MECHATRONICS CONTEST

GUIDELINES, NOTES, QUESTIONS AND ANSWERS FOR STUDENTS, TEACHERS & PARENTS

Part 1: For both Groups: Juniors (Grade 9 & 10) and Seniors (Grade 11 & 12)

Electricity Guidelines.

There is electricity in almost all houses and industries where there is civilisation. Homes in Canada, U.S.A., Japan and some other parts of the world get 110-120Volts Alternating Current (AC) at 60 Hertz (Hz) from the electricity grid. Homes in United Kingdom, India, Malaysia, and many Asian, European, African, Australian countries get 220-240 V AC at 50 Hz. To know more about voltages, frequencies used and the plugs and sockets worldwide, you may visit: http://en.wikipedia.org/wiki/Mains_electricity_by_country#Voltage_ranges

These mains voltages are too high and dangerous for students to work with as they can result in injury or even death. Adults work at these voltages after learning how to safely handle such voltages and use safety equipment and suits. So we will not be using these voltages in our projects.

We will only use Battery voltages of not more than 12 Volts DC that you get from Car Batteries in our notes and Questions and Answers. For our experiments and Car project we will be using only 6 Volts DC that you get from 4 alkaline cells.

Difference between electrical and electronics circuits.

Electrical circuits usually have resistances (such as lamps, heating elements), inductors (as in transformers, inductance coils, motors, generators) and capacitors.

Electronics circuits may have some or all of the above and semi-conductors, (diodes, LEDs, Transistors, IC chips, etc.) Collectively resistances, inductors, and capacitors and semi-conductor devices are known as electronic components).

In fact, nowadays most traditional electrical equipment uses electronic components. So much so that to make a distinction between electrical and electronic circuits is difficult. They overlap so much.

The Institution of Electrical Engineers (IEE) has now become Institution of Electrical and Electronic Engineers (IEEE). Even in Electric Power Transmission many electronic components are in use and its use is expanding.

Mechanics and Mechanical Equipment.

These involve machines which use levers, gears, pulleys, belts, wheels and many other parts. They use different materials to suit the various requirements and functions of the parts. A mechanical engineer has to learn and understand about the strengths and properties of the materials used/selected for use, speeds, acceleration, forces, friction, torque, work, energy, power etc. to design and construct machines which can last a long time, efficiently and safely and do the exact work expected of them.

Mechatronics

Mechatronics is the new engineering where Mechanical, Electrical, Electronics, controls by software and many other engineering knowledge and of course Math converge. In our Mechatronics car we use a little of each of these areas and understand the basic math and science involved in most of these fields. In our project we are not using any microcontrollers and controls by software. We hope to introduce these in future projects.

LET US LEARN A LITTLE ABOUT THE MECHANICS REQUIRED:

Note on Motor Specifications: We tried to get the performance curves for the toy motor we supplied. However neither the supplier nor the manufacturer was able to get them. For the purpose of the design of our Mechatronics Car, we give below, sufficient data to be able to design a good car and answer the judges' questions:

Motor is designed to operate from 4.5. To 6 Volt D.C. power sources.
No load speed = 8,000 revolutions per minute (rpm).
Stall torque = 100 gm-cm = approximately 1 N-cm.
Best efficiency of 60% occurs at around 800 rpm.
Highest Mechanical Power Output occurs at 4,000 rpm.
For your design purposes we recommend you to assume an operating speed of 5,000 rpm when driving the car. It would generate a torque of 40 gm-cm (=0.4 N-cm) at this speed when a 6 Volt Battery is used to power the motor. The current drawn by the motor is about 0.6 Amps

Now we will see how we can use the values above for our designs for belt driven pulley, gear train and Propeller designs.

Glossary of terms to recollect:

Force = mass x acceleration: Measured in Newtons, kg-force, kg-weight, gm-force, gm-weight, lb-weight and other units.

Weight = Force with which the earth attracts a body due to gravity. It has same units as Force. But traditionally the word "weight" is omitted when we weigh fish, meats, vegetables and ourselves. Doctor's office will weigh you in kg and not kg-weight or Newtons.

Torque = Moments = Force x Distance from turning point: Measured in Kg-metre, Newton-Metre, N-cm, gm-cm and other units.

Work = Force x Distance moved. Measured in Newton-metre or Joule, Kg-m etc. it has the same units as Torque, but do not get confused between the two.

Energy is closely related to work. To do work you need energy. When you lift a body, the work you do is stored as **Potential Energy**. When you throw a ball, the work you do is converted to **Kinetic Energy** in the ball. Law of Conservation of Energy states that you cannot create or destroy energy – it can be converted from one form to another. In a motor you convert Electrical Energy into Mechanical Energy. In a battery you convert chemical energy to electrical energy: Has the same units of measurement as Work.

Power is the rate of doing work or rate of conversion of energy. The power of an electric motor =torque at the shaft x angular velocity). Power is measured in Joules/Sec: Also called Watts. Other measures are horsepower (=746 Watts), foot-pound per minute etc.

Belt driven pulleys.

You can transmit work or energy from one pulley to another using endless belt. They turn in the same direction in Fig 1a, and in opposite directions in Fig 1b.

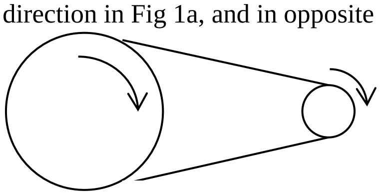


Fig. 1a: Direct drive

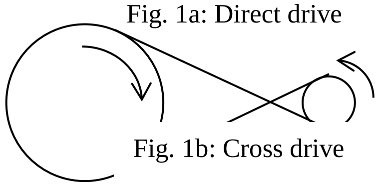


Fig. 1b: Cross drive

The rotational speeds of the pulleys will be inversely proportional to the diameter of the pulleys. If the larger pulley is 40 mm in diameter (dia.), and the smaller pulley 10 mm in dia. then the smaller pulley will turn 4 times (40/10) faster. One of the pulleys (the **drive** pulley) can be turned by hand or a motor or other means and the other pulley will be the **driven** pulley and this can drive another item such as a wheel.

Q: If a motor running at 5,000 rpm drives a 10 mm dia. pulley (drive pulley), and is connected by an endless belt to a 38 mm dia. pulley (driven Pulley), what is the speed of the driven pulley in rpm?

A: Pulley ratio = 1:3.8. Hence the speed ratio is 3.8:1. The 38 mm pulley turns at 5,000/3.8 = 1,316 to the nearest rpm.

Q: If the 38 mm pulley is connected to a pair of wheels of dia. 50 mm, with the same common axle of a toy car, at what speed will the car run on the road?

A: The rpm of the wheel=rpm of 38 mm pulley = 1,316.
When the wheel turns once, the distance travelled
= The circumference of the wheel
= Diameter of wheel x π = 38 x π = 119.38 mm.
The distance travelled in 1 min
= 119.38 x 1,316mm
= 157.08 metres
Speed of car = 157 m/min
= 9 km/hr: to the nearest whole number.

Q: If the car is to race on a 20 metre long track what will be its timing?

A; It travels 157.08 metres in 1 minute.
To travel 20 metres it takes= 60/157.08 x 20 sec. = 7.64 secs: To 2 decimal places.

Gears:

Gears have teeth around the periphery to engage with other gears. The direction of rotation is reversed when 2 sets of gears engage. In a way they behave like pulleys but do not require belts.

Q: *A gear wheel with 10 teeth is fixed to the shaft of a motor. The motor runs at 5,000 rpm. This gear is engaged with a gear wheel having 40 teeth. The larger gearwheel drives 2 wheels of 2.25" dia. of a toy car with the centre of the gear wheel in the axles of the car wheels. What will be the speed of the car in km/hr. (to the nearest whole number)?*

A: Gear ratio = 10/40 = 0.25, Hence the 40 teeth gear wheel rotates at 5,000x0.25 = 1,250 rpm.
The diameter of the road wheels = 2.25" = 2.25x25.4 mm = 57.15 mm.
Circumference of wheel = 2πr= πd =179.54 mm
= distance travelled when wheel turns once.
In 1 min distance travelled = 1,250 x 179.54mm = 0.2244 km.
Speed in km/hr = .2244 x 60 = 13 km/hr.

Q: *If the motor in previous question generates a torque of 40 gm-cm, what is the traction force of the car on the ground? Assume no loss in the drive train. Answer to whole number.*

A: As there are no losses, the torque on the wheels will be the same as the torque from the motor.
= 40 gm-cm.
The radius of the wheel = 57.15/2 mm = 2.86 cm.
Traction force = 40/2.86 = 14 gm. force.

Propeller (Fan).

It is possible to make the car to be driven by the reaction on a fast turning propeller blade. This is how propeller driven aeroplanes (now mostly replaced with Jet planes, but still used in small planes) work. Many hobbyists make model planes and helicopters driven by propeller. Also rafts/boats to work in marshy lands, hovercraft etc. use thrust created by a high speed fans for their movement.

The math required to design efficient propellers and calculate speeds etc. is beyond the scope of this project. You will learn once you enter university for engineering course!

However, you can try fitting a propeller (not supplied) or make a propeller of your own using old CDs as given in the book referred to in the Rules and Conditions. See if you can make the car to run faster than by belt drive or gears.

ELECTRICITY AND ELECTRICAL CIRCUITS.

Let us learn to use light bulbs, (a type of resistore which glows and gives light and heat), resistors, and switches in electric circuits. We shall use batteries as sources of Electrical energy.

It is good to get some terms cleared at this point:

Cells & Battery.

Cells are single units of sources of electricity with an open circuit voltage (when the cell is not delivering any current), known as Electro Motive Force (EMF), which depends on the electrolytes and electrodes used in the cell. It has a positive (+) and a negative (-) terminal. Its EMF is measured in Volts. When it delivers current, the current is measured in amperes. A series of cells connected in series (end to end) is called a battery. In common parlance we call the single cell also as a battery. So from now on we will use battery for single cells as well. You may visit:
http://en.wikipedia.org/wiki/Battery_(electricity)
to learn more about batteries.

(You will find good articles on most subjects we like to know more of in "Wikipedia" web-site. If you find the treatment too high a standard, ignore those sections and just absorb the simple explanations only).

Some batteries are disposable and cannot be re-charged. Zinc–carbon batteries, alkaline batteries Lithium cells are disposable batteries and are also called *Primary Batteries*. Zinc-Carbon and Alkaline batteries have an EMF of 1.5 Volts while Lithium batteries have EMF of 3 Volts. Another class of batteries can be re-charged and re-used. They are called *Secondary Batteries*. Examples are, Lead Acid cells (as used in cars & motor cycles) having an EMF of 2.1 Volts, Nickel Cadmium (NiCd) cells and Nickel Metal Hydride (NiMH) cells having an EMF of 1.2 Volts, and Lithium-Ion (Li-ion) cells having EMF of 3.6 Volts. For most applications we consider the voltage of a Car Battery as 12 Volts, and Alkaline Batteries as 1.5Volts

Same types of batteries come in different sizes. For example, alkaline batteries come is D, C, AA, AAA etc. sizes. They all have the same voltages (1.5 Volts) but the larger ones have higher capacities. i.e. they can supply larger currents for longer periods.

Batteries should be handled and disposed of carefully as some of them can explode under certain conditions. The chemicals used in batteries are corrosive. So carefully dispose of leaking batteries.

Electric Bulbs.

These are designed to work at a certain voltage, and are rated with a power rating of Watts. Bulbs used in household lighting in Canada & USA are rated to work at 120 V AC and rated at various Wattages such as 5, 15, 25, 60, 100 Watts etc. Nowadays we mostly use lower power Compact Fluorescent Lamps (CFL), and Light Emitting Diode (LED) bulbs.

For all design purposes they are treated as resistances, as we will see later on.

Resistance and Ohm's Law.

Resistances are those devices which provide opposition to the passage of electricity. In household appliances you find the heating elements in kettles, stoves, and the bulbs mentioned above. For more details please visit:
http://en.wikipedia.org/wiki/Electrical_resistance
Resistance is measured in Ohms and is defined as Voltage (Volts)/Current (Amperes).
This is written as: R=V/I. From this you derive that: V=IR, and I=V/R using simple math that we know of.
When a Voltage is applied across a resistance, a current passes through and heat is produced. The power dissipated by the resistance is measured in Joules/second, also called Watts.
W= IV, where I is in Amps, V is in Volts, and W is in Watts.
If you combine with Ohms Law using simple math, you get $W=I^2R = V^2/R$ etc.
If you type "Ohm's law" into a search engine such as Google, you will find various charts showing methods of using these formulas. Here is a good site:
http://www.hamuniverse.com/ohmslaw.html
Most resistances we use can be considered to have a constant value at all working temperatures. Resistances also have the same value when current passes in either direction. Incandescent bulbs have a low resistance when cool and rapidly rise to the required temperature when hot. In our examples given later, we will assume the resistance would be constant at the value of the hot filament.
If we have many resistances: R_1, R_2, R_3, etc., we can connect them in series or parallel or a combination of series and parallel.

Equivalent Resistance when connected in series (R) = Sum of the resistances. $R = R_1+R_2+R_3$

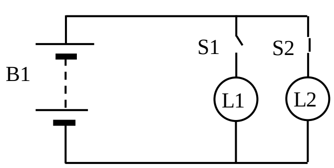
Equivalent Resistance when connected in parallel (R) is given by:

$1/R = 1/R_1+1/R_2+1/R_3$ etc.

Electronics Engineers and Technicians also learn two other laws which are helpful in analysing networks with resisters, semiconductor etc. They are Kirchoff's Current Law and Thevanin's Theorem. Of these Kirchoff's Law is useful at our level of knowledge. You can learn Thevanin's Theorem when you do more advanced electronic designs later on in your studies. Kirchoff's Law simply stated says that sum of all currents going into a node (a point) is equal to the sum of all currents leading out of the node. Put another way, the algebraic sum of all the currents at a point in the circuit is zero.

Now we will do some exercises based on the above.

Q: *In the figure shown, B1 is a car battery of EMF 12 Volts. L1 is a car bulb rated at 12 Volts & 6 Watts. What is the resistance of the bulb when hot?*



A: $W=V^2/R$. $R=V^2/W = 12^2/6 = 144/6 = 24\ \Omega$

Q: *L2 is a 12Volt, 21 Watt bulb. What is the current through it when S2 is closed?*

$R= V^2/W= 12^2/21 = 144/21 = 6.86\ \Omega$

$I=V/R = 12/6.86 = 1.75$ Amps.

Q: *If both switches S1 & S2 are closed, what is the current drawn from the battery?*

A: Current through L2 is 1.75 Amp. As calculated earlier.

Current through L1 = V/R = 12/24 = 0.5 Amp.

Using Kirchoff's law, the current from battery = sum of the current through L1 & L2 = 1.75+0.5 Amps = 2.25 Amp.

Q: *I have 2 of 6 volt motorcycle bulbs. One bulb L1 is 6 Watts and the other L2 is 12 Watts. I have only a 12 Volt car battery. Is it safe for me to connect the bulbs in series across the battery?*

A: Let us first calculate the resistance of each bulb.

L1 has a resistance of: $V^2/W= 6^2/6 = 6\Omega$

L2 has a resistance of: $V^2/W=6^2/12= 3\Omega$

When they are connected in series the total resistance $=9\ \Omega$

Current drawn from the battery I = V/R= 12/9 = 1.33 Amp.

Now consider the voltage across L1 (6 Watt bulb). V= 1.33 x 6 = 8 volts. So L1 is getting a higher voltage than it is designed for. It will be glow with a power of 1.33 x 8 = 10.64 Watts. This bulb is now being overloaded and will blow out soon.

Lesson learned: *Do not place bulbs or resistances in series without checking if they can handle the power! (Note: If both bulbs were of the same power, then it is OK.)*

Q: *In above question, is it safe for me to connect the 2 bulbs in parallel?*

A: No! Both bulbs will be overloaded and will fuse/blowout immediately. **Lesson Learned:** *Never apply a higher voltage to an electric bulb or resistance than it is designed for.*

Q: *What is the resistance across a switch when it is closed?*

A: Zero. Switch is a short circuit. If the switch has some resistance due to wear & tear or damage, it would heat up. Note: *A switch should not heat up when closed.*

Q: *What is the resistance of a switch when it is open?*

A: Infinity. When a switch is open, there is air between the 2 terminals and air is a good insulator.

Now we will come to the types of resistance we normally use in Electronics. We have supplied a number of resistances (and capacitors, diodes, LEDs, LDR, and transistors too. For the seniors we have also supplied IC chip). We will come to them later on.

Resistors for Electronics

These resistors are normally small, and their value is indicated by a series of coloured bands, known as colour codes. Larger resistors may have the values printed on them. The resistors we supplied are ¼ watt resistors. That means each resistor cannot handle more than ¼ watts of power. Modern resistors have become quite small compared to a few years ago. There are many types of resistors. Most common are made of carbon film, and carbon composition. Wire wound resistors are used to handle larger power.

Colour codes are used for small capacitors and inductors too.

How do you read the colour code?

You should read the colours in a resistor in good daylight or light close to daylight in quality. Otherwise you may mistake the colour. Also you may mistake the colour if you are colour-blind. Don't be surprised. Some of us are colour-blind to various degrees. It is good to use an Ohmmeter to verify the values of the resistor, if you find that you make many mistakes, better to practice and compare with measured values. (I will cover how to use a multi-meter and measure Ohms, Voltages and milli-amperes in a later section)

Resistors have 3 colour bands round its body. There is sometimes a 4^{th} Band known as the Tolerance band. This would be Gold, Silver or no band. I will explain that later. Now let us see how to read a resistor. A) Hold the resistor with the band closes to the end on your left

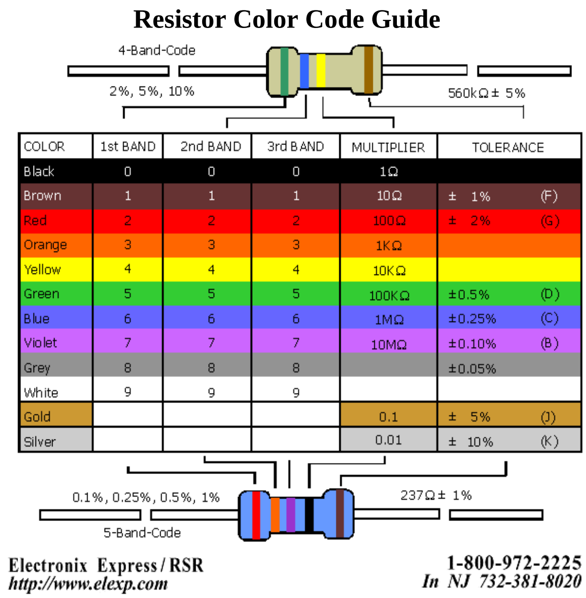
side. Now read the colour of each band Say Brown, Red, Yellow.
Brown = 1, Red = 2 and yellow = 4. Wow: How do you remember that? I will show you an easy method a little later. For now what you should remember is that the first 2 colours are written down as they are: 12. The 3rd band shows the number of zeros that should follow. That means 4 zeros = 0000. Now read the resistor value as: 120000 ohms. = 120Kilo Ohms, written as kilohm or kiloohm (1 kilohm = 1000 Ohms). Yes, in electronics hundreds of thousands and even a few million ohms are common. While we measure voltage in Volts, we mostly measure current in milliampere (mA) and even microampere. (μA).

Warning: *Do not try to measure current till we come to it. Never set your multi-meter to mA or A as you may accidentally connect to a voltage source and fuse your meter! Or even cause a fire hazard! Also do not set the meter to Ohms and apply any voltage!! If you have never used a meter, please ensure that a knowledgeable adult supervises your work. Be patient till we show you how to measure them. Even so, ensure a knowledgeable adult or teacher supervises your work.)*

The tolerance band.

When a resistance is manufactured, they can never get the exact value that is shown by the colour band. If it is a high quality precision resistor the value may be accurate to within 1%. Lower precision resistors may have higher tolerance. Most resistors we use have 5%, 10% or even 20% tolerance. If you don't have tolerance band, it means the tolerance is 20%. As manufacturing precision has improved of late, the 20% tolerance resistors are very rare. You may get some old resistors with 20% tolerance. 5%, 10% and 20% resisters are good enough for most work except where higher precision is required as per the design. High precision resisters such as 1%, 2% are mostly used inside the multi-meters you use. Such resistors are expensive, and very high precision meters are very expensive. For our purposes most meters available in the market are good enough. Also nowadays multi-meters are quite affordable (say $10 to $60 for higher precision ones.) It is very important to learn to use a meter properly- read the manual and get experienced adult supervision and advice before using them.

See the colour coding in the Code Guide I reproduced from the web-site below:
http://www.elexp.com/t_resist.htm



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

The following site has a built in calculator. It reads the value when you enter the colours.
http://www.csgnetwork.com/resistcolcalc.html
For the Judges' Questions, you do not have to know the colour code by heart. You may be shown a chart and asked to read some resistances that are given to you.
When we write down the values of resistance, it is common practice to place the K (for kilohm), M (for Mega Ohm, sometimes written as Megaohm or Megohm) or R (for Ohm) in place of the decimal point. Thus 3K6 means 3.6 Kilohms, 6M8 means 6.8 Megohms, 1R5 means 1.5 Ohms. 15R means 15 Ohms. Fairly neat isn't it?
Now let us do some design calculations using resistors.
Q: *47R, 1K0 and 1K5 are 3 resistors in series. Each is of ¼ watt power handling capacity. What is the highest voltage that can be applied without any of the resistors getting overloaded*?
A: As they are in series, the same current passes through them. The power = I^2R, the higher R will heat up more. Hence what is the highest voltage the highest resistor 8K1 can be subject to without overloading?
$W=0.25 = V^2/R=V^2/1500$.
$V^2=0.25 \times 1500 = 375$
V= 19Volts.
1k5 can stand a voltage of 19 volts. Hence the total voltage across all resistances=
19/1500x(1500+1000+47)
= 19/1500 x 2547= 32 volts.
So we find that at the 6 Volts we work these set of resistance are very safe against overheating/overloading.

LDR & THERMISTORS

We have supplied you a Light Dependent Resistor (LDR). It is a Cadmium Sulphide (CDS) photocell. The dark resistance is very high, say 500K, and in fair light it drops to, say 5K. The LDR is a special type of resistor which reduces in value when light falls on it through the glass window in it. Different models have different resistances at various light levels.

Q*: What is the resistance of the LDR supplied to you when there is no light falling on it?*

A: Close the glass window, and measure the resistance with a multi-meter set to a proper ohms range. It may be about 500 K

Q: What is the resistance of the LDR when light falls on its glass window in your dining room?

A: It depends on the amount of light. In a room lit to enable reading comfortably, it may be about 5 to 10K.

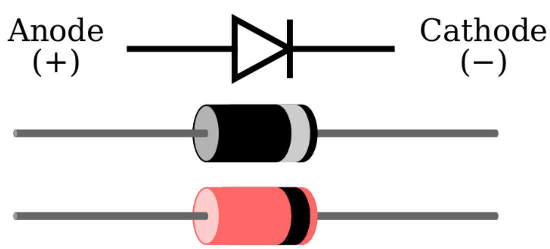
Thermistors are resistors which change with temperature. They can be used as thermometers. Thermistors are of 2 types: Ones where the resistance increase with rise in temperature are called Positive Thermal Coefficient (PTC) thermistors. If the resistance decreases with temperature, they are called – you guessed it – Negative Thermal Coefficient (NTC) types.

SEMI CONDUCTORS

Semi Conductors are made of materials which has the property of allowing current to pass in one direction, but not the other. Well known materials are silicon, Germanium etc. Such devises are called Diodes. Depending on the materials and processes used, some of the diodes can emit light. Then they are called Light Emitting Diodes (LED). When diodes are combined in specific ways we get Transistors which has special properties we will study under Transistors. For now let us get to know more about Diodes.

Diodes

Diodes have two wires. One is called the Anode and the other Cathode. There are many excellent articles on diodes in the web-sites. See the Wikipedia site:
http://en.wikipedia.org/wiki/Diode
This diagram is from Wikipedia.



The current flows from the Anode to the Cathode. Note that the Cathode side has a band around it.

Note: *When we talk of current we mean the conventional current which was believed to be from Positive pole to negative pole. Later it was discovered that it is the electrons that flow from negative pole to positive pole. The conventional method of marking remained as positive current flows from +ve to –ve. This is opposite to the real flow of electrons.*

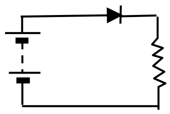
The diode has the following property. If you apply a +ve voltage to the cathode with respect to the anode, the diode does not pass a current and behaves like an insulator. If you increase the voltage very high the insulation breaks down. This will not happen at the voltages we normally work with.
If you reverse the voltage and apply a +ve voltage to the anode with respect to the cathode, no current will flow till a certain voltage is reached. This voltage is around 0.6 to 0.7 volts for silicon diodes. This forward bias is required before the silicon diode conducts current. After this the voltage across the diode increases very little for most working current range.

So for our designs of diodes, remember that when it is forward biased, it conducts, and has a voltage of 0.7 across it. When a diode is reverse-biased, no current flows.

Warning: Never connect a Diode, LED or Transistor directly across a battery. You should use at least 200 Ω resistor in series with the LED. See the Question below to calculate the proper value of resistance.

For LEDs the forward bias is quite different for different colours of LED.
Visit:
http://en.wikipedia.org/wiki/LED
to know more about LED’s.
Red LED’s have a forward bias in the range of 1.7 V Yellow about 2.1 V. Green about 1.9 V. This will vary slightly when the devices are drawing different currents.

Q: *What resistance should you use in series with a Diode to pass 5 mA when connected to a 6Volt supply?*



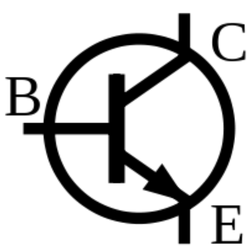
A: The diode will drop 0.7 volts. Hence voltage across Resistance =6-0.7 = 5.3 V.
Resistance required = V/I=5.3/5 ≈1K0.

Note: *When current is in milliamps, the Resistance will be in Kilohms. So there is no need to convert to Amps & Ohms.*

Q: If the Diode in previous example was a Yellow LED with forward bias of 2.1 volts. What will be the current when the resistance used was 1K0?
A: The LED drops 2.1 Volts, hence voltage across resistor = 6-2.1 =3.9 V. Hence current = 3.9/1 = 3.9mA. This may light the LED rather dim. Try 470Ω, to get double the current.

Transistors.
Transistors are 2 diodes so arranged and designed that it behaves as a signal amplifier, or as a switch. There are basically two types of Transistors: PNP & NPN.
Please visit:
http://en.wikipedia.org/wiki/Transistor
The diagrammatic view of PNP and NPN transistors obtained from Wikipedia are shown below.

The transistor is a three terminal device. One terminal is connected to the Base (B), One to the emitter (E), and the other to the Collector (C).



Q: How do you know which is PNP and which is NPN in a circuit diagram?
A: Remember that the arrow is marked from P to N. Also the collector to base behaves as a Diode, placed opposing the Emitter diode. For clarity, I have added a thin red coloured arrow to show the Collector diode. *(Normally this arrow is never drawn, but here, I have added it for clarity).* So in the upper diagram, the base is P, the collector and emitter are N. It is an NPN transistor.

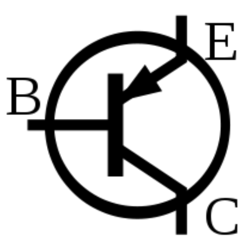
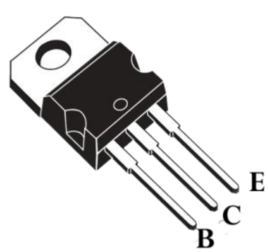


Diagram in the left is a PNP transistor. I have not shown an arrow in the C-B diode. As I said earlier, this is never drawn.
Q: What is the difference in the connections for an NPN or PNP transistor circuit?
A: In most circuits the positive and negative terminals of the battery has to be reversed. For PNP transistors, the Emitter is always +ve with respect to the base, while for NPN transistor the emitter is –ve with respect to Base.
Note: *In the book "Mechatronics for the Evil Genius" by Newton C. Braga, we referred to in our Rules, Conditions and Specifications (Page 14) uses an NPN Darlington transistor. This year we too have supplied an NPN Darlington transistor. (Previous years we supplied a PNP transistor).* ***After you register for the Contest, we will supply more details of circuits and other help along with the parts. We will also give email address where you can get additional help if required.***

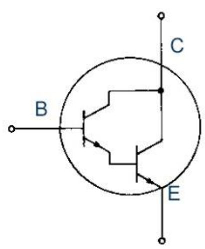


Typical use of Transistors.
Transistors are used in various configurations for different requirements of designs. They come in various sizes to cater to different power (Wattage), and different frequency response and amplification factors.

Let us take a closer look at the design given in the book. The Darlington Transistor is actually two transistors internally connected to give a high amplification or gain. In this circuit it is used as a switch to turn the motor on or off. Of course to turn a motor on/off we do not need all the sophistication of electronics. A simple switch could have switched on the motor. We wanted to introduce the use of some simple electronics for the students to get interested in more advanced electronics and micro-controllers used in robotics and Mechatronics. We hope that purpose has been achieved. Also we wanted them to learn the use of math and science in the design of such equipment. Not just as an assembly of commercially made parts with full instruction sheets, without any understanding of the inner working of the products.

Let us look at a circuit that would work as required.

The NPN Darlington Transistor we supplied is TIP 120 (equivalent to TIP 122 given in the book) as you can read on the case. If you type this number in a search engine you will get its pin configuration and other parameters.
The diagram below (left) identifies the Base (B), Collector (C) and Emitter (E). The NPN Darlington transistor is shown in diagrammatic form as:



You can see how the 2 transistors are interconnected. When the transistor is on and saturated (when working as a switch), the Voltage between Base and emitter would be about 1.2 to 1.4 V as there are 2 transistors inside. The Collector-Emitter (C-E) volts then can be about 0.5 V (see data sheets). At high currents a transistor can heat up. That is why they have designed it to be connected to a heat sink. For our project, a heat sink may not be required.
Note: *You can close the LDR with a pen cap to prevent light falling on it. Many of the pen clips have holes at the end for ventilation. Please seal such holes with black tape or opaque gum.*

Let us see some questions that may arise from this circuit.
Q: What should be the minimum voltage between the Base and the Emitter before the Darlington transistor conducts current and the motor turns on?
A: 1.2 to 1.4volts, as there are 2 base-emitter junctions in series in the Darlington Transistor.
Q: As light falling on the LDR is reduced, its resistance increases. What would be the resistance of the LDR when the Darlington Transistor just stops conducting?
A: When the transistor just stops conducting, the B-E voltage is just below 1.2V Volts. The LDR and 1M0 resistor has a voltage of 6 volts across it, with 1.2 V across the 1M0 and 4.8V across the LDR. R of LDR at this time is: 1 x 4.8/1.2 = 4.0 MΩ. But the resistance of the LDR when dark = 500 K. (See the package or web-site for specifications). So the transistor would be slightly leaking some current but not enough to turn the motor. Do you agree?
Q: If you agree with the above answer that there would be some leakage, what would you do to stop such constant leakage?
A: Reduce the resistance to 470K or 390K to reduce or remove the leakage current.

ELECTRONIC MEASUREMENTS
Any engineering work requires measurement. Electronics is no exception. In fact, in electronics very sophisticated measurement devices are required for designs, and for trouble shooting. An Electronics technician always uses a multi-meter to measure various parameters. Basic ones are VOM meters meaning Volts, Ohms and Milliamperes. More sophisticated meters measure frequency, temperature, capacitors, inductors etc. Even more sophisticated are Oscilloscopes, which shows in graphical form the variation of voltages with time. If you have or have access to an oscilloscope, you are very gifted. You may find it useful to study certain waveforms, especially in the senior group. Supervision by an experienced adult or teacher is very much stressed if you are using an oscilloscope. For our purposes a simple VOM meter, either Analogue or Digital is sufficient. In the digital category, there are Auto-ranging meters, where you have only one position to measure say Voltage. The meter will automatically change ranges to the required value and show the correct voltage. This is a very nice feature indeed. But I would prefer in the first instance you to use the ones where you have to manually set the ranges.

Here are some hints on measuring currents, resistances. and voltages.

1. **Safety First:** Always use it under advice and supervision of a knowledgeable adult/teacher. Even with small voltages, it is possible to bust up a brand new meter in a fraction of a second.

2. **Measuring Current:** This is the last thing you should learn. I gave it first as a warning not to try it and burn out your meter, and/or blow out your home fuse and get scolded. Yes. Don't use the meter on the household voltages until you have many hours of good experience under proper instruction. E.g. These days meters can be bought from many shops for as low as $5.00. Here is a case study of my friend's son Bernard. Bernard got his first meter, and wanted to check the household voltage. Sparks flew, and his house fuse blew. He got scolded by his mother for 2 hours! She stopped only because she ran out of breath. Bernard was unhappy as his meter would not measure anything after that. What went wrong? When I inspected the test prod, it had fused. The fuse inside the meter has fused. Also the household fuse had fused. Bernard had set the meter to measure current and put the prods into the wall socket! **Lessons learned:**
   1) Never play with the mains till you know how to measure electricity using small voltages such as our 6 Volt supply.
   2) *Never measure current as your first measurement experience. You have to break into a circuit to measure current. Keep it as your last lesson under proper guidance.*
   3) Milliammeters and Ammeters have a low resistance, and would behave as short-circuits when placed across any voltage. ***Never do that.***
3. **Measuring resistance**: This is a very easy and safe measurement. **Warning:** *Do not use the Ohms range of the meter on any circuit which is live. Measure resistances only on circuits which are not connected to sources of power. Ohmmeter uses a battery inside the meter to measure resistances.* First set the ohms to a range higher than the value you estimate for the resistance. If you are not sure, use the highest range and gradually go down to get an accurate value. Then hold the 2 prods together and adjust the zero (in analogue meters). In Digital meters there may not be zero adjustment. Learn to read the proper scales in analogue meters and the proper ranges K, M etc. in digital meters.
4. **Measuring Voltages**: This is usually done while the circuit is live. Set your range to a higher value than you estimate and take the reading by carefully placing the prods on the points of interest across which you want to measure voltage. If you want to measure the current, one way to do it without cutting into circuit is to measure the voltage and divide by the resistance across the voltage. Make sure the prods are properly insulated leaving only the tips exposed, so that the prods do not touch unwanted points resulting in wrong readings.

Now let us take some examples in the form of Questions and Answers.

Q: What is the order of the internal resistance of a milliammeter? a: 2R0,. b: 1K0, c:1M0, d:10M0?
A: a: 2R = 2 Ohms. A milli-ammeter has a small resistance only. Ammeters internal resistance are even smaller. That's why it acts as a short circuit when a voltage is applied.

Lesson Learned: *Never apply a voltage across a meter set to mA or Amp.*

Q: What is the order of internal resistance of a good Voltmeter? A; 2R0, b: 1K0, c: 1M0, d: 10M0?
A: d or c: Voltmeters have a very high internal resistance. Read and understand the specifications of your meter.

Q: How would you measure the voltage across a battery when the motor is running?
A: Set the meter to measure DC Voltage of suitable range and apply the test prods across the battery terminals.

Q: How will you measure the voltage across the LDR?
A: Set the meter to measure DC voltage of suitable range and apply the test prod across the LDR.

Q: My voltmeter has an internal resistance of 1M0. I want to measure a small voltage across a 1M0 resistor which is connected in series with another 1M0 resistor. The meter shows 4 Volts. Do you think the 4 Volts shown is correct?
A: No. When the meter of 1M0 is applied across a 1M0, it becomes an equivalent resistance of 0M5. (ie. ½ Megohm). The circuit is affected by the insertion of the meter and the meter will show a lower value of the voltage across ½ M and not 1 M.

Your design notes can be similar to the notes given above with sketches and calculations. They may be hand written and manually drawn or done in a Computer as your own work. (Note – Hand drawn sketches and notes carry equal credits to computer drawn ones)

OK. That's all for the Juniors project. Seniors Group has yet another Part. Seniors please read Part 2. Also.

We hope that all of you enjoy doing this project and get some challenging and satisfying experience. If so all of you are winners.

We hope to continue with this or similar projects in years to come. Your feedback is most welcome.

Best wishes and Good luck.

PEO Scarborough Chapter, Mechatronics Volunteer team.

Notes:

When you register for the Contest and we supply you the parts, we will be giving you **more guidelines, Notes and Questions and Answers.** Also **practical circuits and connections diagrams will be supplied** so that your team may choose the best circuits for your car.
Of course you are welcome do your own design if you so prefer.

Juniors: You have to Read & do only Part 1 (This part).

Seniors: Please Read & do Part 2 also. Your project will include Part 1 and Part 2.