully at Table L22-1. It outlines the system "at rest."

   a. Input. You have pushed the PBNO plunger, connecting the input pins 12 and 13 to ground.

   b. Processor

   ▪ TP1. With the plunger held down, pins 12 and 13 are connected to ground. The inputs to the first gate are zero volts. The output (pin 11) is the opposite (full voltage) because this is a NAND gate.

   ▪ TP2. The capacitor fills almost instantly (TP3).

   ▪ TP3. RC1. Review the answer to #6 in Lesson 21.

   ▪ TP4. Both inputs to the second gate (pins 1 and 2) are now high, and the output (pin 3) of the second gate is low. That means that pin 3 is connected by the switches inside the chip to ground (pin 7).

   b. Output (TP4). Now because there is a voltage difference between V+ and pin 3 (output) the power flows through the LED through the IC, to ground (pin 7) and the LED turns on.

2. Do it first. It is simply moving one part.

   a. At rest, the LED turns on. Return to the explanation of TP4 to explain why it is on now. TP4 is Hi at rest. Voltage from pin 3 flows through the LED to ground.

   b. Press the PBNO plunger. When you push and release the plunger, the LED actually turns off for a timed period, then turns on again automatically. Because pin 3 goes Lo when active, no voltage from pin 3 means the LED is off.

   c. Thinking again, review TP4. The LED was off when there was no voltage difference (9v = 9v) In this situation, when the circuit is active, what voltage is pushing against ground? That's not as hard as you imagine, because pin 3, the output of the NAND gate, is low when the inputs are high. So, nothing is pushing against nothing. What's the result?

   d. Another question: Is this setup, with the LED to ground, active when the LED is on or off? Off!

Lesson 23
Understanding Voltage Dividers

NOTE The midpoint shows the remaining voltage, not the voltage used. The answers are related to the actual voltage you provide to the circuit. BUT the results at the midpoint should be EXACTLY half of the voltage supplied (V+).

Regarding the exercises, the most common problem is that people forget to subtract the voltage used by the first resistor from the total voltage.

Assuming 9v+:

1. $9v(1/11) = .8v$

2. $9v - .8v = 8.2v$

3. $tp = 0.8v$

4. $tp = 2.5v$

5. $tp = 8.8v$

6. $tp = 8.6v$

7. $0.045v$ used. $8.955v$ remains

Lesson 24
Creating a Light-Sensitive Switch

Do pay attention to this small lesson. If you don't think that voltage dividers are important, just Google the phrase "voltage dividers."

Lesson 25
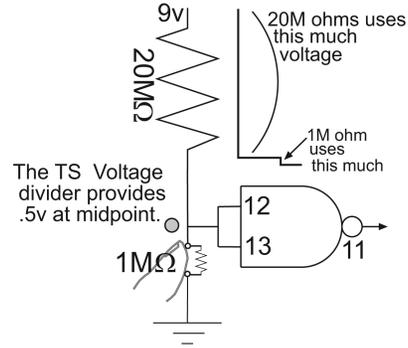## The Touch Switch

Figure A1-3 explains a great deal.

Figure A1-3

Lesson 26
Building the NAND Gate Oscillator

Can you see the pattern (Table A1-7)?

TABLE A1-7	These Represent Ideal Results for Table L26-1		
R4	**C2**	**Comment**	**Expected flashes in 10 seconds**
1.0 MΩ	0.10 μF	Focus on the math to predict the results. Soon it will get too fast to count.	20 flashes in 10 seconds
2.2 MΩ	0.10 μF	Twice the resistance gives half the rate as the one just done.	10 flashes in 10 seconds
4.7 MΩ	0.10 μF	Doubled resistance = half speed of fill/drain rate!	5 flashes in 10 seconds
10 MΩ	0.10 μF	Half the rate of flashing again.	2 flashes in 10 seconds
10 MΩ	0.01 μF	The cap is 1/10 the size. That affects how quickly it drains!	10 flashes in 10 seconds
4.7 MΩ	0.01 μF	This fill/drain rate is actually 10 times faster than the .1 μF. You should be able to count this rate: 5 flashes per second.	50 flashes in 10 seconds
2.2 MΩ	0.01 μF	The pattern continues. Yes, you can count it: 10/second. You might have difficulty counting this rate.	100 flashes in 10 seconds
1.0 MΩ	0.01 μF	This is twice as fast as the one just completed. You can see that it is flashing but you can't count it. It's going at 20/sec.	200 flashes in 10 seconds

Lesson 38
RC1—Creating the Switch

1. Introducing the zener

   a. The zener diode will always use its rated voltage (as long as the voltage is available) to an accuracy of 1 percent.

   b. 5.1 volts will remain the exact answer for your reading across the zener diode, but the remaining voltage will vary, depending on your battery.

2. You have to breadboard this circuit and measure it yourself.

   ■ With the zener inserted the wrong way, you can expect a voltage drop of .5 to .8 volts. The rest is used by the resistor and LED. The LED is normal brightness.

   ■ With the zener inserted properly (cathode opposing voltage) it uses 5.1 volts. There is little left to share between the LED and resistor. The LED is dim.

3. The breakdown voltage is the amount of voltage needed to "break down" the diode's property of being a one way valve.

4. 12 minus 7.9 = ?

Column 2: Creating the Switch

1. Figuring peak voltage. Assume 9v input (see Table A1-8).

TABLE A1-8	Relating to Table 38-3; This Means That the Circuit Will Not Work with a Battery at 7 Volts or Less
V+ – (VD1 + VD2 + VDZ) = Output	
9V – (.8 V + .8 V + 5.1 V) = Expected	
2.3 = Expected V	

2. Variable answer. This depends on the size of C1. Using part sizes noted in Table L38-4, it should drain to 0.0 volts in less than 10 seconds.

3. Regarding the push button:

   a. Touching across the bottom of the push button bypasses the hardware switch. Yes, some small amounts of voltage do pass. Remember, the finger's resistance varies between 100kΩ and 2MΩ. Results will vary widely here, but shouldn't (can't) exceed the voltage recorded in #1.

   b. The answer here is the same as in the first part of this question.

4. These results are in direct relationship to the RC timing. Once you know the standards, you can predict any changes.

5. With and without the zener.

   a. With the zener diode in place, it takes a short time for the voltage at the output to fall from 2 volts to 0 V.

   b. With the zener replaced with a wire, it takes much longer to fall from nearly 7 volts to 0 V.

Lesson 39
The 4046 Voltage-Controlled Oscillator

Be sure that you use as little space on your breadboard as possible. Just use 15 or fewer rows.

1. Pin 3 is an input and MUST be conditioned. Pin 4 is a digital output providing either V+ (HI) or connection to ground (LO). It was just as easy to condition pin 3 by connecting it to pin 4 as it would have been to connect pin 3 to ground.

2. Two logic states are Hi and Lo.

3. Unconditioned input creates a situation where that input reacts with static and radio waves. That situation produces unexpected/unpredictable results.

4. Replacing C1 with 10 times the value should make the rolldown effect last about 10 times longer. Refer to Appendix B for the capacitor's tolerance.

5. Measure your V+ (supply voltage) at pin 16.

6. The voltage recorded here will be half of V+ measured at pin 16.

8. Look at the definition given in Table L39-1.

9. A square wave is produced by having a set of regularly occurring clock signals. Such a signal is shown in the answer for question #7.

10. I suggest the 47 kW resistor balanced against the 100 kW trimpot. Remember the trimpot? You used it back in Lesson 23. Build this simple setup and try it out. Remember, the frequency is determined by three factors as noted in point #6 of the 4046 data sheet.

11. This is a voltage divider using an LDR to control the frequency output. You will find that a low frequency (slow pulse) is created in the light. This will create a high frequency (fast pulsing) in the dark. Now think about it. How would you get a high frequency while the circuit is in the light?

12. You don't have to know the frequency to understand the answer. By increasing the resistor by 10 times, you would decrease the "fill and drain" of the capacitor by 10 times. The output is 10 times slower.

13. When pin 12 has Infinite resistance, the ending frequency is 0 Hz. As the resistance decreases, the final frequency for the circuit at rest increases.

Lesson 40
Introducing the Walking Ring 4017 Decade Counter

1. A conditioned input is shown in Figure A1-4.

   a. Conditioning means to connect the inputs to either Hi (V+) or Lo (gnd). Are you getting the idea that this is an important concept? Often, this is done through a 100 K ohm resistor. This makes it very easy to "inject" the opposite condition to the pin when needed.

   b. This doesn't work! Look at it. When you close the push button's connection, you would only create a short circuit, connecting voltage to ground directly.

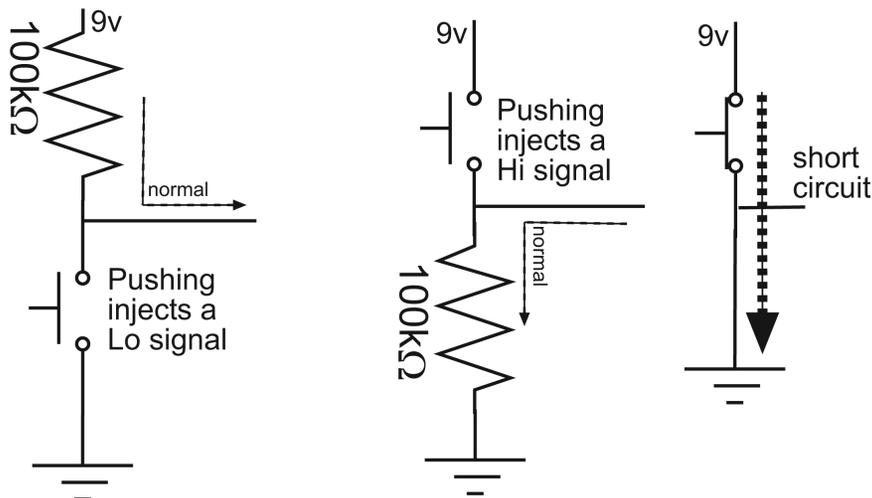2. All systems are controlled by their inputs.

3. If you don't recognize the word "ectoplasm," it just means I'm dating myself. Take an evening and watch the old Ghost Busters movie. When you don't connect the tips of the probes together, they act like antennas.

4. Well? What causes the problems?

5. Unconditioned inputs => unpredictable outputs.

6. Read the data sheet!

   a. What pin is connected to the output of the 4046? It is the input to the 4017.

   b. and c. are referring to the only other two inputs on this chip. What is their function and pin number, and how are they conditioned?

7. Again, look at Table L39-1 for the definition.

8. Remember that the result from the 4046 output was a square wave with a frequency over 50 Hz. The DMM shows a reading of half of V+ because of an averaging effect: 9v half the time and 0 volts the other half. The DMM will show 4.5 VDC. The signal on the right shows a different situation. Even at the very beginning, the rolldown might be too slow for the DMM to show the averaging effect noted in Figure A1-5.

9. If you are unsure, use the virtual oscilloscope and your test probe to check it out.

10. Take this info right from the data sheet. The other outputs move from Hi to Lo with each clock signal. The carryout holds this state for the duration of five clocks and then flip-flops.

Lesson 41
Understanding the Clock Signal Used by the 4017

This is a very important task.

3. It doesn't matter which one is on.

4. and 5. I've had people get what they think is "no movement" or movement back one or forward one. Guess what? When it looks like it has moved back "one" it has actually moved forward by nine steps. Often, when there is no movement, it either jumped forward by 10 steps or did not move at all. Also, what looks
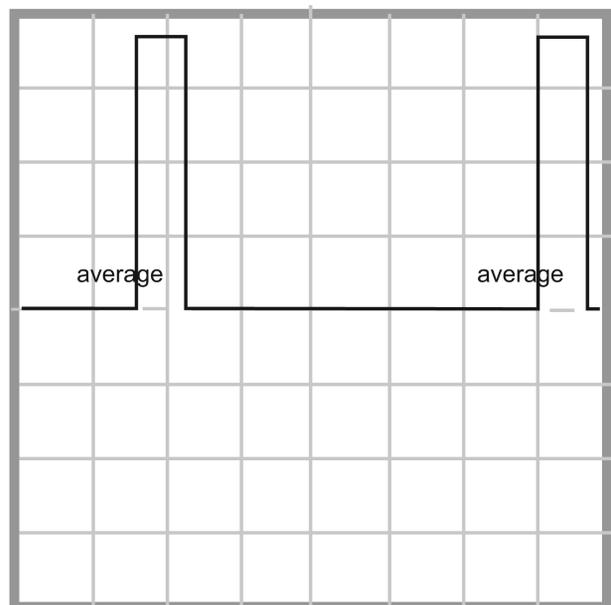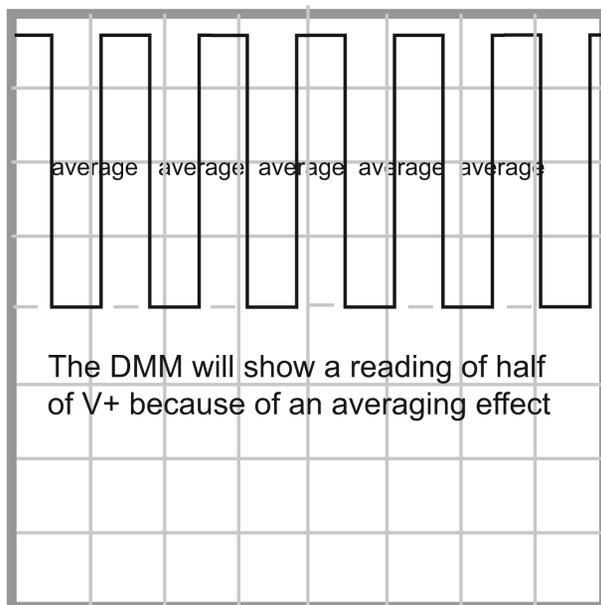

The DMM will show a reading of half of V+ because of an averaging effect

Figure A1-5

like a single step might also be 11. Yes, the 4017 can step forward so quickly that you don't notice any change on the LED. It is reasonable to say that the steps from a bounce could be in the 10 microsecond (uSec) range. Ten of those 10 uSec bounces together make .0001 second, which is still pretty quick.

Lesson 42
Controlling the Count—Using the Chip's Control Inputs

Be sure the correct resistor values are in place for this exercise.

Just to be sure that it is working at all:

■   RESET: Touch the reset probe from pin 15 to voltage. That should bring the count back to output 0 and pin 3 will go high while all other outputs go low.

■   ENABLE: Just to be sure that it is working at all, touch the enable probe from pin 13 to voltage. That should freeze the count. Whatever the active output is, it will remain high, and the clock signal at pin 14 will be ignored. There will be no advance in the count.

1.   When enable (pin 13) is connected to voltage (High) this freezes the count.

2.   The count should freeze on that output.

3.   If the rolldown has stopped, connecting the enable to Hi will appear to have no effect.

4.   If you keep the enable high when you start the rolldown, it will appear that nothing happens. The current output remains high. Nothing moves. The scanning camera system is easy to understand, and very inexpensive. It sells for as little as $200. Amazing!

5.   Pin 1 is related to output 5.

6.   That will produce a cycle through outputs 0, 1, 2, 3, 4, 0, 1, 2, …

7.   The carryout will remain Hi constantly in this setup.

8.   Inputs that need conditioning:

a.   The clock input (pin 14) is conditioned by the state of the output of the 4046 chip, either high or low.

b.   Reset must be set low, or there will be no count. If it is high, the count returns to output 0.

c.   Enable must be kept low as well. When it is set high, the count freezes at that output.

9.   The 4017 controls the 4066 so that it switches between channels at preset intervals, adjusted faster or slower by a voltage divider input. The 4066 rolls between four channels that feed in succession to the recording or observation unit.

Lesson 44
Control the Seven-Segment Display Using the 4511 BCD

1.   Display should show 1.

2.   Display should show 2.

3.   Display should show 3.

4.   Full set (Table A1-9).

5.   Regarding the "load" pins:

a.   They are inputs and need to be conditioned.

b.   The 100k ohm resistor allows the injection of a high signal if you want to do so.

6.   The range of a four-digit binary number goes from 0000 [decimal 0] to 1111 [decimal 15]. This represents 16 numbers (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15).

7.   The 4511 counts only to decimal 9 [1001].

8.   0111 is 4 + 2 + 1 = 7

TABLE A1-9   If the Four LEDs Counting Binary Don't Match the Decimal Numbers, Use Reset

Number	B8	B4	B2	B1	Binary Word	Seven-Segment Displays
Zero	Low	Low	Low	Low	0000	0
One	Low	Low	Low	High	0001	1
Two	Low	Low	High	Low	0010	2
Three	Low	Low	High	High	0011	3
Four	Low	High	Low	Low	0100	4
Five	Low	High	Low	High	0101	5
Six	Low	High	High	Low	0110	6
Seven	Low	High	High	High	0111	7
Eight	High	Low	Low	Low	1000	8
Nine	High	Low	Low	High	1001	9
Ten	High	Low	High	Low	1010	10

9. The other inputs:

   a. LT is Lamptest. It is held high. All outputs go high when it is set low.

   b. Blanking, at pin 4, is held high for normal operation. All outputs go low when it is set low.

   c. Store at pin 5 is held low. Set high, it acts like the enable on the 4017, freezing the count.

TABLE A1-10   It's Easier to See the Relationships Between the Three Variables

Ohm's law produces a hyperbola when graphed.
Volts = Ω (Current)
Let Volts = 1 and solve for either Current or Resistance
1V = Ohms/Amps   Ohms = 1V/Amps

Lesson 49
Transistors as Amplifiers and Defining Current

See Table A1-10. The graph in Figure A1-6 shows that the three variables directly affect each other.

Keep thinking about plumbing . . . water flowing in pipes.

1. To take a small signal and make it bigger by increasing the voltage, the current, or both.

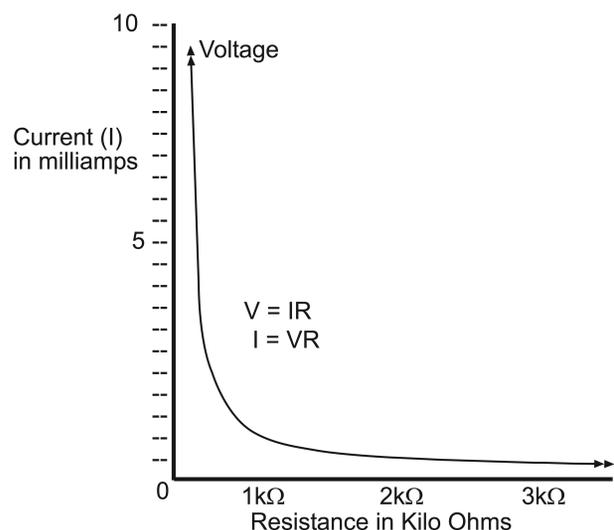2. Ohm's law works for both water and electrons (Table A1-11).

Figure A1-6

TABLE A1-11	Analogy and Comparison of Electricity to Water	
Pressure (force)	**Current (amount)**	**Resistance (restriction)**
The force pushing the water: gravity	Amount of water— ft³/second	Hose width limits the amount able to flow
Volts	Amps (I)	Ohms Ω

3. Two factors needed to create current:

    a. Force to push (voltage for electricity). If there is no force, nothing will be moved.

    b. Material to move. Electrons are pushed. If there are no electrons available, there is no flow. Insulators have no electrons available. Picture an empty stream bed.

4. Basic units representing current:

    a. (equation) in water: m³/second or ft³/second

    b. Coulomb

5. A coulomb: 1 c = $6.241509629 \times 10^{18}$ electrons per second.

6. How many per second? $.0153c \times 10^{18} = 1.53 \times 10^{16}$ = 15,300,000,000,000,000 electrons per second

7. Refer to the information you gathered in Lesson 5.

8. Comparing city water system to an electronic system:

    a. Pressure in the hose comes from the city water system.

    b. Pressure in electronic systems is called voltage.

    c. Squeezing the hose decreased the cross-section area the water can flow through. The result is extra resistance, restricting the flow.

d. Increasing resistance decreases the amount of flow.

e. Current decreases as the resistance increases.

f. Current increases as the resistance decreases.

Lesson 50
Defining Work, Force, and Power

1. Force is measured in Newtons.

2. 1 N force moves about 100 grams upwards against the force of gravity (specifically 98g).

3. Work is the amount of force exerted on an object over a distance.

    Force × Distance = Work

4. By definition:

    If Force = 0.0, then Work must equal 0.0

    If Distance = 0.0, then Work must equal 0.0

5. Work is measured in Newton-meters.
    1 NM = 1 joule

6. 1NM (or 1 joule) is achieved by moving 98 grams a distance of 1 meter straight up.

7. Power is the RATE at which work is done.

8. Common unit for power is watts (W):
    1W = 1NM/second

9. How about a large stone that is falling at the same rate as a small stone?

10. Here, .027W = 27 mW (milliwatts)

11. Use the same data you gathered in Lesson 5 (see Table A1-12).

TABLE A1-12	That's Why the LED's Brightness Changes So Much for What Looks Like Such a Small Change In Voltage; it Concerns Both Voltage and Current			
Resistors	V Drop Across Resistor	Current (V=IR) : I=V/R	Available Power to LED P = VI Watts = Volts x Amps	
100Ω	5.80 v	I = 0.058 A	0.33 W	330 mW
470Ω	6.85 v	I = .014 A	0.095 W	95 mW
2.2kΩ	7.08 v	I = .0032 A	0.022 W	22 mW
10kΩ	7.17 v	I = .00071	0.0050 W	5 mW
47kΩ	7.23 v	I = .00015	0.0010 W	1 mW
220kΩ	7.28 v	I = .000033	0.00024 W	.24 mW

12. $150\text{ W} > 22\text{ W}$

13. Figuring $VI = W$: $I = W/V$:
$I = 100W / 120V$: $I = .83$ Amp

Five LEDs at 50 mA each in a 3-volt system.
$V \times I = W$: Then $3v \times .050A = .15$ W. Five LEDs at .15 W each will use a total of .75W.

14. Power used by different ranges of LEDs (see Table A1-13).

TABLE A1-13	Referring to Table 50-2
Regular red	1.8v x .03A = 0.054W
Regular green	2.1v x .03A = 0.063W
Regular yellow	2.3v x .03A = 0.069W
Hi bright yellow	2.1v x .05A = 0.105W
Ultra bright red	2.4v x .05A = 0.120W

15. Figure Amperage:
$V = IR$
$I = V/R$
$I = 2.05 / 100$ W

Figure Power:
$V \times A = $ Watts
$2.05V \times .0205A = .0420$ W

Not really. If it does light up, it will be very dim.

Lesson 51
What Do I Have to Gain?: Definitions

What do I have to gain? Pay close attention to the entire lesson "Gain in the NPN Transistor."

It is worth taking the time to understand the information in Table L51-1.

Diode testing is a feature common to multimeters. Look for the "diode symbol" on the dial. The measurements and outputs for good transistors will remain the same. A reading of .68 on one DMM will be the same on another DMM.

$V_{drop} = V_{total} (R1/R1 + R2) : V_{drop} = 9.0v(1000/1000 + 2700) = 9000/3700 = 2.4v$

$V_{total} = V_{drop}1 + V_{drop2} : 9.0V = 2.4V + V_{drop2} : V_{drop2} = 9.0V - 2.43V = 6.57V$

Calculate the current through each load of a series circuit.

$2.4V/1000Ω = .0024A$

$6.57V/2700Ω = .0024A$

Current through a series circuit is constant.

Use the given resistor values. That way you'll generate consistent results.

Set it up and do the measuring. Use your results in Table L51-1 as reference.

Lesson 52
The World Is Analog, So Analog Is the World

1. The NPN action is noninverting. The noninverting input on the lm741 is at pin 3.

2. Noninverting: If the input is positive voltage, the output voltage is positive as well. If the input voltage is negative, the output voltage will be negative.

3. Inverting: If the input is positive voltage, the output voltage will be a negative voltage. If the input voltage is negative, the output voltage will be a positive voltage.

4. Gain = Output/Input
   Gain = 100/10 = 10

5. Data sheet information:
   a. http://www.analog.com/en/amplifiers-and-comparators/operational-amplifiers-op-amps/products/index.html
   b. http://www.national.com/ds/LM/LM741.pdf. NOTE: This is no longer a simplified data sheet, but your first exposure to the real thing. Just remember: On any data sheet, there is lots of information you don't need. Don't be dazzled. The trick is to find what you do need.

6. Two different packages.

7. Page 2 of the data sheet has that information. The numbers on your chip will tell you specifically 741A, 741, or 741C.

8. Look on the second page of the data sheet. It should be the first row of the table.

9. Second page still, rows 9, 10, and 11 of the table.

10. Third page of the data sheet, Power Consumption Row.

11. Third page, Power Consumption Row

12. Page 5 of the data sheet: 20 total

Lesson 53
Alternating Current Compared with Direct Current

Electronics is all about being able to control the signal. To do this, you must be able to see and compare input and output signals.

So far, we've concentrated on looking at signals in the 9 volt range that have to be cut down to less than 1 volt using our "scope probe."

Now you need to see signals that are in the 10 mV range, microscopic in comparison. To see these signals, you need to have a clean connecting cord that doesn't decrease the signal.

Here you make two identical test cords. Each has a 3mm plug on one end and two clips on the other. Be sure to clearly mark them as Test Cord 1 and Test Cord 2. Without clear identification, your work area quickly becomes a jumble of unidentified wires. I've not only marked mine, I've used a different color cover for the signal feed on one of them.

Please see www.mhprofessional.com/computingdownload for complete instructions and photos for creating test cords.

1. The test cord versus the scope probe:
   a. The test cord is a simple connection between the alligator clip and the plug.
   b. The scope probe has a 1:11 ratio voltage divider built into it.

2. You can use the Virtual Scope program to create your own wave files. They must be wave files. You will need 1 kHz, 450 Hz, and 270 Hz. I must emphasize that you want to keep the standard signals as analog wave files. Find a method to play the wave files. Only wave files will generate the input we need to see. Do not convert them to MPG format; MPGs are a digitized file that provides

different results. Try one and see for yourself. If needed, export a wave file (*.wav) to your personal player or create an audio DVD/CD that will run on a stand-alone music system.

3. You can expect different voltages for the different frequencies. However, at full volume, all frequencies were at the maximum voltage that my little system could provide. These will vary from system to system.

At full volume from the HEADPHONE output	1000 Hz produces .935 vAC (935 mVAC)
	450 Hz produces .961 vAC (961 mVAC)
	270 Hz produces .967 vAC (967 mVAC)
At full volume from the SPEAKER output	1000 Hz produces 2.24 vAC
	450 Hz produces 2.27 vAC
	270 Hz produces 2.27 vAC

4. This is not a question, but does hold very important information. Be sure to read it.

5. Same as #4.

6. Set 1,000 Hz at 250 mV. Now, without changing the volume control, change the output file to 450 Hz. Upon remeasuring, you will notice that the voltage between the signals changes significantly as you change frequency.

7. Same here as #6.

8. Just look at the output of any "wave" file recording on the virtual oscilloscope.

Lesson 54
AC in a DC Environment

1. Definitions

   a. DC. Direct Current is defined by current (the movement of electrons) all going in one direction.

   b. Positive voltage: In simplest conventional terms, positive voltage is considered to be moving in the wire from left to right. The current is viewed as being pushed from "source to ground."

   c. Negative voltage: In simplest conventional terms, negative voltage is considered to be moving in the wire from right to left. The current is viewed as being pulled from "ground to source."

2. A good analogy for DC is water being displaced in a pipe. For our purpose, wind is a good analogy too. The particles actually move from one place to another.

3. AC is constantly changing direction, but essentially staying in one place.

4. The best analogy here is to compare the movement of the electrons to how sound moves through the air. The particles essentially stay in one place, but bounce against each other.

5. Difference between AC and DC as indicated in Figure L54-7.

  a. DC: Electrons get displaced and moved from point A to point B.

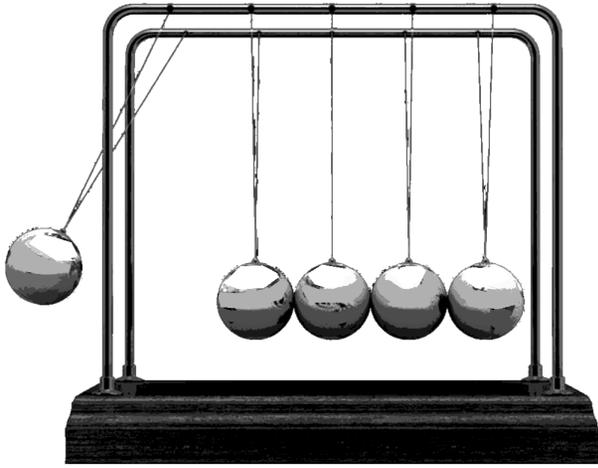 b. AC: Electrons get moved from point A to point B, and then from B back to A. See Figure A1-7.

Figure A1-7

6. The natural reference for AC is ground.

7. Using DMM set to DC to measure AC:

  a. In AC, all forces average out at ground (0.0 volts).

  b. AC measured using DC settings shows zero because of an averaging effect.

  c. With zero (ground) as reference, the sum total movement of the electrons is zero.

  d. AC means that for every positive movement (V+) there is an equal but opposite movement the other way (V−). The average of the real movement is zero if the reference is ground. The DMM set to DC will show the reference point as 0.0 volts DC. If the AC reference point is 5V, the DMM will show the average as 5 VDC. It will not show AC potential unless it is set to AC.

8. In AC, the amount of force above and below the reference point is always the same, by definition.

Lesson 56
Using Feedback to Control Gain

The pictures in "What to Expect" show how to adjust the signal.

■ Have your system turned on.

■ Adjust the signal strength to 10mV while it is connected.

If you adjust while disconnected, you will find that the added strain when you do connect it (yes, work is involved) will drop the real input. You can't predict really how much the input will drop (see Table A1-14).

Table L56-1 is shown twice.

TABLE A1-14	Reality Readings—A Good Dmm Shows Its Quality Here			
VAC between	Input = 0 V	Input = 10.7 mVAC Gain = 1 Pot + R4 = 997 Ω	Input = 10.7 mVAC Gain = 5.02 Pot + R = 5.02 kΩ	Input = 10.7 mVAC Gain = 10.0 Pot + R4 = 10.01 kΩ
TP_{input} to TP_A	0.1 mV	0.0 mV	0.0 mV	0.0 mV
V_{input} = TP_A to TP_{Ref}	0.0 mV	10.7 mVAC	10.7 mVAC	10.7 mVAC
V_{Output} = TP_{Out} to TP_{Ref}	1.3 mV	Bouncy 12.8 to 13.6 mVAC	Bouncy 57.3 to 58.1 mVAC	Bouncy 77.1 to 78.1 mVAC
TP_{invert} to TP_{Ref}	0.0 mVAC	.3 mVAC	.4 to .5 mVAC not bouncy	0.0 mVAC
TP_A to TP_{Invert}	0.1 mV	10.7 mVAC	10.7 mVAC	10.7 mVAC
V_{Drop} Across 100 ohms	0.0 V	10.8 mVAC	56.7 mVAC	110.7 mVAC

a. Accuracy regarding a gain of 1? Dividing the output 10.8v by the input 10.7v is pretty close to 1.

b. Accuracy regarding a gain of 5:

- Expected: $10.7 \times 5.02 = 53.4$

- My reality provided 56.7: I was 6 percent off there. Great for what we are doing.

c. Accuracy regarding a gain of 10:

- Expected: 107

- My reality was off by 3.7. Error of 3.4 percent. (See Table A1-15.)

2a. Gain = 1 : 2(b) Gain = 5 : 2(c) Gain = 10

3a. Gain = 1 : 2(b) Gain = 5 : 2(c) Gain = 10

4. Burnt out R3

a. R3 is the initial input. If it is burnt out, there is no connection. Consider that air is a great resistor. It's pretty near infinite, especially for our purposes. Any number over infinity approaches zero. Gain is functionally zero.

b. Not at all.

c. No.

TABLE A1-15	Ideal Results			
VAC between	Input = 0 VAC	Input = 10 mVAC Gain = 1	Input = 10 mVAC Gain = 5	Input = 10 mVAC Gain = 10
TP_{input} to TP_A	0.0 mVAC	0.0 mV	0.0 mV	0.0 mV
V_{input} = TP_A to TP_{Ref}	0.0 mVAC	10 mVAC	10 mVAC	10 mVAC
V_{Output} = TP_{Out} to TP_{Ref}	0.0 mVAC	10 mVAC	50 mVAC	100 mVAC
TP_{invert} to TP_{Ref}	0.0 mVAC	0.0 mVAC	0.0 mVAC	0.0 mVAC
TP_A to TP_{Invert}	0.0 mVAC	10 mVAC	10 mVAC	10 mVAC
V_{Drop} Across 100 ohms	0.0 mVAC	10 mVAC	50 mVAC	100 mVAC

5. A shorted resistor has no resistance; that is, resistance = 0.0 ohms. Gain is figured by a simple ratio of R1 to R2. But what if R2 is 0.0. You cannot divide by zero. So this doesn't work in theory. In reality, the Op Amp tries to create infinite gain. It just doesn't work.

6. Feedback (Table A1-16).

The Op Amp increases the voltage. By increasing the voltage, it increases the power by a small amount. The next step is to increase the current.

Lesson 57
Building a Power Amplifier Controlled by an Op Amp

1. See Table A1-17.

2. Table L57-1 (see Table A1-18).

TABLE A1-16	This Is Table L56-2: The Current Remains the Same as the Gain Changes		
Gain	**VAC Drop across Pot + R4**	**Resistance**	**Current**
1	10.8 mV	1k ohm	0.0000108 A 0.0108 mA
5	56.7 mV	5k ohm	0.0000113 A 0.0113 mA
10	110.7 mV	10k ohm	0.0000110 A 0.110 mA

TABLE A1-17	Same!
When gain = 1	When gain = 10
R3 voltage drop = 10 mVAC	R3 voltage drop = 10 mVAC
R3 Value = 1000 ohms	R3 Value = 1000 ohms
V = IR : 0.01V = I x 1000	V = IR : 0.01V = I x 1000
I = 0.00001 amp	I = 0.00001 amp
.01 V x .00001 amp = 1×10^{-7} Watt	.01 V x .00001 amp = 1×10^{-7} Watt

TABLE A1-18	Power Output Across 200Ω	
	Gain = 1 (set to min)	**Gain = 11 (set to max)**
VAC across 100 ohms	5.3 mVAC 10.6 mVAC across 200 ohms	27.9 mVAC 55.8 mVAC across 200 ohms. This is really just a functioning gain of 5.
V/Ω = I	0.0063V/100W = 0.000053 amps Each resistor receives the same amount of current. The voltage drop would have been .0106V across 200 ohms.	0.0279/100Ω = 0.000279A
VA = Watt	.0053V x .00053 = 2.8 x 10^{-7} Watt 0.00000028 watt across one resistor load. There are two loads, so we get to double it. Now there are 5.6 x 10^{-7} watts for the full load. AMAZING. That's 5.6 times the power output than the input. BUT look at Lesson 57. We got better results without the transistors.	.0279 x .000279 = 7.8 x 10^{-6} 0.0000078 watt across one resistor load. There is 0.000015 W across the two loads. 15.0 x 10^{-6} = 150 x 10^{-7} Compared to the input, that looks great. BUT! Not really—I know. I dropped all those numbers at the end. When working to two significant figures, you don't round— you drop.

3. In Lesson 56, without transistors: maximum output = 0.00010 Watt = .1 mW and in Lesson 57, even with the transistors, the maximum output is .125 mW.

   So, what's wrong? It looks like the transistors were just getting in the way. The power amplifier isn't working because there just isn't enough power to get the transistors to burp!

4. Power Output with the power amp in place should be between .5 W (nominal) and and 1 Watt (maximum).

Lesson 59
Introducing Transformers and Putting It All Together

1. Highly variable results. You want to measure sound, so don't blow on the speaker. Blowing will create a very high reading (100 mVAC), but it doesn't measure the sound. A good reading on the sound would register 8 to 12 mVAC.

2. Hook up the speaker to the oscilloscope.

3. Adding in the speaker and taking care of feedback.

4. Amplified wave form. To get it to fit, you will have settings at 10 mV/division. The drawing should look very much like the first one, but the amplitude has changed (Figure A1-8).
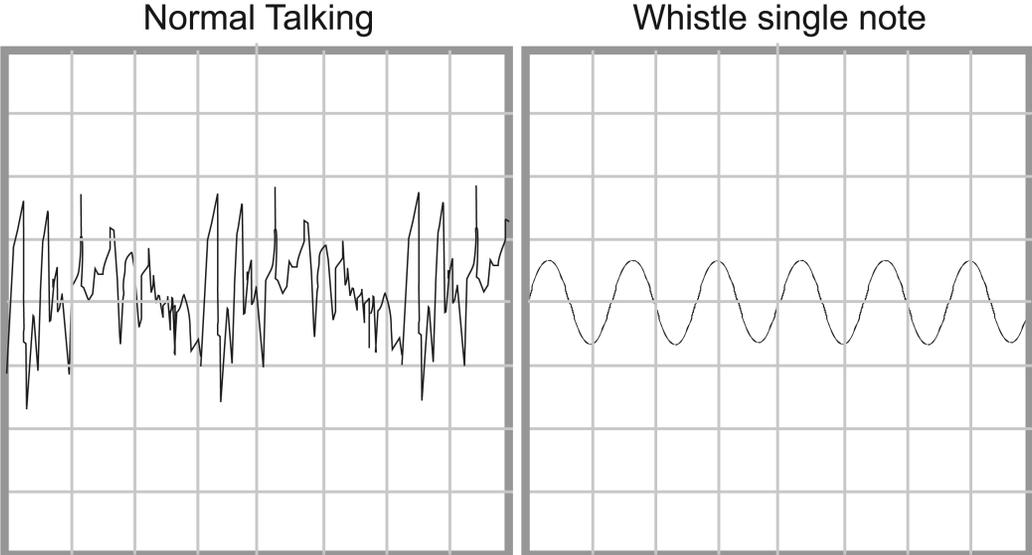
Normal Talking   Whistle single note

Figure A1-8