This is an explanation of how the merit badge kit functions. There are several topics worthy of discussion. These are:

1. LED operation.
2. Resistor function in this design.
3. Switch operation.

**LED Operation**

The schematic symbol for an LED is:

![LED Symbol](image)

LED stands for light emitting diode. A diode is a more general term that describes an electronic component that allows electrons to flow through it (current) in only 1 direction. Current will only flow from the anode to the cathode. A light emitting diode has an additional characteristic, in that when enough current flows through it, the LED will light up. The amount of light the LED puts out is proportional to how much current flows through it, up to a limit. If too much current flows through it, the LED can overheat and ‘burn up’.

It is important to install an LED correctly in the PCB when assembling the kit. If installed backwards, no current will flow through the diode, and the LED will not turn on.

**Resistor Operation**

The schematic symbol for a resistor is:

![Resistor Symbol](image)

A resistor is an electrical component that resists the flow of electrons (current). Units for resistance is ohms. The larger the resistor value, in ohms, the more resistance to electron flow the resistor exhibits.

This is important in the operation of the kit, because a resistor is used to control how much current is allowed to flow through the LED. This accomplishes two things in this design:
Firstly, and most obviously, setting the resistor value (in our case, it is set to 200 ohms) will limit how much current can flow through the diode, and consequently how much light the diode will emit.

Secondly, this resistor value will have a direct effect on battery life. If we used a smaller resistor, then more current would flow through the diode, more light would be emitted, but the batteries would run down more quickly.

Switch Operation

There are two types of switches used in the kit design. The first switch is a SPST, or single pole, single throw switch. The schematic symbol for that is:

![SPST Switch](image)

This switch is used to connect the battery to the rest of the circuit. It is the on/off switch. If the switch is in the off position, there is not connection from the battery to the circuit board components. Hence, the circuit is off. Note that this type of switch is used in many places, though the size and amount of current the switch can handle varies. A good example of general use of this switch type is the wall switch that turns on the lights in a room.

The second type of switch used in this design is the momentary, push button switch. The schematic symbol for this switch is:

![Momentary Switch](image)

There are 2 of these switches used in this design. One switch is used as a ‘START’ button, and the second is used as a ‘MODE’ button. The operation of this switch is fairly straightforward. Pressing the button down will connect the two terminals of the switch, while releasing the switch disconnects the two terminals.

Microcontroller Operation

The microcontroller is a small computer chip that can be programmed to perform a specific function. In the case of this merit badge kit, the microcontroller (micro) waits for the ‘START’ or ‘MODE’ button press, and controls the LED display accordingly.

Several display modes are available, but we will only discuss in detail the single LED mode (available when the circuit is powered up, before the ‘MODE’ button is pressed), and discuss briefly the two LED mode.
First, let’s discuss the technique used to turn on an LED. For this design, there are 12 LEDs that can be lit. The way the circuit is designed, and the way the software has been written, only 1 LED is turned on at any moment. This is necessary for those LEDs 1-8 and 12, since all these LEDs share 1 current limiting resistor. Since all these LEDs share a single resistor, if 2 LEDs where turned on at the same time, their light intensity would go down, because total current is determined by the resistor. This would basically allow only half the amount of current to go through each of these 2 LEDs, and their intensity would be dramatically less. So, for this circuit’s operation, only 1 LED may be turned on at a time.

**LED Multiplexing**

I use a simple technique called multiplexing when lighting the LEDs. Let’s use the case when we want to show 2 LEDs on at the same time (the 2 LED mode). Since we are only allowed to turn on 1 LED at a time by virtue of the circuit design, we turn one LED on for a short time, and then turn the second one on for a short time, and we repeat this sequence very quickly. Even though we are turning 1 LED on and then off, and turning the other LED on and then off, to our eyes it appears that both LEDs are turned on at the same time. This technique can be extended so that all 12 LEDs can appear to be turned on at the same time. This is a very popular technique used on many displays.

A benefit of using this technique is that it reduces the number of components used for this design, and more importantly, it reduces how much current we need from the batteries, which makes the batteries last longer. Since we are only turning on one LED at a time, we use a minimal amount of current from the battery. Imagine if the circuit was designed such that all 12 LEDs could be turned on simultaneously, we would use the batteries up 12 times faster.

**Circuit Operation**

So, here is a description of the software that is running in the micro, and how that relates to the circuit operation.

Once the circuit is powered up, a single LED is illuminated, which indicates the micro is ready for an input from one of the switches. If the ‘MODE’ button is pressed, the micro adjusts itself to change how the LEDs will be controlled. When the ‘START’ button is pressed, the micro begins displaying the LEDs in the selected sequence. As long as the ‘START’ button is pressed, the LED spin rate will stay at its maximum rate. Once the ‘START’ button is released, the micro will begin slowing the spin at a predetermined rate. The randomness of the circuit (which is the last LED lit when the spin cycle is completed?) is determined by how long the ‘START’ button is pressed.

The micro consists of a CPU (central processing unit), memory and I/O.

The CPU executes the command sequences defined by the program I wrote to do this function. This program is written in the ‘C’ programming language.

Memory holds temporary values that the program uses while controlling the circuit. An example of a memory item would be which LED is currently being displayed. This would take on the value of 0 to 11 (for 12 LEDs), and would be changed when a different LED is to be displayed.
I/O stands for Input/Output, and is the part of the microcontroller that interfaces to our circuit. There are 2 inputs defined for this design; ‘START’ and ‘MODE’. When one of these buttons is pressed, the voltage that is present at that particular input will be connected to ground (0 volts). When the button is released, the voltage will return to a voltage value that is the same as the battery voltage (approximately 4.5 volts). Logically we can say that when the button is pressed, a logical 0 is presented to the microcontroller pin, and when the button is released, a logical ‘1’ is presented to the pin. The operating program is continuously monitoring these 2 inputs, and can detect when the input changes from a 1 to a 0 and when it changes from a 0 to a 1. The program modifies its operation based on how it interprets these 2 inputs.

There are 12 outputs in this design, each one controlling a single LED. When the output pin is driven to a logical ‘1’, the LED connected to that pin will light up. The following schematic diagram illustrates one LED circuit.

For the purposes of this discussion, we will use a green LED as an example. From a datasheet of a typical green LED:

**Electrical / Optical Characteristics at TA = 25°C**

<table>
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<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Device</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Test Conditions</th>
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<td>( \mu \text{A} )</td>
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<td>( V_{\text{r}} = 5 \text{ V} )</td>
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</table>

Notes:
1. Wavelength = \( \lambda \pm 1 \text{ nm} \).
2. Forward Voltage: \( V = 0.1 \text{ V} \).

Of importance from this datasheet, the forward voltage drop across this LED is typically 2.2V, but a maximum of 2.5V. If we assume a maximum voltage drop across the LED, we can calculate how much current will go through the LED in our circuit.

From Ohms LAW: \( I = \frac{V}{R} \). Since \( V_{\text{BATTERY}} = 4.5V \), and \( V_{\text{LED}} = 2.5V \), the current will be:
\((4.5 - 2.5) / 200 = 0.010\) Amps \(\Rightarrow\) 10 milliamps.

From this, we can say that each LED, when lit, sees about 10 milliamps of current. This determines the light intensity of the LED (and as previously discussed, the longevity of the batteries).

So, when the micro sets one of its outputs to logical 1, the LED will turn on, and its intensity will be determined by the 200 ohm resistor. The micro program will control the order of LEDs and timing of LEDs, until the predetermined sequence has concluded.

I will make a final comment about R2-R4, which are individual 200 ohm resistors dedicated to a single micro output and LED. These separate circuits are identical in function to the other LEDs that share a single resistor, but the separation is necessary when I want to write a new control program into the micro. There are 4 special pins used when writing a new program, three of which are also used to control LEDs.

Also, R5, which is a 56K resistor, connects to a special pin on the micro that has no functional purposes when operating the circuit, but does have a purpose when operating the micro in a special debug mode, which is used when writing the program.
## Decimal - Binary - Octal - Hex - ASCII Conversion Chart

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SOLDERING IS EASY
HERE'S HOW TO DO IT

BY: MITCH ALTMAN
(SOLDERING WISDOM)

ANDIE NORDGREN
(COMICS ADAPTATION)

JEFF KEYZER
(LAYOUT AND EDITING)

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DISTRIBUTE WIDELY!
Soldering is a really useful skill. It is also way easy! Really, it is! You'll see. Soldering is also lots of fun!

If you know how to solder, you can make just about anything with electronics, which is just too cool! There are many ways to make good solder connections. I'm going to explain how I do it.

Let's get started!

This is a soldering iron. Its tip gets hot enough to melt solder, which is metal. That's about 200 degrees Celsius!

Safety tip #1 (of 3): If you touch the tip, you will let go very quickly!

This is solder. It is made of metal, usually tin and lead. The elements Sn and Pb.

It is actually hollow and filled with rosin (similar to the stuff used to make bows for violins sticky).

The elements Sn and Pb.

This is solder. It is made of metal, usually tin and lead.

The best solder for electronics has rosin core and is 60% tin, 40% lead. Also known as flux.

There are other types, for instance lead-free solder, but it has toxic chemicals in its core, and it is not quite as easy to use as solder with lead. It also corrodes soldering iron tips quickly. If you can only get lead-free solder where you live, it's OK, but please don't breathe in the nasty smoke.

Safety tip #2 (of 3): Lead is poisonous. It gets on your skin when you hold the solder, so wash your hands after soldering!

We use the soldering iron to melt the solder and make electrical connections. When the solder heats up, the rosin melts almost immediately. The metal follows shortly thereafter.

The rosin flows around what you want to solder, cleans the metal, and helps make a good solder connection.

Safety tip #3 (of 3): If you don't wash your hands after soldering, the lead may get in your body, where it gets stored in your brain for your entire life. If enough collects there then you go insane, and you lose all of your friends. So - wash your hands after soldering, and keep your friends!
Electronic circuits are made up of electronic parts connected together. For a circuit to work correctly, we need to connect everything that should connect together, and not connect anything that should not be connected.

There are many ways to connect electronic parts together, but perhaps the easiest way is with a printed circuit board (PCB or just “the board”). The PCB makes it easy because it has pads for each part. If you look carefully at the PCB, you will see lines connecting pads together with other pads – these lines are called traces.

All of the parts have wires sticking out of them: leads (pronounced “leedz”). All of these wires, regardless of what they look like, are called leads since they lead to the parts. Most pads have a hole in the middle – this is where the lead pokes through and makes a connection to the circuit!

If you put all of the leads from the parts into the correct pads for the parts and if you put all of the parts in the correct orientation and if you make all good solder connections, then the circuit will just work! This is because the board connects everything that should be connected, and nothing that should not be connected.
We'll start with a resistor.

Resistors have two leads and (unlike some parts, such as diodes, which have a "plus" side and a "minus" side) can be placed in their pads in either direction.

PCBs usually have markings to show where each part goes (and if the orientation matters, the PCB usually has some way to show you this).

Since the word "resistor" starts with the letter "R", the PCB usually marks places where resistors go with an "R", followed by the resistor's number, such as "R3".

So, to solder in the resistor, you start by finding the correct value of resistance from the project's documentation.

Then bend the two leads of the resistor down the width of the part, like this:

Then place the two leads through the two pads on the PCB for this resistor.

You push the resistor's leads through the pads until the part rests flat on the PCB.

(Sometimes you may need to wiggle and tug gently on the leads from the bottom of the PCB to do this).

For most PCBs, all of the parts are placed through the pads on the printed side of the PCB (which we'll call the top of the board), and we'll solder all of the pads on the bottom of the board.

Then you turn the PCB over so we can solder the two pads.

As you turn the PCB over, you will need to hold the resistor with your finger so it doesn't fall out of the board.

As I said earlier, soldering irons get hot enough to melt metal. That means that the tips get hot enough to oxidize quickly, which basically means that they get dirty just sitting in the air!

The oxides are an insulator for heat, so we want to clean them off the tip before each solder connection so the heat flows nicely and we can make good solder connections.

This is why we have a wet sponge: to clean the oxides off the tip. Just scrape the tip across the sponge gently, then rotate the iron and scrape gently across the sponge again.

This should make the tip silvery and somewhat shiny — ready to solder. Remember to clean the tip like this before each connection you make — the tips oxidize quickly! If the tip is nice and silvery and shiny, you can make good connections.

Time to actually solder!

Hold the soldering iron in your dominant hand, like you would hold a pencil.

Hold the solder in your other hand.
Touch the cleaned tip to both the pad and the lead of the part you want to solder. Keep it there for about 1 second, so everything heats up nicely.

Then add about 1mm to 3mm of solder under the tip.

Don’t add it above the tip, since that melts the solder only onto the tip, where it doesn’t do any good. We want the solder to flow nicely all around both the pad and the lead to make a good connection.

The solder won’t melt until it actually touches the hot soldering iron tip, but once it touches the tip, that’s when it melts, and you can then add your 1mm to 3mm of solder.

But—and this is very important—keep the soldering iron tip on the pad and lead for about 1 more second since it takes time for the solder to flow around the pad and the lead, and it will only flow when it is hot.

Then, pull the solder away.

Then pull the soldering iron away, and take a look at your perfect solder connection! See how easy it is!

Please note that the solder cools down and hardens quickly all on its own. It only takes about a second, and then you are ready for your next solder connection.

That smoke that you saw when the tin/lead solder melts is the rosin vaporizing.

It contains some chemicals that are not good for you, so try not to breathe it!

You can blow gently on the connection as you solder to keep the smoke away from your lungs.

Now put that soldering iron back in its stand while we’re not using it.

The stand keeps the hot iron safely on the table. Most people say that it’s not fun to have it land in your lap!
Let's take a look at what makes a good solder connection.

You can tell a good solder connection because the solder totally covers the pad and surrounds the lead.

Also, the solder makes a small bump.

If you can see any of the hole or pad and so there may not be a connection where we need one.

If this is the case, no problem - just repeat the procedure (clean the tip, touch the tip for 1 second on the pad and lead, add 1mm to 3mm of solder, pull the solder away, keep the tip on the pad and lead for 1 more second, and pull the tip away), and it should then be totally fine.

If there is too much solder, that means that you added so much solder that there is a solder blob on a pad that is big enough to also touch another pad, creating a connection where there should not be one. This can happen.

If it does, no problem! Just clean the tip, hold the tip to the solder blob between the pads for 1 second.

Then bang the board against your work table to fling the excess molten solder to the table.

The connections should then be fine (though you may need to lightly scrape any excess solder from the PCB, which you can usually do with your fingernail). You may want to wear safety glasses!

In between too much and too little solder is a lot of leeway. This is one reason why soldering is easy.

Some people like to solder parts to their pads after adding a bunch of parts to the board.

I prefer to add and solder only one part to the board at a time. I find this easier since there aren't so many leads that can get in the way of my soldering iron.

Also, if I add more than one part to the board I sometimes miss soldering a pad, since it isn't so easy (as you might think it would be) to see which connections are soldered.
After soldering all of the leads of the part you are soldering, it is time to cut off the excess leads. This must be done to ensure that the excess leads do not bend over and short to another lead or pad. If this happens, then there will be a connection where we do not want one.

To cut the lead, we'll use a small wire cutter. One side has flat cutting edges, and the other side has a deep groove.

Place the flat edge down, parallel to the PCB, just at the top of the little bump of solder. Squeeze the handles, and the cutting edges snap shut. Which turns the excess lead into a projectile that hits you right in your eye!

Safety Tip #3 (of 3): Always hold the lead you are cutting with one hand while you cut with your other hand.

If you always do this, you will always be safe. You may also want to wear safety glasses!

If the excess lead is too short to hold onto (but long enough to potentially short out to something on your PCB), then position the wire cutter, hold your fingers over the lead, and then squeeze. This will keep the excess lead from hitting anyone in the eye (or shorting out somewhere on your project).

If you always do this, you will always be safe.

Leads that are already very short, such as IC sockets, do not need to be cut—they have leads that are too short to bend over and make shorts.

If you make a mistake, it is totally OK. All mistakes are fixable (though some are easier than others). And making mistakes is how we learn to become better at everything we do.

While soldering is easy, unsoldering takes lots of practice. And if you make a mistake, you get to have some practice!
As you solder more, you will pick up many tips and tricks that will make soldering even easier.

But you are now totally ready to solder just about anything!

If you really want to get fancy, or if you think you will be soldering lots, or soldering a bunch of small things you can buy a decent soldering station, complete with a stand and sponge for about US$60.

If you like soldering, and want to solder well, you'll want to buy some good tools, but you do not need to spend a lot of money to get them.

You can buy a decent soldering iron (in the shape of a long, fat pencil) for about US$15.

You'll need a soldering iron stand that fits a wet sponge, which will cost you about US$6.

Then you'll need an OK wire cutter, for another US$6.

Buy a pound roll (or a 500g roll) of decent solder for about US$35 and you'll be set for years of satisfying soldering.

If you really don't need more, but you might also want long nose pliers (about US$6) and wire strippers (about US$10). And safety glasses can be bought for as little as US$2.

If you can get it, I recommend 60/40 tin/lead with rosin core. (As I mentioned before, lead-free solder will work fine, but it is not as easy to work with).

Enjoy!
Ohms Law

The relationship between Voltage, Current and Resistance in any DC electrical circuit was firstly discovered by the German physicist Georg Ohm, (1787 - 1854). Georg Ohm found that, at a constant temperature, the electrical current flowing through a fixed linear resistance is directly proportional to the voltage applied across it, and also inversely proportional to the resistance. This relationship between the Voltage, Current and Resistance forms the bases of Ohms Law and is shown below.

Ohms Law Relationship

\[ \text{Current, } I = \frac{\text{Voltage, } V}{\text{Resistance, } R} \text{ in Amperes, } A \]

By knowing any two values of the Voltage, Current or Resistance quantities we can use Ohms Law to find the third missing value. Ohms Law is used extensively in electronics formulas and calculations so it is "very important to understand and accurately remember these formulas".

To find the Voltage, (V)

\[ V = I \times R \]

V (volts) = I (amps) \times R (Ω)

To find the Current, (I)

\[ I = \frac{V}{R} \]

I (amps) = V (volts) \div R (Ω)

To find the Resistance, (R)

\[ R = \frac{V}{I} \]

R (Ω) = V (volts) \div I (amps)

It is sometimes easier to remember Ohms law relationship by using pictures. Here the three quantities of V, I and R have been superimposed into a triangle (affectionately called the Ohms Law Triangle) giving voltage at the top with current and resistance at the bottom. This arrangement represents the actual position of each quantity in the Ohms law formulas.

Ohms Law Triangle

![Ohms Law Triangle](image)

and transposing the above Ohms Law equation gives us the following combinations of the same equation:

\[ V = I \times R \]

\[ I = \frac{V}{R} \]

\[ R = \frac{V}{I} \]

Then by using Ohms Law we can see that a voltage of 1V applied to a resistor of 1Ω will cause a current of 1A to flow and the greater the resistance, the less current will flow for any applied voltage. Any Electrical device or component that obeys "Ohms Law" that is, the current flowing through it is proportional to the voltage across it (I α V), such as resistors or cables, are said to be "Ohmic" in nature, and devices that do not, such as transistors or diodes, are said to be "Non-ohmic" devices.

Power in Electrical Circuits

Electrical Power, (P) in a circuit is the amount of energy that is absorbed or produced within the circuit. A source of energy such as a voltage will produce or deliver power while the connected load absorbs it. The quantity symbol for power is P and is the product of voltage multiplied by the current with the unit of measurement being the Watt (W) with prefixes used to denote milliwatts (mW = 10⁻³W) or kilowatts (kW = 10³W). By using Ohm's law and substituting for V, I and R the formula for electrical power can be found as:

To find the Power (P)
\[
\text{P} = \text{V} \times \text{I} \\
\text{P} \text{ (watts)} = \text{V} \text{ (volts)} \times \text{I} \text{ (amps)}
\]

Also,

\[
\text{P} = \text{V}^2 \div \text{R} \\
\text{P} \text{ (watts)} = \text{V}^2 \text{ (volts)} \div \text{R} \text{ (}\Omega\text{)}
\]

Also,

\[
\text{P} = \text{I}^2 \times \text{R} \\
\text{P} \text{ (watts)} = \text{I}^2 \text{ (amps)} \times \text{R} \text{ (}\Omega\text{)}
\]

Again, the three quantities have been superimposed into a triangle this time called the Power Triangle with power at the top and current and voltage at the bottom. Again, this arrangement represents the actual position of each quantity in the Ohms law power formulas.

**The Power Triangle**

![Power Triangle Diagram]

and again, transposing the basic Ohms Law equation above for power gives us the following combinations of the same equation to find the various individual quantities:

\[
\text{P} = \text{I} \times \text{V} \\
\text{I} = \frac{\text{P}}{\text{V}} \\
\text{V} = \frac{\text{P}}{\text{I}}
\]

One other point about Power, if the calculated power is positive in value for any formula the component absorbs the power, that is it is consuming or using power. But if the calculated power is negative in value the component produces or generates power, in other words it is a source of electrical energy.

Also, we now know that the unit of power is the **WATT**, but some electrical devices such as electric motors have a power rating in the old measurement of "Horsepower" or hp. The relationship between horsepower and watts is given as: 1hp = 746W. So for example, a two-horsepower motor has a rating of 1492W, (2 x 746) or 1.5kW.

**Ohms Law Pie Chart**

To help understand the relationship between the various values a little further, we can take all of Ohm’s Law equations from above for finding Voltage, Current, Resistance and Power and condense them into a simple Ohms Law pie chart for use in AC and DC circuits and calculations as shown.

**Ohms Law Pie Chart**

![Ohms Law Pie Chart Diagram]

As well as using the **Ohm’s Law Pie Chart** shown above, we can also put the individual Ohm’s Law equations into a simple matrix table as shown for easy reference when calculating an unknown value.
Example No1

For the circuit shown below find the Voltage (V), the Current (I), the Resistance (R) and the Power (P).

\[
\begin{align*}
I &= \text{2A} \\
V &= \text{24V} \\
R &= \text{12Ω} \\
P &= \text{48W}
\end{align*}
\]

Voltage \[ V = I \times R = 2 \times 12Ω = 24V \]
Current \[ I = V \div R = 24 \div 12Ω = 2\text{A} \]
Resistance \[ R = V \div I = 24 \div 2 = 12\text{Ω} \]
Power \[ P = V \times I = 24 \times 2 = 48\text{W} \]

Power within an electrical circuit is only present when BOTH voltage and current are present for example, in an Open-circuit condition, voltage is present but there is no current flow \( I = 0 \) (zero), therefore \( V \times 0 \) is 0 so the power dissipated within the circuit must also be 0. Likewise, if we have a Short-circuit condition, current flow is present but there is no voltage \( V = 0 \), therefore \( 0 \times I = 0 \) so again the power dissipated within the circuit is 0.

As electrical power is the product of \( V \times I \), the power dissipated in a circuit is the same whether the circuit contains high voltage and low current or low voltage and high current flow. Generally, power is dissipated in the form of Heat (heaters), Mechanical Work such as motors, etc Energy in the form of radiated (Lamps) or as stored energy.
Resistor Value Examples

First Ring is units
Second Ring is Ten
Third Ring is number of zero’s

Example of Color Rings

<table>
<thead>
<tr>
<th>First Ring</th>
<th>Second Ring</th>
<th>Third Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black = 0</td>
<td>Red = 2</td>
<td>Red = X 100, Brown = X 10</td>
</tr>
<tr>
<td>Red = 2</td>
<td>Red = 2</td>
<td>2200 ohms</td>
</tr>
<tr>
<td>Black = 0</td>
<td>Red = 2</td>
<td>020 ohms</td>
</tr>
</tbody>
</table>

Test of Color Rings

<table>
<thead>
<tr>
<th>First Ring</th>
<th>Second Ring</th>
<th>Third Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown = ___</td>
<td>Green = ___</td>
<td>Brown = ____ = ____ohms</td>
</tr>
<tr>
<td>Green = ___</td>
<td>Red = ___</td>
<td>Yellow = ____ = ____ ohms</td>
</tr>
</tbody>
</table>