Atomic Structure (a review)

Why can't we see an atom if we have a powerful enough microscope?

It's almost improper to say we see matter. What we see is reflected energy. When you hit a bell, it resonates at a frequency depending on the properties of the bell. When radiated energy (photons) hit an atom, the atom resonates at a frequency (or frequencies) also. There is a narrow band of frequencies that we can see from about 400 nm to 700 nm in wavelength. Below this frequency is Infrared, energy we can perceive as heat, and radio waves. Above this frequency is Ultraviolet, and beyond.

When a wave of photons hit a group of atoms, the electrons are raised to higher energy levels. Energy is stored in the electron at a higher energy level. Eventually the electron acquires an excessive amount of energy than can be retained. The electron gives off the excess amount of energy, which gets radiated out (as photons or phonons), and falls back to the lower energy level it should be. This process is repeated endlessly. The rate of absorption and radiation of energy gives the radiated energy a frequency. Often that frequency falls into the spectrum of frequencies we see as visible light. Now that we know how we see, let's see what there is to see.

An atom is made up of a cloud of electrons surrounding a nucleus. The nucleus is made up of Protons and Neutrons, which are made up of quarks, which are made up of... (We may never know the answer to this endless question). An atom so small, it is on the edge of imagination. The nucleus of the atom is smaller, and electrons are smaller still. The electrons are made of not much more than energy, themselves. They have almost no mass, but a predictable amount of energy. The electrons are in motion around the nucleus, traveling at about 300,000 km per second. When you take into consideration how small the atom is, the electron is making a phenomenal number of revolutions per second. The question of where is the atom at any given instant is meaningless because we can't define an instant small enough to say when the electron is at any instant. The Uncertainty Principle may as well be a poem.

Most books show a picture of an atom with the electron in close proximity to the nucleus. A more realistic drawing would be difficult to put on a page. Speaking in non-specifics, if the nucleus were the size of a quarter, the first electron shell would be about a hundred meters away. Specifics would depend on Temperature, Pressure, and Gravity. The orbit (not the best word to choose) of one electron around an atom is roughly spherical, as with Hydrogen. In Helium, with two electrons in the first shell, the orbits of the two electrons take on the shape of a fat ice cream cones, opposite on another. The atom takes on a shape somewhat like an hourglass. This atom is constantly tumbling in a random pattern, influenced by external forces. The nucleus also is doing a random tumble with the protons rotating to chase the position of the electrons. In the next more complex atom, Lithium, the electron shell has three electrons. Since the first shell can only have two electrons, the third electron starts another shell. This orbit takes a toroid shape around the middle of the hourglass. This shell is also influenced at any given instance by where the electrons are in the inner shell, as well as external forces. As more complex structures are formed, the shape takes on more complex configurations.

The atom is primarily nothing but empty space, made of unimaginably small particles with relatively great distances between them.

These great distances are filled with absolutely nothing we can perceive as stable matter or energy.

What is there to see?

Conductors, Insulators, and Semiconductors

Whether an atom is a good conductor of electricity depends on how many electrons are in the outer shell of the atom (the Valence Shell). One, two, or even three electrons in the valence shell make good conductors. The electrons are easily pulled away by external force. If the outer shell has seven or eight electrons, it's hard to free an electron. These elements make bad conductors, or good insulators. In between conductors and insulators is a group of elements called Semiconductors. They are neither good conductors, nor are they good insulators. Carbon, Silicon, and Germanium, are popular semiconductor materials.

These statements are true whether we are talking about atoms or molecules. Even a good conductor can make a bad conductor when included in a molecule. To put it in a simple case, Iron is a good conductor. When formed into molecules with Oxygen (as in Iron Oxide, or rust) it becomes a bad conductor. The valence electrons of the Iron are tied up by the Oxygen, and are no longer available to conduct electricity. Likewise, a semiconductor may be doped with another poor conductor to make a reasonably good conductor.

Conduction

I have read some appalling stories about how electricity flows in basic electronics books. I agree simplification is necessary, but it shouldn't be misleading. One such story says that electrons are at rest (not moving, shown sleeping) until a voltage is applied, and then suddenly take off at 186,000 miles per second. Another describes AC as electrons at rest, slowly increasing in speed until they reach a maximum, then decrease in speed to zero, then increasing slowly in the other direction to a maximum speed, finally slowing down to zero again to make a complete cycle. That such things should ever be taught, especially in the 1990's, is frightening.

Of course, that someone in the future may look back at my descriptions, and being equally appalled by my words, is also a possibility. Nonetheless, I continue...

Electrons (at standard temperature, pressure and gravity) are never at rest. They are constantly in motion from atom to atom, or molecule to molecule, at a speed of 300,000 km per second (or 186,000 miles per second, if you prefer), or closely at that speed anyway. I don't have any instrument that would measure the difference. Since this motion is random, there is no perceptible current.

When a voltage is applied to a conductor, the electrons of the conductor are both repelled by the more negative potential, and attracted to the more positive potential. The movement is almost instantaneous, although, it may take an individual electron a little longer to move from point A to point B (at normal temperature, pressure and gravity, anyway). At extremely low temperatures, super conduction becomes a factor, resistance disappears, magnetism does weird things, but that's another story.

If we could imagine what is happening somewhere along the conductor at the atomic level, we may see something like this:

As an electron feels the applied negative voltage, and the attracting positive voltage, it is motivated to leave its present orbit around the nucleus, and move to an atom closer to the more positive charge. This action leaves a hole (an absence of an electron) in the atom it just left. The atom with the hole now has a more positive charge than it used to, and attracts another electron from an atom closer to the more negative charge. This tension between the free electrons and the positively charged nucleus is the source of that quality we call voltage.

What we can imagine happening is electrons (negative charges) moving from negative to positive, and holes (positive charges) moving from positive to negative.

If you take a narrow necked bottle filled with water, and pour it out, do you see water coming down, or bubbles coming up? The same is true for electric current, with the electrons flowing in one direction, and holes flowing in the opposite direction. The concept of hole flow becomes important when we get to the study of semiconductors.

Electromagnetism

An electron has a magnetic field. As long as all the electrons are moving in a random direction, the magnetic fields cancel one another out, and no perceptible field is present. When a voltage pushes the flow of electrons in a unified direction, these magnetic fields add to one another and a magnetic field is present around the wire.

If we wind the wire into a coil, these magnetic fields add to one another, and a strong magnetic field develops around the coil. We can simulate a permanent magnet by applying a DC voltage to the coil. The negative side of the coil, takes on a polarity equal to the North Pole of a magnet. There is no notable difference between the magnetic field of a permanent magnet, and that produced by a current through a coil.

The electromagnet has the advantage of being one we can control. We can use this electromagnet phenomenon to make an electric motor, or an electric generator. Large electromagnets are used to move cars and scrap steel around in junkyards. There are countless uses for electromagnets.

Induction

An electromagnetic field crossing a conductor induces a voltage in the conductor. Likewise, a wire crossing a magnetic field gets a voltage induced into it. As long as there is a difference of motion between the wire and the magnetic field, there will be an induced voltage in the wire. This happens at the component level, as well as at the atomic level. At the atomic level, the electron moving from atom to atom creates a magnetic field, which crosses the electron structure of neighboring atoms. The electrons of the neighboring atom are affected by this magnetic field, and the electrons are motivated to move also (but in the opposite direction as the electron that caused the magnetic field). This induced current is an opposition to a change in incoming current, and this effect we call inductance. Any conductor has an inductance of some kind (at standard temperature, pressure, and gravity). In superconductor environments this world is upset, see Bose-Einstein Condensate).

If we wind turns upon turns of wire around one another, this induction characteristic is magnified, and we create strong magnetic fields. If we place another winding of wire close to the original coil of wire, we get an induced current in the second winding. This makes a transformer with primary and secondary windings.

Transformers

If we take one winding of wire, and wind a second winding around it, the magnetic field produced by one winding will induce a voltage in the second winding. The voltage induced in the second winding will depend on the ratio of windings. If the first winding, we'll call it the primary, has the same number of turns as the second winding, we'll call it the secondary, the voltage on the secondary will be equal to that of the primary. (Neglecting any loss. In the classroom, all our transformers are perfect. In the real world, transformers are less than 100 percent efficient. It depends on the design of the transformer.)

If the secondary has more windings than the primary, we have a step-up transformer. That is, the voltage on the secondary will be higher than the primary. If the secondary has fewer windings than the primary, we have a step-down transformer. That is, the voltage on the secondary will be lower than the primary. An isolation transformer is designed to have the same voltage on the secondary and primary. In all cases, the voltage on the secondary has no reference to ground. That is, it provides isolation from ground on the primary circuit.

Please note than we cannot gain power in the transformer. If we step up voltage on the secondary, we have less current available to draw. If we step down voltage, we have more current available. Watts available in the primary (Volts times Amps) will always be the same in the secondary. That is, the same maximum Watts available. How much current we have flowing in the primary depends on how much current we have flowing in the secondary, which depends on the characteristics of the load.

Step-down transformers will have fewer turns of larger wire on the secondary. Fewer turns means lower voltage. The larger wire is to accommodate higher current.

So, how does drawing current from the secondary of a transformer result in more current flowing through the primary? What’s the connection? Are the electrons in the secondary linked to electrons in the primary by the magnetic field?

Yea! Right! And the universe is one infinitely inter-linked universal entity. Let’s get out of the dark ages, shall we? The answer is Permeability.

When we pass an AC current through a coil, it creates a magnetic field around the coil. The inductance (AC resistance) of the coil depends on the size of the wire, the number of windings, and the nature of whatever the coil is wound around. Is it air, ferrite, iron, lead? Each type of core material has a quality called permeability. If we bring a piece of metal close to a coil, it effects the permeability of the coil just as changing the type of core material would. This changes the inductance of the coil, which changes the current through the coil. (Somewhat like a metal detector, right?) The secondary winding, and its load, also affects the permeability of the primary winding. When we pull more current from the secondary of a transformer, the permeability of the transformer changes, which changes the inductance of the primary, which causes more current to flow.

Keep in mind, in a transformer, the magnetic field must be constantly moving. Transformers work on AC, not DC. If we apply DC to a coil, we get an inductive reactance only on the rising and falling edges of the signal. While the DC level is constant, the only effect the coil has on the circuit is the resistance of the wire. When the signal rises the magnetic field expands, and we have some degree of energy stored in the magnetic field around the coil. When the DC level drops, the magnetic field collapses, inducing a current flow in the wire in the opposite direction as the original signal. This inductive kick can be a hazard to the components of the circuit if it is not taken into consideration. Note the presence of protective diodes across coils, and transistors designed to drive inductive loads.

Capacitance

A capacitor is two (or more) plates of conductive material, separated by an insulator. In a capacitor, the insulator is called a dielectric. Since there is no actual electrical contact between the two plates, it would seem that current would not be able to flow through a capacitor. The electrostatic pressure caused by the voltage being applied to the plates can cause electrons to be pushed off the more positive plate, resulting in a charge between the capacitor plates. The closer the plates are together, or the larger the plates, the higher the capacitance. The material of the dielectric also plays a role in capacitance. Different materials have a different dielectric constant (k). Air and a vacuum have a dielectric constant of 1 (the reference value by which all other materials are compared). To make a short list:

Material	Dielectric Constant
Air	1
Vacuum	1
Waxed Paper	3.5
Mica	6
Glass	8
Ceramic	100+ (depending on structure and type)
Metal Oxides	(higher)

What this means is that, roughly speaking, a capacitor made of mica one thousands of an inch thick would have six times as much capacitance as one of similar size of air or a vacuum. Many other materials are popularly used. Tantalum and Aluminum oxides are popular. Plastic films are good for making capacitors for audio circuits, or RF applications, or where high reliability is required. Consult a parts distributor's catalog for all the possibilities and applications.

I remember reading somebody's description of a capacitor's operation as saying that the charge of a capacitor was stored in the distorted field of the electrons in the dielectric. It would seem from that, a vacuum could not be used as a dielectric in a capacitor. I don't think that is so.

Another story I have read is that a capacitor stores electrons. I can’t let that one pass either. For every electron that goes into a capacitor, another electron leaves. The number of electrons stays the same. Capacitors store an electrical charge (not electrons).

When a capacitor charges, the electron entering the negative side pushes an electron off the positive side, storing a charge equal to one electron. But, the capacitor stores charges, not electrons.

The charge is stored in the area of the dielectric, between the plates, but it is improper to say the charge is stored in the material of the dielectric. This subject leaves a need for a better explanation. It can't be stored in the material of the dielectric, because even a vacuum may be used to make a capacitor. The material of the dielectric, as described above, in deed, affects capacitance but there is something missing to this story. Some would say that the charge is stored in the plates of the capacitor. This is a good concept. We can make a capacitor without material for a dielectric, but we can't make one without plates.

The best story I would repeat about capacitor operation concerns electrostatics. The charge is stored in the electrostatic field, between the plates. All the formulas work, and dielectric constants work into the formula.

To get up to date on capacitors, I remember my High School electronics teacher talking about capacitors and how large a Farad was. In his world of paper and plastic capacitors, a one Farad capacitor would "fill this whole room". Today, a one Farad capacitor is about a half cubic inch, and is used on CPU boards in place of a battery to keep power to CMOS RAM when power is removed. (High School was a long time ago for me.)

Questions I've never answered about capacitors

Not being one of those to claim to know everything, or make up answers that are incorrect, just to have an answer (I hate when people do that). "An educated person is firmly aware of what he doesn't know," quote me on that one.

By what force does the capacitor actually transfer the energy from one plate to the other? Some books describe it in the same terms they use for magnetism, but, to me, magnetism is not at work here, is it? If we put two metal plates in a magnetic field, we don't get them to take on a charge. I have never done any experiments concerning capacitors in a magnetic field, and having it affect the capacitance, or charge the capacitor.

Some books say it is electrostatic forces at work, as opposed to electromagnetic. I have the same questions concerning this story. Never having done any experiments, I couldn't support or deny the story. It just doesn't sound like a complete theory to me.

We can readily show that the capacitor does work, but all our stories are empirical logic, not rational theories, supported by solid explanation of cause and effect.

Most of the explanation are only explanations-by-comparison, and say "it kind of works, like ..." Don't give me this type of explanation. It sounds like "The principle of Correspondence" from Hermetic philosophy. Such obsolete ways of thinking should have been tossed aside long ago. If you don't really know what you are talking about, say so. Don't make up a bunch of BS just to justify the letters behind your name, in hopes that nobody realizes you don't know what you are talking about.

If anybody has a better explanation of how capacitors work, I'm seriously interested in listening.

Voltage and Current

Voltage is the motivating force behind the flow of electrons. Current is a matter of how many electrons are in motion passed a given point in a given time.

To keep up with a current trend (no pun intended) to avoid the term "current flow" to describe the flow of electrical charges, I will try to avoid the use of the term here, also. Current is already defined as the flow of electrical charges, so the term current flow is like saying the flow of current flow.

Normally an atom has an equal number of electrons (with a negative charge), and protons (with a positive charge). In a conductor, when an electron is pulled away, it leaves a hole (an absence of an electron) and the forces between the electron structure and the nucleus result in a positive charge on that atom. This force is the basis of that quality we call voltage. This is a static force being exerted on the circuit at any given point with reference to another point. The presence of this voltage is what causes current to flow (whether you view current flow as positive or negative charges). Voltage doesn't flow, current flows.

Voltage is measured in Volts, and given the symbol V, or sometimes E, or EMF for ElectroMotive Force (literally, the force that motivates the electrons).

Current is measured in Amps, or Amperes, and is given the symbol A, or sometimes I, for Intensity of current flow. This is a measure of how many charge carriers (electrons or holes) pass a given point in the circuit in a given time.

Resistance

Resistance is the opposition to the flow of charge carriers (electrons or holes) in a circuit. It is a matter of how good a conductor the material is, as well as temperature, pressure and gravity. Temperature plays an important factor in resistance. Pressure and gravity have an effect in extreme conditions. This statement is true for any place in this paper that mentions STPG (Standard Temperature, Pressure and Gravity).

Resistance is measured in Ohms, and usually given the symbol R, or sometimes Omega, from the Greek alphabet. Since this text will be converted to ASCII, I couldn't give the actual symbol here; it wouldn't stay with the text.

Many texts still reference resistors as having tolerances of 20%, 10%, and 5%. I haven't seen a 10% or 20% resistor since I saw a vacuum tube. Most resistors today are 5%, with 2% values coming into popularity at a reasonable price.

The color code follows in later text, but is not worth elaborate discussion. It is worth getting to know. You can find it in any book on Basic Electronics. What is usually omitted is the fact that this same color code scheme is used for capacitors, and even diodes in some cases. Some manufacturers also use this same color code to refer to color-coded wires. A Blue wire with a red stripe would be called wire 62, and would be unique in that circuit. This makes troubleshooting a lot easier if you have to trace a wire down.

Another point not mentioned enough is that resistors don't come in all possible values you can make up with the color code. 5% resistors only come in certain values.

OHM'S LAW

Many of the "Grand Old Men of Electricity" got their name tied to an aspect of electronics to which they made contributions. The "Electromotive Force" of Volta's days is now called Volts. The "Intensity of Electrical Current" of Ampere's days is now called Amps. In a way it is a shame to getaway from descriptive names of these characteristics of electricity and use the non-descriptive terms Volts and Amps. Having said that, we will move the conversation along to Ohm's Law. Ohm states that:

$I = E/R$

In words, the formula states, "The current in a circuit is proportional to the applied voltage and inversely proportional to the resistance." What he was trying to say is that current in a circuit increases with increasing applied voltage, and decreases with increasing resistance. (My kids would say "well, duh!")

E is in Volts. E is for EMF (Electromotive Force); the force that motivates the electrons. This is the electrical pressure in the circuit that pushes (-), or pulls (+) the electrons through a circuit.

"I" is in Amps. This is the actual amount of current flowing through a circuit, or a part. "I" for Intensity.

R is in Ohms. This is how much opposition to current flow a component has.

As long as we know two of these factors, we can find the other.

$E = I \times R$

Amps times Ohms gives us Volts.

$$I = \frac{E}{R}$$

Volts divided by Ohms gives us Amps.

$$R = \frac{E}{I}$$

Volts divided by Amps gives us Ohms.

Power, measured in Watts, is an indication of how much heat a part, or a circuit, will give off, or consume. This is strictly a mathematical computation, but does equate to other units of heat or power in other sciences.

$P = E \times I$

Volts times Amps gives us Watts.

$$E = \frac{P}{I}$$

Watts divided by Amps gives us Volts.

$$I = \frac{P}{E}$$

Watts divided by Volts gives us Amps.

Basic Circuits 1

The objective of this session is to get you familiar with the fundamentals of reading a schematic, and applying Ohm's Law. We will introduce you to a few schematic symbols and build simple circuits.

Referring to schematic document number "BC 1", these are the schematic symbols of a battery, a switch, an incandescent lamp, and a resistor. Batteries and switches you may already be familiar with, we've all handled both.

Resistors

Resistors are devices made of some member of the semiconductor family, usually carbon, but not in all cases. We use resistors to tailor the amount of current we want to flow in a circuit. The schematic symbol is, as shown in the drawing.

For basic electronics classes we use resistors to symbolize "any component, in general". All components have some degree of resistance, and can be substituted by a resistor for the purpose of learning the basics of Ohm's Law. For Ohm's Law, it doesn't matter if the 100 Ohms in the circuit is a real resistor, a lamp, a heater, a motor, or what ever. It is "some component" that has a certain resistance.

Later we will get around to using real parts and learn their characteristics. For basic Ohm's Law, we are only concerned with the resistance of these devices, and use resistors to symbolize their presence in a circuit.

Flashlight

The top drawing is a schematic of a flashlight. We have a battery, a switch, and a lamp. The other side of the lamp returns to the other side of the battery, completing our circuit. We must have a complete circuit for current to flow.

We apply power from a 6 Volt battery. Our switch is either On (zero resistance and allows current to flow), or it is Off (infinite resistance, preventing current from flowing). (In the real world these extremes are not found, but this is basics, so our components work perfectly and simple.)

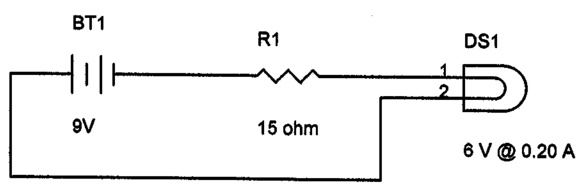
When we turn the switch on electrons leave the negative side of the battery (the smaller line), travel through the switch, through the light, and to the positive side of the battery. When the switch is off no current can flow, and the light goes out.

We have a 6 Volt battery and a light that runs on 6 Volts, so our world is correct. How much current do we have flowing? The manufacturer of the lamp states that at 6 Volts, the lamp should draw 0.20 Amps. Ohm's Law states that E/I = R, so we have 6 V divided by 0.20 Amps, or 30 Ohms.

Roll your own flashlight

Consider that you are McGyver, trapped in a room of electronic components and needed a flashlight. Looking around you, you find a 9 Volt battery, a 6 Volt lamp (rated at 0.20 Amps), and an assortment of resistors. If you try to run the lamp off of 9 Volts, it will exceed its ratings and blow out. You need to limit the current through it to 0.20 Amps, from a 9 Volt source. What resistor do you need?

You are applying 9 V. You know the lamp will drop 6 V at 0.20 Amps. A quick calculation (9V – 6V) shows that the resistor will have to drop 3 Volts across it. Ohm's Law, again, 3 V / 0.20 A = 15 ohms. We look through our drawers of resistors and pull out a 15-Ohm resistor, and build our circuit.



What component do we use to select the amount of current we want to flow in a circuit?

1) What is the schematic symbol for a resistor?

2) What is the schematic symbol for a battery?

3) What is the schematic symbol for an incandescent lamp?

4) What is the schematic symbol for a wire?

5) What is the schematic symbol for a switch?

6) In order for current to flow we must have _________________.

COMPONENTS

Resistors

The purpose of resistors is to determine the amount of current we want to flow in a circuit. Resistors (perfect resistors, anyway) have the same resistance to AC or DC. If you have had the chance to play with components, one of our basic exercises is a series circuit made up of a resistor and an LED. The voltage drop across the LED is fairly constant over a range of operating current. We select the resistor to get the current we desire to flow through the LED.

A resistor is a semi conductive material, typically carbon or some metal oxide, that is neither a good conductor, nor a good insulator.

Reactors (capacitors and inductors)

In contrast to resistors, there is a group of components called reactors. They exhibit a different resistance to AC than to DC. These are basically capacitors and inductors. Reactance is resistance to an AC signal. Capacitors have Capacitive Reactance. Inductors have Inductive Reactance.

Resistors

Resistors are made of a semiconductor material, usually carbon, and are rated according to how much resistance it has, in ohms. Leaded components are typically cylindrical in shape, with leads coming out the ends (axial case). Colored bands show the rating of the resistor, in ohms. The physical size of the resistor indicates its wattage.

The color code used for resistance is an industry standard, used for many other components. This color code is worth getting to know.

The first three bands follow this system:

Black	0	Green	5
Brown	1	Blue	6
Red	2	Purple	7
Orange	3	Gray	8
Yellow	4	White	9

The first two colors are interpreted as numbers (significant digits). The third is the multiplier (how many zeros should be added to come up with the resistance). For instance, a resistor with yellow, violet, and red stripes would be 4700 ohms.

To get resistor values below 10 ohms, the third band may be Gold or Silver. A Gold third band indicates a value between 1.0 and 9.1 ohms. A Silver third band indicates a value between 0.1 and 0.91 ohms.

The forth band gives the percentage value:

Gold	5%
Silver	10% (seldom seen anymore)
(none)	20% (really old, you are not likely to ever see these)

Many schemes have been created to aid in remembering the color code.

Black	(Bad)	0	Violet	(Violet)	7
Brown	(Boys)	1	Gray	(Generally)	8
Red	(Race)	2	White	(Wins)	9
Orange	(Our)	3		(the)	
Yellow	(Young)	4		(Gold)	5%
Green	(Girls)	5		(and)	
Blue	(But)	6		(Silver)	10%

Not all possible values are represented. The pattern they follow is another thing worth spending some time with, and getting to know. 5% values are 5% values, whether they are resistance, capacitance, voltage, or anything else. The pattern formed is the same.

10	22	47
11	24	51
12	27	56
13	30	62
15	33	68
16	36	75
18	39	82
20	43	91

Surface mount resistors

Surface mount components are small rectangular, flat packages. The top surface is usually black and the sides are white. The resistance is stated in numbers, as if they were colored bands. A resistor of 4700 ohms would say “472”.

Surface mount resistors, being smaller packages, cannot dissipate the heat a larger package can, and typically have ratings of 1/8th, 1/10th, or 1/16th of a Watt. These are a ceramic substrate with the resistive material covering the top side. A coating covers the resistive material, usually black. The ends are covered on three sides (top, end, and bottom) with a metal cap that makes the connection to the board.

2% and 1% devices

On occasion you may find resistors with five colored bands, instead of four. The fifth band will usually be Brown (1%), or Red (2%). These values have three significant digits, followed by the multiplier, and Brown or Red. A resistor with Brown, White, Brown, Red, Brown stripes would be 19,100 ohms, 1%.

Most resistors you will encounter in the gaming industry will be the 5% variety.

Another thing you may want to watch out for. On schematics, decimal points often become blurred, or faded out. There is a trend in schematic creators to label resistor values, avoiding decimal points. Instead of labeling a resistor as 1.2K ohms, it will say 1K2. In either case the resistor is 1200 ohms.

Construction

Most resistors today are “Carbon Film” construction. Physically, these are a ceramic rod with carbon film coating it, and metal caps on each end to connect the leads on. A plastic coating covers the resistor, and colored stripes show the rated value.

Higher wattage resistors are usually “Metal oxide” instead of carbon. If you remember from earlier lessons, metal oxides are not good conductors, and the oxides may be tailored to give a specific resistance.

Older resistors were “Carbon Composition” construction. These devices are a rod of carbon with leads attached, and covered with a plastic (brown) coating. These are the ancient devices that came in 20%, or 10%, and seldom 5%, ratings. Avoid these devices. Carbon Composition devices offer no improvements, and have a few design flaws.

Just to give you an idea of how old these devices are, the last time I saw a 20% resistor in a circuit, it was a hand wired chassis with vacuum tubes. The last time I bought them, they were manufactured in 1971.

Carbon Composition devices change effective resistance at higher frequencies. At high frequencies we get a phenomenon called “Skin Effect”. The current tends to stay close to the surface of the device. For carbon composition devices, this means that the whole resistor no longer affects the current.

Metal oxide, and metal film devices are a ceramic rod with all the resistor material on the surface. Higher frequencies do not get this skin effect.

Failures in resistors

Other than suffering physical damage, the only way resistors fail is to burn up, and open. Resistors do not short out. A given physical size case is rated at a certain wattage, typically ¼ W. As you pull current through it, we get a voltage drop across the resistor (I x R). When the voltage drop and current exceeds the rated wattage value (E x I), the body can no longer dissipate the heat, and it gets hot. In extreme conditions the resistor may get so hot it actually bursts into flame. Metal film devices are capable of dissipating more heat for a given size package. Metal film resistor also are covered with a colored ceramic coating, instead of plastic. These devices are flameproof. They are guaranteed not to burst into flame. They may get hot enough to burn another nearby component, but the resistor will not burst into flame.

Wire Wound resistors

Lower wattage resistors are typically 1/4 W. Some are 1/8 W, or 1/2 W, or 1 W. Above 1 Watt, we need a design that can tolerate higher temperatures. The resistive element is usually a metal wire that is not a good conductor, like tungsten, or a compound like Nickel-chromium (nichrome). The case is ceramic material, round or square, to tolerate the high heat that may be encountered. Usually these devices have their values printed in numbers, or as a coded part number. Colors tend to change under heat, so colored bands are avoided.

Resistance

Continuity is (theoretically) zero Ohms. No resistance. An open is (theoretically) infinite resistance. Maximum resistance. The real world seldom actually sees either extreme. Continuity is any resistance low enough to allow current to flow easily. An open is a break in the circuit that allows no meaningful current to flow. Resistance is what the real world sees as an opposition to current, measured in Ohms.

Wire has some resistance, usually measured in Ohms per Foot, and is usually some number close to zero, a small fraction of one Ohm for most measurements. For long runs, even this resistance can be meaningful.

Capacitors

A capacitor is two (or more) conductive plates separated by an insulator. They have a very high resistance to DC, and a resistance to AC that changes with frequency. Capacitors have less resistance as the frequency gets higher.

The forces at play here are the electrostatic charges that build up on the plates. Even if there is no complete path through the capacitor we can still pass a change in voltage through the capacitor. As we apply a voltage to one plate of a capacitor it builds up a charge on that plate. The insulator between the plates is so thin that the electrostatic field on one plate can be felt through the insulator and move affect electrons on the other plate, leaving a charge between the plates.

For the purpose of capacitors (and batteries) this insulator is called a dielectric. A capacitor can store a charge between its plates, just like a battery. This is another characteristic of capacitors, the ability to store a charge.

Capacitance is measured in Farads. One farad is a relatively large value. Most capacitors are rated in micro-Farads (millionths of a Farad). This value indicates the capacitors ability to store a charge. A capacitors resistance to AC is called Capacitive reactance, and changes with the applied frequency according to the formula:

Xc = 1/(6.28 x F x C)

Xc is Capacitive reactance, measured in Ohms
6.28 is actually 2 x pi (3.14159…)
F is the frequency, in Hertz
C is the capacitance, in Farads

Inductors

An inductor is basically a winding (or windings) of wire. Inductors have very little resistance to DC, and a resistance to AC that also changes with frequency. Just opposite that of capacitors, as frequency gets higher inductors have a higher resistance.

Light Emitting Diodes

w - wavelength of the light emitted, in nm (nano-meters), approximate values
V - Typical forward voltage of the junction

w	Color	V	
940	IR	1.3 to 1.7	(lowest frequency)
900	IR	1.2 to 1.6	
880	IR	2.0 to 2.5	
690	Red	2.2 to 3.0	
640	Red	1.6 to 2.0	
615	Orange	1.8 to 2.7	
590	Yellow	2.2 to 3.0	
565	Green	2.2 to 3.0	
430	Blue	3.6 to 5.0	
370	UV	(only recently came out around 2002, no details at time of printing)	

The white 2-leaded LEDs are really blue LEDs with a phosphor surface that glows white.

As with any diode, the forward conduction voltage depends on the chemistry of the semiconductor material. All diodes emit light somewhat. The light comes from electrons combining with holes in the junction, and releasing excess energy as radiation. With proper construction and materials, we can design Light Emitting Diodes with radiation in specific frequencies we can see. In doing so, the forward conduction voltage raises to 1.2 V, to 3.0 V, or more. The reverse breakdown voltage also becomes dangerously low (around 4 to 6 Volts), and needs to kept in consideration when designing. In a Germanium diode, this forward voltage would be closer to 220 mV. In Silicon, it may be 600 mV to 1 V. Most LEDs are single junction devices with unusual forward voltages. Some of the materials used in LEDs are Indium Phosphide, Gallium Arsenide, Gallium Arsenide Phosphide, Gallium Phosphide, Gallium Nitride, just to name a few.

In contrast, your typical incandescent tungsten light covers 400 nm to 950 nm, and is more yellow than white. It lacks somewhat in the UV range. A good white light would cover from UV to IR. (Maybe a Mercury Vapor or Halogen bulb might be closer to white.)

The sensitivity of CdS cells covers a range from 500 nm to 650 nm, and lacks sensitivity in the IR range. I just thought I'd throw that in here. It didn't seem to fit anywhere else.

The wave-like nature of matter

According to Einstein - E = mc2
According to Planck - E = hv

E = Energy
m = mass
c = the speed of light
h = Plank's constant (6.63 x 10-27 erg-sec)
v = frequency
w = wavelength

It follows that mc2 = hv.
or
m c c = h v

if w v = c (wavelength x frequency = the speed of light)

then substituting wv for one of the c in mcc=hv, we get mcwv = hv

if we divide each side of the equation by wv we get mc = h/w

To solve for wavelength we need to:
multiplying each side by w, we get wmc = h

dividing each side by mc we get w = h/mc

Putting this formula into words, what it means is: matter has a wavelength (h/mc) which is equal to Planck's constant divided by momentum (mc). It follows that matter may be viewed as a function of a wave like motion, or matter is a wave function.

Not that I'm disputing the conclusion, but I don't have total confidence in people that substitute math for logic. I read in a book recently that according to mathematical models, in a collapsing universe, time will run backwards. Specifically stating that instead of a glass dropping off a table and shattering, the pieces of glass would gather together into a glass and jump up on a table assembling. I'm sorry. I have a hard time following that one. He may be a brilliant mathematician, but I have to disagree with the conclusion.

As far as the wave - particle question goes, I can agree with the conclusion, to a limit, but the method of reasoning seems ill conceived. Is Einstein's "E" the same as Planck's "E"? Just because something would have a wave characteristic, doesn't mean it is a wave. A bell resonates at a frequency, that has a wavelength, but let's not confuse the wavelength for the bell.