Gears Educational Systems, LLC

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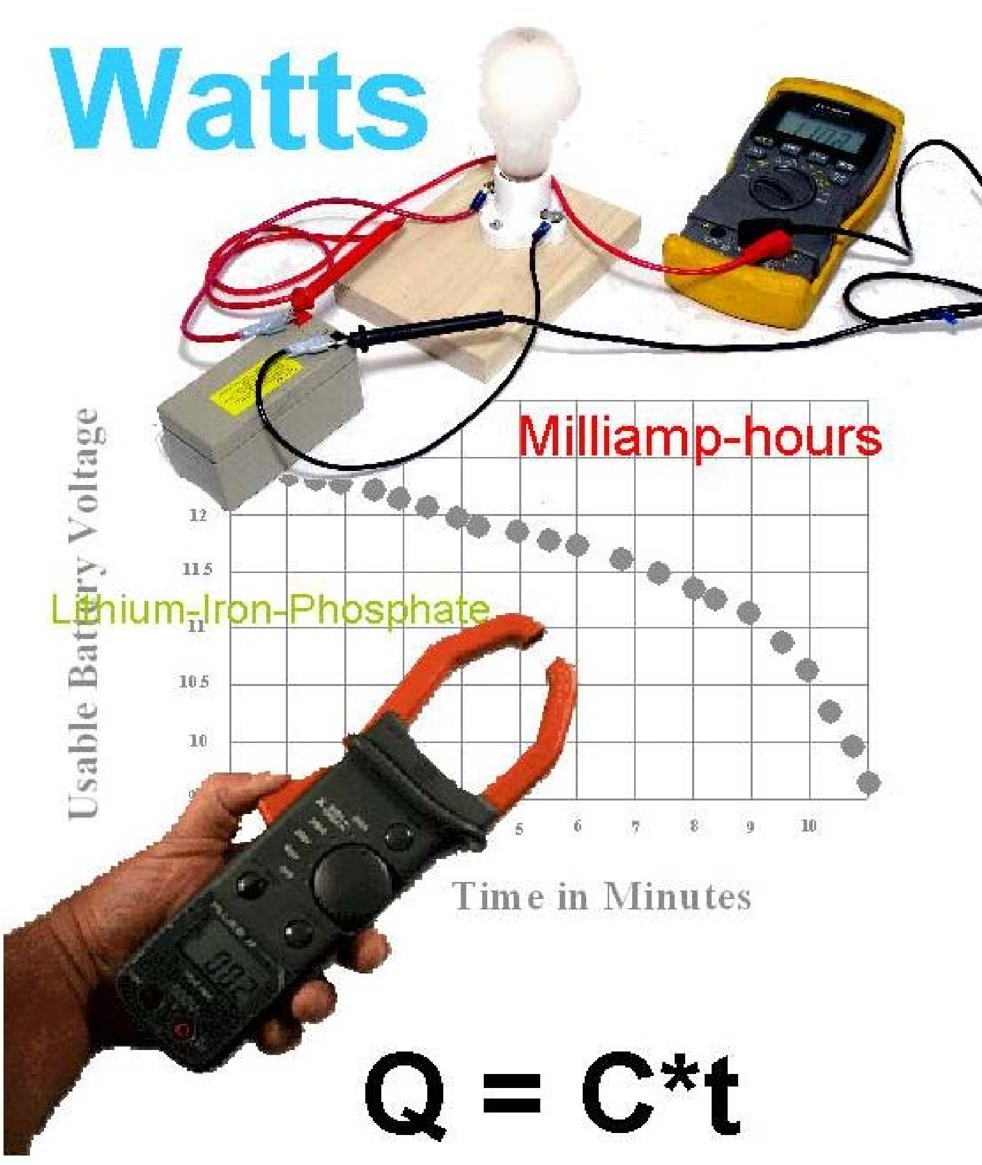
Battery Basics

Research, Test, Measure,Analyze, and Select the Optimal Battery



C A P A C I T Y

Battery Basics Terms

These are essential terms used when discussing and describing batteries and battery performance. Review these terms at the beginning of the lesson.

Amp Hour	Current Draw	Lithium-ion
Ampere	Constraints	Lithium-polymer
Anode	Cycle Life	Nominal Voltage
Battery	Deep Discharge	Open Circuit Voltage
Battery Packs	Discharging	Ohms
Battery Capacity	Energy	Overcharging
Cathode	Energy Density	Primary Cell
Cell	Internal Resistance	Resistance
Charging	Watt hours	Secondary Cell
Closed Circuit Voltage	Nickel Cadmium	Voltage
Current	Nickel Metal Hydride	Watts
	Milliamp-hour	

Tools/Materials

Battery Test Circuit	Face Shields/Goggles	Recording Sheets
Volt Meter	Spare bulbs	Comfortable Chair
Ammeter (10 amp+ rating)	Stop Watch	Chalk/white board
Bulb Socket	Pencils	Supervisory Adult
Test Leads (2 pair)		Suitable Battery Charger

Objectives

Students and teachers who participate in the instructional activities described in this lesson will:

1. Use meters to measure amperes (current) and voltage of a circuit through which a battery is being discharged.
2. Perform tests to record data used to determine the actual capacity of a battery under a specific load.
3. Source and read battery manufacturer's specification sheets and compare them to the results of their tests.
4. Use a spread sheet and graphs to analyze the performance of the batteries being tested.
5. Develop the skills and techniques necessary to determine the performance of any available battery.
6. Calculate the energy density of a battery given the manufacturer's specifications and/or battery test results.
7. Match battery performance and specifications to specific project requirements.
8. Apply their understanding of battery performance to create mathematical models in order to determine the suitability of a battery for a given current and voltage application.

Topics to Review Before You Start These Units

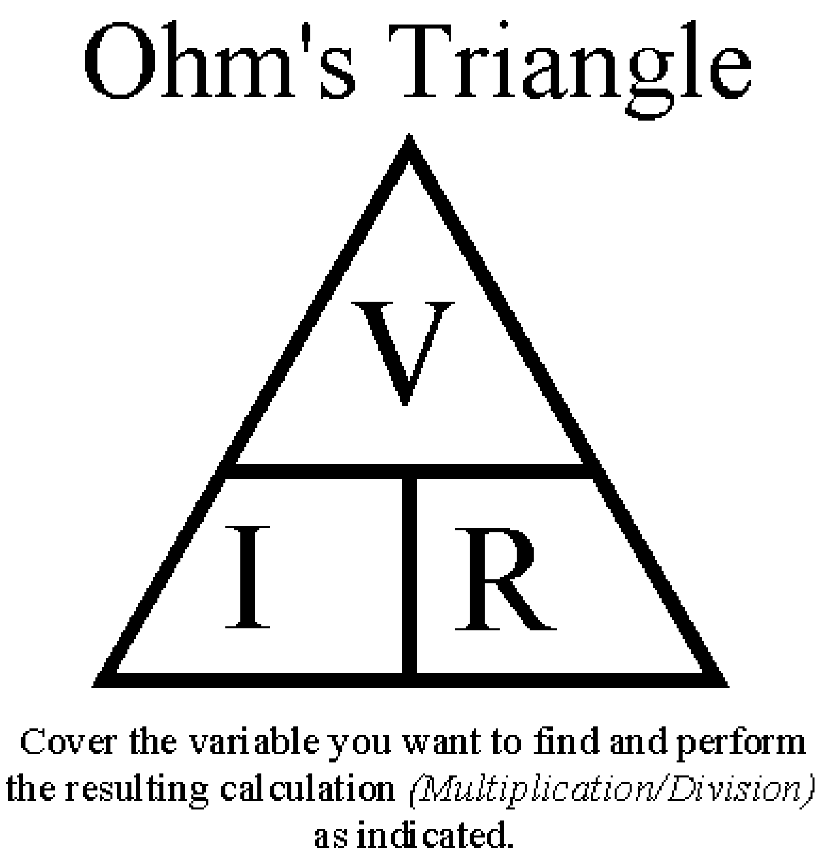
- Basic electrical units: (Amperes and Current) (Voltage and Electromotive Force, EMF) and (Ohms and resistance)

- Solve algebraic expressions with a single variable. Example: Using Ohm's Law, review methods for solving this equation for each and every variable.

$$E = I*R \qquad I = E/R \qquad R = E/I$$

Each of these expressions describes the relationship between Current (I), Voltage (E) and Resistance (R) in an electrical circuit.

- How Ohm's law is used to determine the current, voltage or resistance in an electrical circuit when any two of the variables are given as well as the algebraic statement that describes Ohm's Law
- How to measure volts, amperes and resistance with a Multimeter.
- The meaning and use of scientific prefixes such as micro, milli, kilo and mega.



Standards Addressed in These Lessons

National Council of Teachers of English Standards
(http://www.readwritethink.org/standards/index.html)

- Students adjust their use of spoken, written, and visual language (e.g., conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.
- Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.
- Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

(9-12) Science and Technology Standards (from the National Science Standards web page)
http://www.nap.edu/readingroom/books/nses/html/6a.html#unifying
Unifying concepts and process standard
Conceptual and procedural schemes unify science disciplines and provide students with powerful ideas to help them understand the natural world. Unifying concepts and processes include:

- **Systems, order and organization** *(Batteries are components that can be modeled mathematically using a basic understanding of physical science concepts that include Resistance, Amperage, Voltage and Watts)*
- **Evidence, models and organization** *(Graphing battery data and making mathematical predictions based on that data, and comparing the results to actual tests can help solidify understanding how to choose and use different batteries for differing applications)*
- **Change, constancy and measurement** *(Battery capacity and energy density are dependent on the battery chemistry, weight and volume.)*
- **Form and function** *(Understanding that battery capacity and performance depend on chemistry, size, weight and discharge conditions is necessary to make informed battery engineering and purchasing decisions)*

Motion and Forces
Voltage is the force that moves current through a given resistance. By testing and evaluating the capacity and performance of batteries, students and teachers will become more familiar with abstract science concepts like voltage, current and resistance, as well as energy and power.

Interactions of Energy and Matter
Batteries are electro chemical devices. The nature of the chemistries employed in the manufacture of the battery effect the capacity and performance of the batteries. Some examples of battery cell chemistries and voltage are provided below:

Description

The battery pack is one of the defining aspects of any portable or mobile electronic project. Since the battery pack affects the weight, range, operating time and cost of the project it is essential that a designer or engineer be capable of selecting an optimal battery strategy for a particular application.

The following outline suggests one possible method for selecting an optimal battery pack for a given application:

1. Determine the necessary voltage(s)
2. Calculate the minimum current requirements for the given application with respect to current requirements to support the operating time and/or range.
3. Determine the minimum battery capacity.
4. Determine the appropriate physical requirements. (Size and weight)
5. Consider chemistry, cost, connections, charging requirements
6. Research vendors and select battery packs

The Battery Basics lesson is designed to provide students with an opportunity to develop a working understanding of battery technology and use that understanding to properly design or acquire battery packs that are appropriate for a given application.

Participating students will source and read manufacturer's specifications as well as test, measure and create mathematical models to describe and select optimal battery packs given the voltage, current capacities and energy requirements for a particular application.

The knowledge and skills described in this lesson will be used to solve real world engineering problems that require students to analyze a particular battery application and make an informed decision concerning the selection of an optimal battery voltage, capacity chemistry, form factor and charging system necessary to successfully meet the constraints imposed by that application.

Battery Basics

Batteries are energy storage devices that are particularly useful for powering small portable devices like phones, laptops and entertainment devices as well as mobility devices that travel over the earth's surface, through water and in the air.

Batteries used in these applications are engineered to meet the unique design constraints imposed by these different applications.

These constraints include:

Number of Cells or Voltage

The term battery refers to a system of one or more cells. A cell represents a particular chemical combination capable of producing a voltage and current. Different chemical combinations produce different voltages. By combining cells in series the voltage of a battery pack can be increased as a multiple of the number of cells x the voltage for each cell. Caution: Do not integrate cells of different chemistries into the same battery pack.

Activity: Using manufacturers literature or the internet to research available information about 2 of the 4 different battery cell chemistries. Find and record as much as you can about the two chemistries that you chose to research. Using what you learned, find two different vendors who can supply battery packs for each of the (2) battery chemistries you have researched. Record the cost and capacity of the battery packs you find. Create a presentation slide or report for each of the two chemistries and present your findings.

Log your research and findings in your notebook

Battery Chemistry

A rechargeable battery is referred to as a storage battery and is usually constructed of one or more secondary cells. Each cell is capable of producing a specific voltage with respect to the electro-chemical make up of the cell.

Batteries store energy through changes in their internal chemistry. When a battery is discharged through a load like a circuit or a motor, the internal battery chemistry undergoes a change. When the battery is charged, the chemical change is reversed, and energy is again stored in the battery. A specific amount of energy can be stored in a battery given the specific battery chemistry, the configuration of the battery, and the battery volume and weight.

There are many dozens of battery chemistries used today, both primary cell (non-rechargeable) or secondary cell (rechargeable) chemistries. Major secondary cell chemistries include, Lead-acid, Nickel-cadmium, Nickel Metal Hydride, Lithium-ion-polymer and Lithium-ion. The choice of battery chemistry is predicated on may factors, some of which include: Initial cost, life cycle cost, ease of use, energy density, voltage and current requirements, and environmental impact (recyclable and sustainability) to name a few.

Nickel Cadmium	1.2	volts +/-
Nickel Metal Hydride	1.2	volts +/-
Lead Acid Cells	2	Volts +/-
Lithium-Cobalt	3.6	volts +/-

Cell Voltage and Battery Packs

For NiCad/NiMH, cell voltage is about 1.2V, for lead acid it is 2.0V, and for lithium cells it is on the order of 3.6V. Typically, portable electronic devices are designed to run on 24, 36, or 48 Volts. To create these voltages, a number of cells are connected in series in order to form a 'battery' that has the desired net voltage. A nominal 36V pack could be made from 10 lithium cells, 18 lead acid cells, or 30 NiMH cells.

Activity: Find and list the cell voltages for as many different battery chemistries as possible within the time given by your instructor. (Usually one period). Record the chemistries in a listed column. For each battery chemistry you research, Note if the chemistries you researched were very common, common, not commonly used or rarely used, and for what applications?. Wherever possible, list the approximate cost per kWhr associated with each of the battery chemistries you research. Present your results to the class.

Log your research and findings in your notebook.

Battery Capacity

Battery capacity is published by the manufacturer as a nominal rating for a given set of discharge conditions. These discharge conditions include rate of discharge (C rate), temperature and minimum cell voltage. Minimum cell voltage is the lowest voltage to which a cell or battery should be discharged. Discharging a cell or battery below the minimum voltage can reduce or even destroy the battery's capacity to hold a charge.

Battery performance parameters can include: Voltage, amp-hour capacity, and C rate (Rate of discharge).

The C rate or rate of discharge refers to the amount of current that a battery can sustain for one hour while remaining within a specified voltage range. For a typical 12 volt battery this voltage range will be between 12 volts to 10.5 volts. At 10.5 volts the battery is considered fully discharged.

Typical units of battery capacity are expressed as milliamp-hours or mA*h and for larger batteries amp-hours or A*h. This rating implies the discharge rate in amperes that the battery can be expected to sustain for a period of one hour.

The mathematical relationship for battery capacity (Q) is simply the product of the current x time.

$$\mathbf{Q = I * t}$$

Capacity in milliamp-hours (Q) = (I) Current in amperes x 1000 x (T) Time in hours
Capacity in amp-hours (Q) = (I) Current in amperes x (T) Time in hours

Battery capacity varies with discharge rate. When you discharge a battery at higher rates, the amp-hour capacity of the battery will be less than the nominal or published capacity.

Battery capacity reduction due to higher current discharge rates is most obvious in the case of lead acid batteries and less obvious for Nickel Cadmium, Nickel Metal Hydride and lithium chemistries.

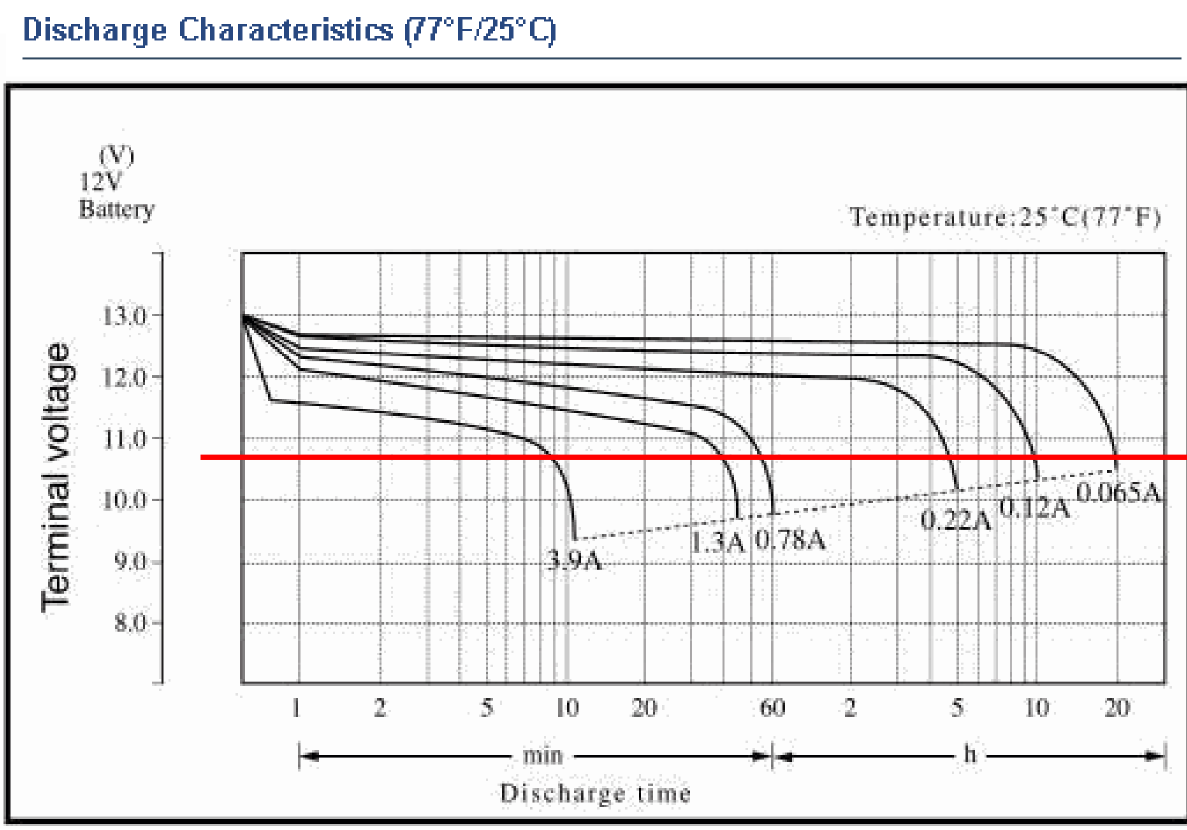
When current is drawn from a fully charged battery pack, the voltage will decrease gradually from slightly higher than the nominal voltage to a fully discharged voltage. For a lead acid battery with a nominal 12 volt rating (6 cells x 2 volts each) the voltage range is typically 12 plus volts at full charge – 10.5 volts at full discharge.

When the discharge curve for a typical battery is plotted, the cell voltage remains relatively flat until the discharge voltage is reached. When the discharge voltage is reached, the battery capacity is exhausted and the cell voltage plummets quickly. Batteries and cells should not be discharged below their rated discharge voltage.

Battery capacity is measured in amp-hours (Ah). A pack that can deliver 1 amp for 1 hour has a capacity of 1 Ah. The battery capacity is usually given by the manufacturer in amp hours (Ah) or milliamp hours (mAh). Suppose a 15lb mobile robot base with two motors draws an average of 4 amperes. If you fit it with a 4 Ah battery pack, it can be expected to run for one hour on average. (Less if you constantly accelerate hard in both direction)

In great part, the size and cost of a cell will vary with respect to the amp-hour capacity of the pack.

The graph below provides discharge curves for the (tested) capacity-offset of the TR 1.3-12V sealed lead acid battery that is shipped (standard) with the GEARS-IDS™   Invention and Design System.



Note: Typically a 12V lead acid battery is considered fully discharged when the “Loaded” voltage drops below 10.5 volts. A fully discharged battery left unloaded can show 12V when tested with a voltmeter! Therefore voltage alone is not an indication of battery charge state.

Note: Nickel-cadmium, nickel metal-hydride and lithium battery chemistries do not suffer as great a capacity offset. They maintain their nominal or rated capacity through a wider range of current discharge rates.

Activity: Find and explain the answer to these questions. "What causes capacity offset" And which battery chemistries are least susceptible to the effects of high current discharge. Why? Present your findings to the class.

Log your research and findings in your notebook.

Watt Hours

The figure that matters most when comparing the energy available in different battery packs is not the amp-hour capacity but the total energy stored in watt-hours.

The watt-hours stored in a battery pack is approximated by multiplying the rated amp-hours by the pack voltage.

Watt hours = Battery Voltage x Amp hours

A higher voltage battery pack with a lower capacity (amp-hours) can deliver the same total energy as a lower voltage pack with a higher capacity. Example: A 24V x 8Ah battery can deliver 192 watt-hours, while a 48V x 4Ah pack can also deliver 192 watts.

Energy Density *(Mass density)*

Usually refers to the energy in Watt hours per unit mass of a battery. The energy available from a given battery can be estimated using the manufacturer's published data for a given battery pack or cell. The information needed to calculate the energy density can also be obtained through direct battery testing.

Battery energy is described in units of Watt-hours/kilogram

*To calculate an approximate value for Watt-hrs use the following formula:

Watt-hours = Nominal Battery voltage x Amp-hour capacity

Note the use of amp-hours as the current units. Convert milliamp-hrs to amp-hours by dividing milliamp-hrs by 1000.

Amp-hrs = Milliamp-hrs/1000

To calculate energy density use the formula below:

Energy Density = Watt-hrs/ Kilograms

Use the manufacturers published information for voltage, capacity and weight to calculate the energy density of any cell or battery pack.

Energy Density = Watt-hours/ mass

(Where mass is given in kilograms or pounds)

Activity: Using the 4 battery chemistries referred to in these lessons: Source vendors who can provide a 4000 – 5000 milliamp-hour, 12 volt battery pack for each of the chemistries. Using the vendors published information for voltage, capacity and weight, create a spread sheet to calculate the energy density in Watt-hrs/ Kilograms and cost/ Watt-hr for each of the battery chemistries. Compare the results of your search and calculations with available published data. Present your findings to the class.

Log your research and findings in your notebook.

** The calculation is only an approximation because the battery voltage and current drop during the discharge. A more accurate approximation of battery energy can be determined through actual testing. A procedure we will engage in later in this lesson.*

Manageability and Battery Life Cycles

Different battery chemistries require different charging regimes and charging equipment. Caution:Battery chargers should only be used to charge battery chemistries for which they were designed.

Different battery chemistries can sustain different numbers of charge/recharge cycles under a set of specified conditions. Read the manufacturers published data sheets to learn what these conditions are. The number of battery cycles (Charge –discharge cycles) affects the total cost of the battery regime.

Battery technologies employ the use of highly toxic chemicals. The battery user should assume the responsibility for proper disposal and recycling of batteries that have reached "End of life". For information on recycling batteries including recycling sites near you, visit the following website:

http://www.call2recycle.org/ "If it's rechargeable, it is recyclable"

Activity: Find and list 2 battery chemistries that are more environmentally friendly and 2 battery chemistries that are least environmentally friendly. Using the website listed above find and record 3 battery recycling locations nearest to you.

Log your research and findings in your notebook for presentation at a later date

Cost (Including Initial cost and lifecycle costs)
Each battery chemistry requires a specific type of charger and charge regime. Battery chemistries and chargers vary in both initial cost and lifetime costs. Lithium based batteries present higher initial costs, than similar capacity batteries employing other chemistries. However Lithium batteries have high energy densities, long life cycles and are more readily recyclable than other chemistries. These factors contribute to lower lifetime costs. There is no answer (yet) to the question, "What is the best battery system I can buy?". The answer always depends on the many factors involved in a particular application. Battery systems and chemistries can be cost compared using the relationship between Cost/Watt-hr. Low cost/Watt-hr figures can indicate cost effective energy storage.

This is precisely why designers and engineers need to have the skills and jnowledge required to analyze battery regimes in order to make the best selection for a particular application.

For example, a battery used in an electric plane must have a high energy to weight ratio. This would imply an investigation into lithium battery technology; whereas a classroom robot application might require low cost, easy availability and continual mid-cycle recharging. This would require a careful look at lead acid battery technology.

Battery systems can be expensive. It is therefore necessary to make careful evaluations of the requirements and constraints imposed by a particular application.

Activity: Find and record the name and website location for 2 vendors who can most economically supply a battery pack and charger meeting the following general specifications:

Battery: Nickel-metal-hydride. 12 volts 2000-2300 milliamp-hour capacity. Note the max discharge rate of the battery you select. Record the recommended charge rate. Share your findings with the class.

Log your research and findings in your notebook.

Cumulative Activity
Create a spread sheet that can be used to compare, evaluate and select a 12-14 volt battery packs made using from a variety of different chemistries. Use the spread sheet to compare data from different vendors in an effort to make a tool that will allow a designer or engineer to make the best battery pack choice for powering a variety of projects.

The spread sheet should provide comparative information about these parameters.

Chemistry
Volume (Size L,W,H)
Capacity (Amp hours)
Energy Density (Watt hours/kilogram) (Watt hours per pound)
Total Recharge Cycles
Battery Cost
Battery cost per Watt hour
Charge System Cost
Recharge Time (From full discharge)
Ease of Recycling
Total Expected Lifetime Cost

Battery Lab Activity #1

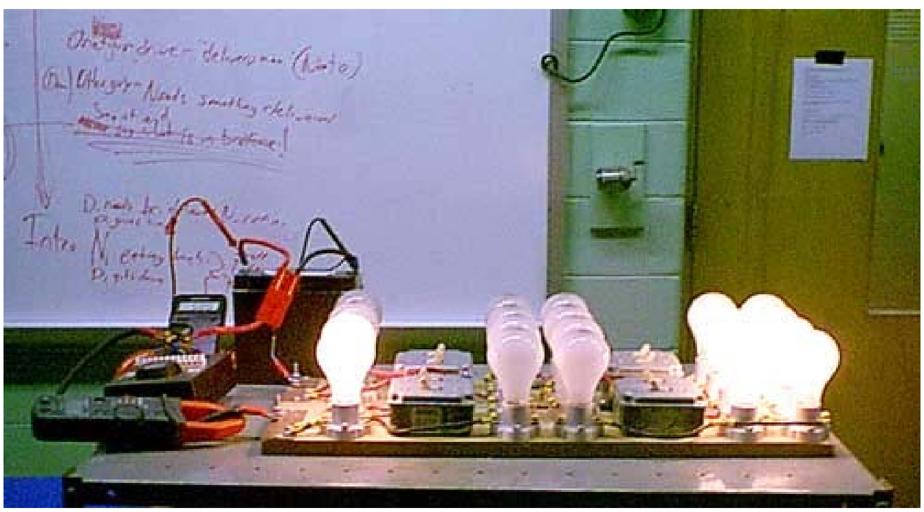
Measuring Battery Capacity

This procedure works well for relatively low capacity batteries between 1000 – 2000 milliamp-hours. For larger batteries, increase the number of bulbs and sockets by one for every additional 2000 milliamp-hour increase in battery capacity. In this example we will construct a single bulb tester and use a 1.3 amp-hour or 1300 milliamp-hour lead acid battery supplied in the GEARS-IDS™ kit.

Note: 1000 milliamp-hour = 1 amp-hour

Materials Needed to Construct a Single Bulb Battery Tester

1pc. 12 Volt 50 watt incandescent bulb *(Purchased from a boating supply store or mariner. Approximate cost $4.00 ea.)*
1pc. Suitable bulb socket *(Purchased from a hardware store. Approximate cost $4.00 ea.)*
2pc. Heavy duty test leads. *(Purchased from an electronics supply store i.e. Radio Shack. Approximate cost $2.00 ea.)*
1pc. Approximately 6" x 8" x ¾" board to hold the bulb and socket. This prevents the bulb from possibly tipping over and breaking.Equipment
1pc. 12 volt battery used in the GEARS-IDS™ kit *(or 12 volt battery of similar capacity)*
1pc. 12 volt battery charger. *(Caution: The charger should be specifically designed for the battery chemistry being tested.)*
1pc. DC Voltmeter
1pc. DC Ammeter



A high current discharge device for testing automotive scale batteries
A complete set of plans for constructing this tester can be found at the end of this document

Construction of the Single Bulb Tester

Collect all necessary materials and equipment. Build the tester shown below.

Test Procedure

Materials and Equipment

- 1pc. Single Bulb Tester as Described Previously
- 1pc. 12 volt battery used in the GEARS-IDS™ kit *(or 12 volt battery of similar capacity)*
- 1pc. 12 volt battery charger. *(Caution: The charger should be specifically designed for the battery chemistry being tested.)*
- 1pc. DC Voltmeter
- 1pc. DC Ammeter
- 1pc. Stop Watch
- 1pc. Battery Discharge Sheet (Found on the next page of this document)
- 1pc. Pen/pencil

SAFETY GLASSES for every participant!

Procedure

Prepare for the test by assigning the following responsibilities to 7 individual students:

- Circuit Connector
- Voltage Readout
- Current Readout
- Timer
- Voltage Recorder
- Current Recorder
- Time Recorder

1. Make certain the battery is fully charged
2. Use the manufacturer's specification sheet to record the necessary information on the Battery Discharge Sheet
3. Connect the test leads to the bulb socket
4. Connect the voltmeter
5. Connect one (Red) test lead to the battery
6. Connect the inductive ammeter to the test lead as shown (left).

Begin the Test

To begin the test simultaneously complete the circuit connection, start the stop watch and record the voltage current and time (0). Record voltage current and time every 15 seconds.

End the Test

The test ends when the battery voltage drops below 10.5 volts

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Battery Discharge Sheet

Date ___________ **Current Draw** _________
Battery Make/Model ___________ **Battery Temp** _________
Total Wattage Output ___________ **Starting/ending**
Watt-hrs ___________ **Voltages** _________

Voltage

13.0																					
12.5																					
12.0																					
11.5																					
11.0																					
10.5																					
10.0																					
9.50																					
9.00																					
sec.	15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60	15

0 Min **1.0 Min** **2.0 Min** **3.0 Min** **4.0 Min** **5.0 Min**

Time (Minutes/Seconds)

ALWAYS WEAR GOGGLES and/or FACE SHIELDS when handling or testing batteries. Always have a supervising adult present.

Compare the total wattage/time figure you obtain with manufacturer's published data and account for significant discrepancies. Hint: The amp hour capacity of a lead acid battery is inversely proportional to the current draw. Thus the tested or calculated amp hour capacity is reduced as the current draw is increased. See the manufacturer's published data on the following page.

This is not true of other battery chemistries including Nickel Cadmium, Nickel Metal Hydride and Lithium cells. These cells will yield the same amp hour capacity within the range of their current discharge ratings.

After the test is completed, enter your results in the example spread sheet provided with this lesson. A representative copy of the spread sheet data is included on page 16. Click here to open the Excel file.

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Graphing Battery Discharge

Directions: This graph shows the data from a 1200 milliamp (1.2 amp hour) battery discharge. The data was recorded during an actual discharge. To use the spread sheet, simply delete the data in the "B" (seconds) and "C" (Voltage) columns and replace it with data from tests perfromed in your own experiments. Note:It may be necessary to adjust the graph parameters. Use the scatter graph option from the chart wizard in order to more easily adjust the range and values for both the x and y axes.

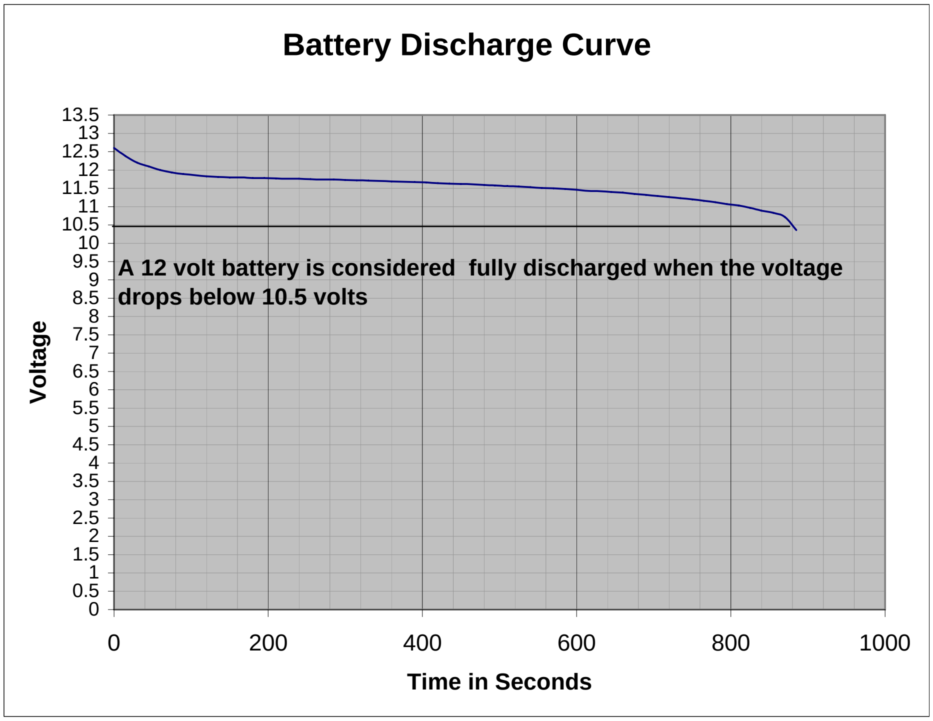
*The figures in blue are obtained from the manufacturer's specification sheet
*The figures in red are obtained from the test results
*The figures in yellow are calculated from the manufacturer's and test data. Do not enter values in those blocks

Battery Nominal Voltage	12	volts	
Fully Dischaged Voltage	10.5	volts	
Amp hour rating	1.2	amp hours	
Average Voltage	11.25	Volts	Do not enter values in this cell
Time in seconds to reach discharge voltage	875	seconds	(from test data)
Start Current	5	Amperes	(from test data)
End Current	4.58	Amperes	(from test data)
Average Amp hours	1.16	amphrs	Do not enter values in this cell
Average Watt hrs	13.10	Watthrs	Do not enter values in this cell

Minutes	Seconds	Voltage
0	0	12.6
0.25	15	12.38
0.5	30	12.2
0.75	45	12.1
1	60	12
1.25	75	11.93
1.5	90	11.89
1.75	105	11.86
2	120	11.83
2.25	135	11.81
2.5	150	11.8
2.75	165	11.8
3	180	11.78
3.25	195	11.78
3.5	210	11.77
3.75	225	11.76
4	240	11.76
4.25	255	11.75
4.5	270	11.74
4.75	285	11.74
5	300	11.73
5.25	315	11.72
5.5	330	11.71
5.75	345	11.7
6	360	11.69
6.25	375	11.68
6.5	390	11.67
6.75	405	11.66
7	420	11.64
7.25	435	11.63
7.5	450	11.62
7.75	465	11.61
8	480	11.59
8.233333	494	11.58
8.5	510	11.56
8.75	525	11.55
9	540	11.53
9.25	555	11.51
9.5	570	11.5
9.75	585	11.48
10	600	11.46
10.25	615	11.43
10.5	630	11.42
10.75	645	11.4
11	660	11.38
11.25	675	11.35
11.5	690	11.32
11.75	705	11.29
12	720	11.26
12.25	735	11.23
12.5	750	11.2
12.75	765	11.16
13	780	11.12
13.25	795	11.07
13.5	810	11.03
13.75	825	10.97
14	840	10.89
14.25	855	10.83
14.5	870	10.72
14.75	885	10.36

14.5 / 870 / 10.72: This is the "Danger zone". The voltage at which a (Nominal) 12 volt battery is considered "Dead"

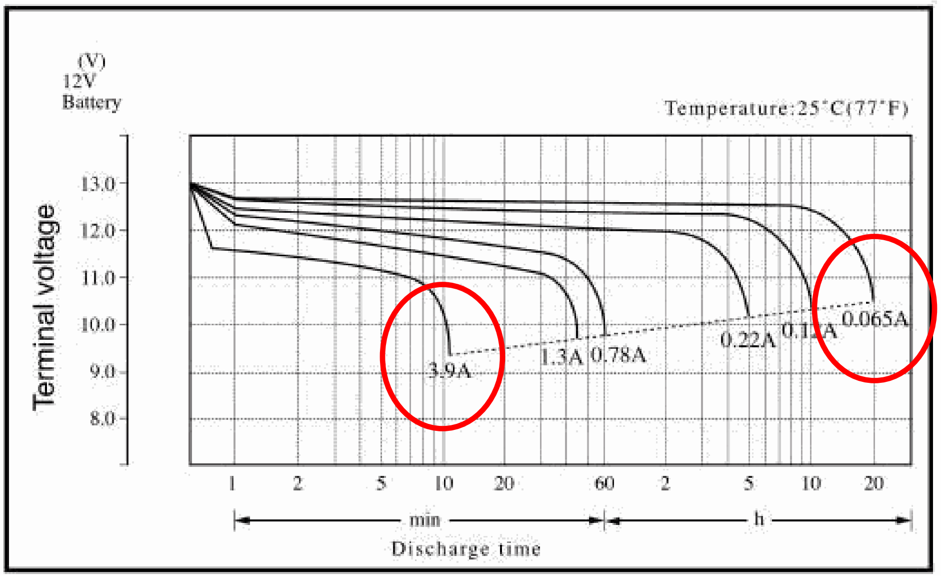
14.75 / 885 / 10.36: Caution: Discharging the battery beyond this point will severly reuce the battery's expected number of charge cycles.



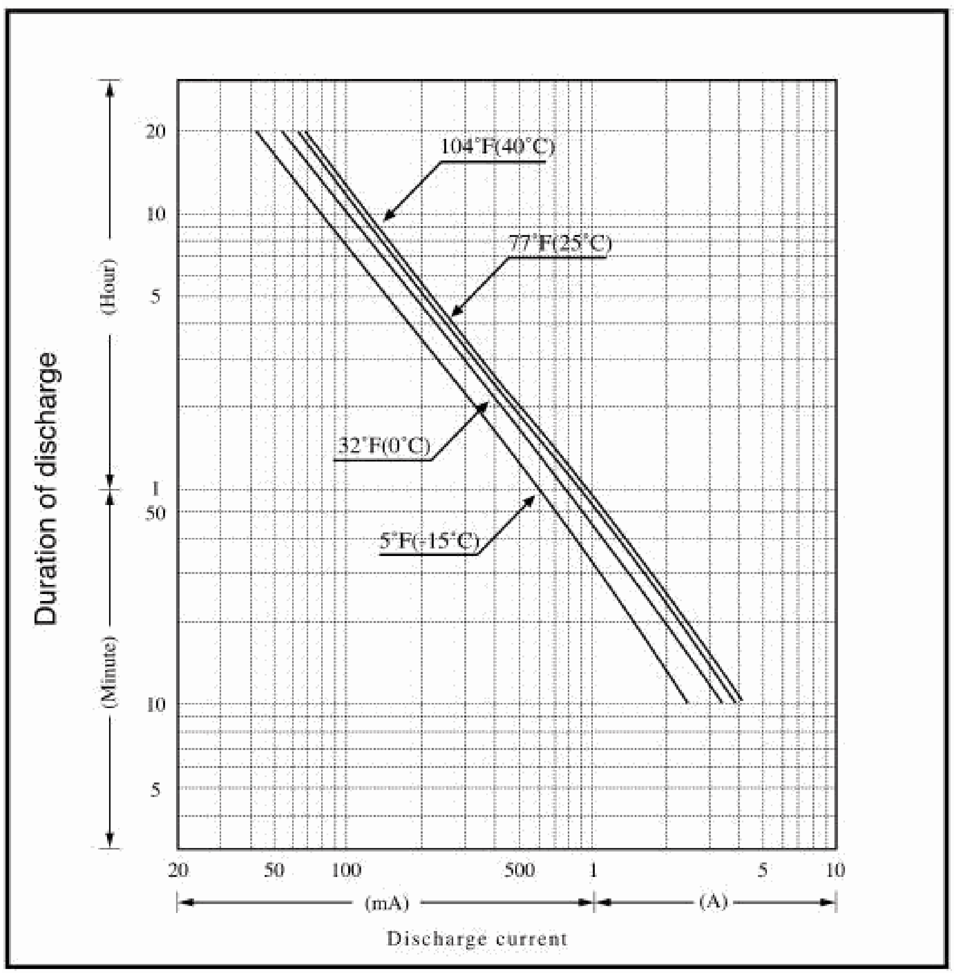
The fact that this battery was discharged to 7.6 volts was done only to illustrate the sharp voltage drop illustrated by the graph above. This sharp voltage drop indicates the battery capacity has been depleted.

Manufacturer's Discharge Data for the Tempest TR1.3-12 SLA Battery used in the GEARS-IDS™ kit.

Discharge Characteristics (77°F/25°C)



Duration of Discharge vs. Discharge Current



Study the graph on the top left of this page. Note that the discharge time for a current draw of 0.065 or 65 milliamps is 20 hours

Note that the discharge time for the same battery at a current draw of 3.9 amperes is only 10 minutes!

This provides evidence that the total amp hour capacity of a lead acid battery is reduced as the current draw is increased.

Here is the math:

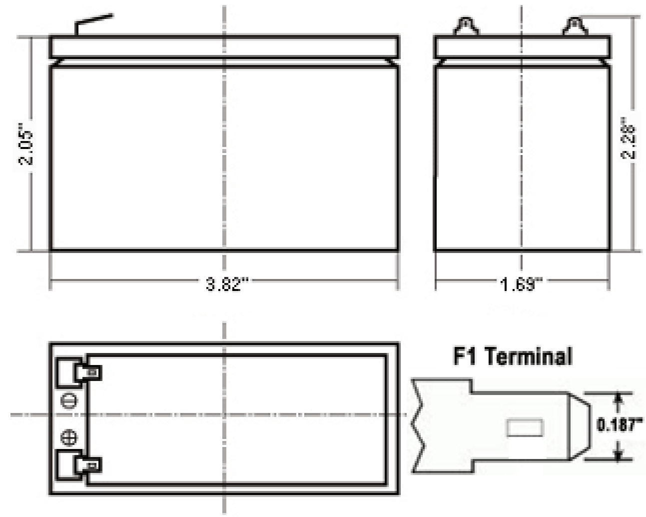
20hrs x 0.065A = 1.3 A hrs
Notice this is the exact same capacity listed by the manufacturer on the battery. It is called the 20 hour rating and is a common rating for lead acid batteries.

Now compute the amp hour capacity for the same battery at a current draw of 3.9 amperes.

11 minutes = 0.183 hrs.

0.183hrs x 3.9A = 0.715Ahrs

This is nearly a 50% reduction in amp hour capacity from the published 20 hour rating.
The graph on the bottom left describes the current reducing effects of cooling the battery. Amp hour capacity is inversely proportional to temperature.



Specifications

Nominal Voltage		12V
Rated Capacity (20 hour rate)		1.3AH
Dimension	Total Height (with terminals)	2.28 in.
	Height	2.05 in.
	Length	3.82 in.
	Width	1.69 in
Weight (Approx)		1.37 lbs.

Characteristics

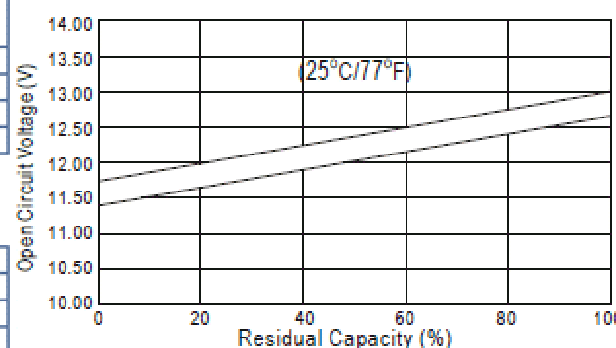
Capacity (77°F/25°C)		20 hour rate (65mA)	1.3AH
		10 hour rate (120mA)	1.2AH
		5 hour rate (220mA)	1.1AH
		1 hour rate (780mA)	0.78AH
		15 min. rate (2.28A)	0.57AH
Internal Resistance		Fully Charged 77°F/25°C	39mΩ
Capacity Affected by Temperature (77°F/25°C)		104°F (40°C)	102%
		77°F (25°C)	100%
		32°F (0°C)	85%
		5°F (-15°C)	65%
Self Discharge (77°F/25°C)		Capacity after 3 month storage	91%
		Capacity after 6 month storage	82%
		Capacity after 12 month storage	64%
Max. Discharge Current (77°F/25°C)		19.5A (5S)	
Terminal	Standard	F1	
	Optional	F2	
Charging (Constant Voltage)	Cycle	Initial Charging Current 260mA (recommended) 14.5~14.9V/ 77°F (25°C)	
	Float	13.6~13.8V/77°F (25°C)	

Constant Wattage Discharge Ratings

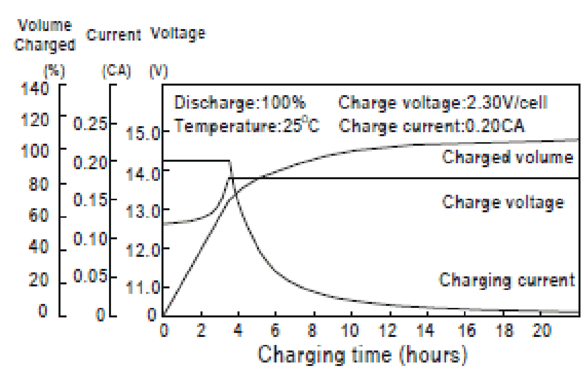
(Watts per Cell at 77°F/25°C)

Cut-Off Voltage	5min	10min	15min	30min	40min	60min
1.50V	11.8	8.1	5.7	3.5	2.5	1.9
1.60V	11.5	7.8	5.6	3.1	2.5	1.9
1.67V	11.4	7.6	5.3	3.3	2.5	1.9
1.70V	10.6	7.3	5.0	3.3	2.3	1.9
1.75V	9.8	7.0	4.7	2.8	2.3	1.9

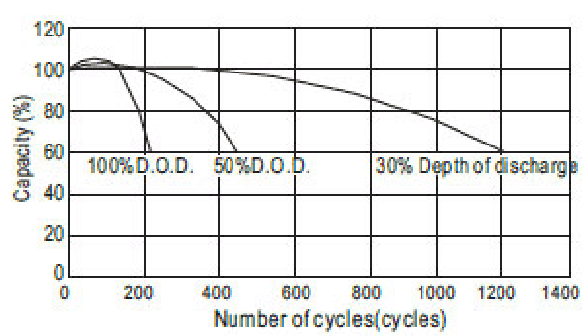
The Relationship for Open Circuit Voltage and Residual Capacity (25°C)



Charging Characteristics(25°C)



Cycle Life(25°C)



Battery Lab Activity #2

Battery Capacity Work Sheet

The following problems, examples and exercises provide an opportunity to use the concepts and knowledge covered in the Battery Capacity lesson.

Directions: Use the manufacturer's data sheet supplied on page 8 of this document to solve the problems described below.

Hint: Use the battery capacity formula to solve problems 1 and 2. **Q = I * t**
Where **Q** = Battery capacity in amp hours, **I** = Current in Ampers (Amps) and **t** = time in hours.

1.) Problem Statement
A Gear head motor has a rated current of 2 amperes. This means the motor can operate indefinitely at that current without damage or danger of overheating. How long can this motor be operated at the 2 amp rated current draw using the Tempest TR1.3-12 SLA Battery. See specifications on pages 14-15.

Answer ______________________

2.) Problem Statement
Assume the same motor is used to power a mobile robot chassis. The chassis requires 2 motors. If the chassis motors are required to operate continually at the 2 amp rated current, how long will the chassis be able to operate?

Answer ______________________

3.) Problem Statement (Extra Credit)

Assume the motors used in both the above problems must operate at 5 degrees F. What are the operating times for each of the two instances above using the same Tempest TR1.3-12 SLA Battery ?

Answer ______________________

Answer ______________________

Gears Educational Systems, LLC

105 Webster St. Hanover Massachusetts 02339 Tel. 781 878 1512 Fax 781 878 6708 www.gearseds.com

Battery Lab Activity #3

Battery Energy Work Sheet

The challenges involved in engineering an electric car battery pack

Electric car development is constrained by the limitations of presently available battery technology and chemistries.

Problem: Research and calculate the cost and weight of a battery pack that could provide a Toyota Prius with the same range as 3 gallons of gasoline. The car is a Toyota Prius.

Create a spreadsheet that can be used to store the research data, make the necessary conversions and calculations and display the data in an orderly and organized manner.

Research the following data:

__________ Prius curb weight

__________ Prius average mileage (Gallons per mile)

__________ Energy density of gasoline (kilowatt hours/kg)

__________ Energy Density of lead acid batteries (kilowatt hours/kg)

__________ Energy Density of lithium cobalt batteries (kilowatt hours/kg)

___________ Total weight of three gallons of gasoline (kg) (pounds)

__________ Weight of lead acid batteries needed to provide the same total energy as 3 gallons of gasoline. (kg) (pounds)

__________ Weight of lithium cobalt batteries needed to provide the same total energy as 3 gallons of gasoline. (kg) (pounds)

__________ The calculated weight of the lead acid batteries is what percent of the cars total curb weight?

__________ The calculated weight of the lithium batteries is what percent of the cars total curb weight?

Battery Lab Activity #4

A Visual Model of Battery Discharge

This demonstration serves as a visual approximation of how a battery discharges over time.

Materials

¼" drill bit	¼" lag bolt
1" drill bit	¼" steel washer
5 Gallon Bucket	¼" rubber washer
1 x 1 ¼" #6 Rubber Stopper	**Stop Watch**

Introduction

A charged battery can be imagined as being like a 5 gallon bucket of water. If a ¼" diameter hole is drilled into the bottom of the bucket, the water would leak out over time, at a rate that could be repeated with accuracy. In fact ancient water clocks were constructed in this manner. The water draining from the bucket is analogous to the current supplied by the battery. The height of the water, above the hole creates the pressure to force the water out. As the water level lowers, the force of the water coming out of the hole drops. The changing height of the water above the hole is analogous to the changing battery voltage during discharge.

If the same bucket (with a ¼" hole) had a 1 inch diameter hole drilled into it, the water would drain faster. Makes sense, right?

This is an experiment worth trying. It is interesting to try and predict how much faster the water will run out of the 1" hole before performing the actual experiment.

What do you think the difference between the rate of discharge through a ¼" and a 1" hole would be?

This activity is offered in the expectation that participants will obtain a "Visual" model of battery current drain and voltage drop by watching the water pressure drop (voltage) as the bucket (battery) empties. The concept of a finite expendable amount of energy being "Drained" from the battery is also helpful.

Is drain rate directly proportional to the hole diameter?
Note that a 4x increase in hole DIAMETER ¼" – 1") results in a greater increase in drain rate. How much greater? This is suggestive of what happens to battery capacity as we increase the current draw.

Is drain rate directly proportional to the cross sectional area of the hole? A 1" diameter hole has about 15x the cross sectional area of a ¼" diameter hole. Will the water drain approximately 15x faster through a 1" hole than through a ¼" hole?

Directions
Note: This activity is best performed outside or in a large sink

1.) Obtain a clean empty 5 gallon bucket. These are often available from restaurants and delicatessens.
2.) On the side of the bucket drill a ¼” hole with a center 1” up from the bottom of the bucket.
3.) Diametrically opposite the ¼” hole drill a 1” hole with a center 1” up from the bottom of the bucket.
4.) Plug the 1” hole with a rubber stopper available from the High School Chemistry lab or local hardware store. Plug the ¼” hole with a ¼” machine screw, 2 flat metal washers, a hex nut and a rubber or leather washer.
5.) Mark a level 3” above the top of the 1” hole with a permanent marker. Fill the bucket to this level.
6.) Add 3 Gallons of water and mark this water line. This will provide you with a reasonably consistent volume and pressure from which to base your observations.
7.) Open the ¼” hole and record the time required to drain the bucket.
8.) Repeat using the 1” hole.
9.) Compare and discuss the results.

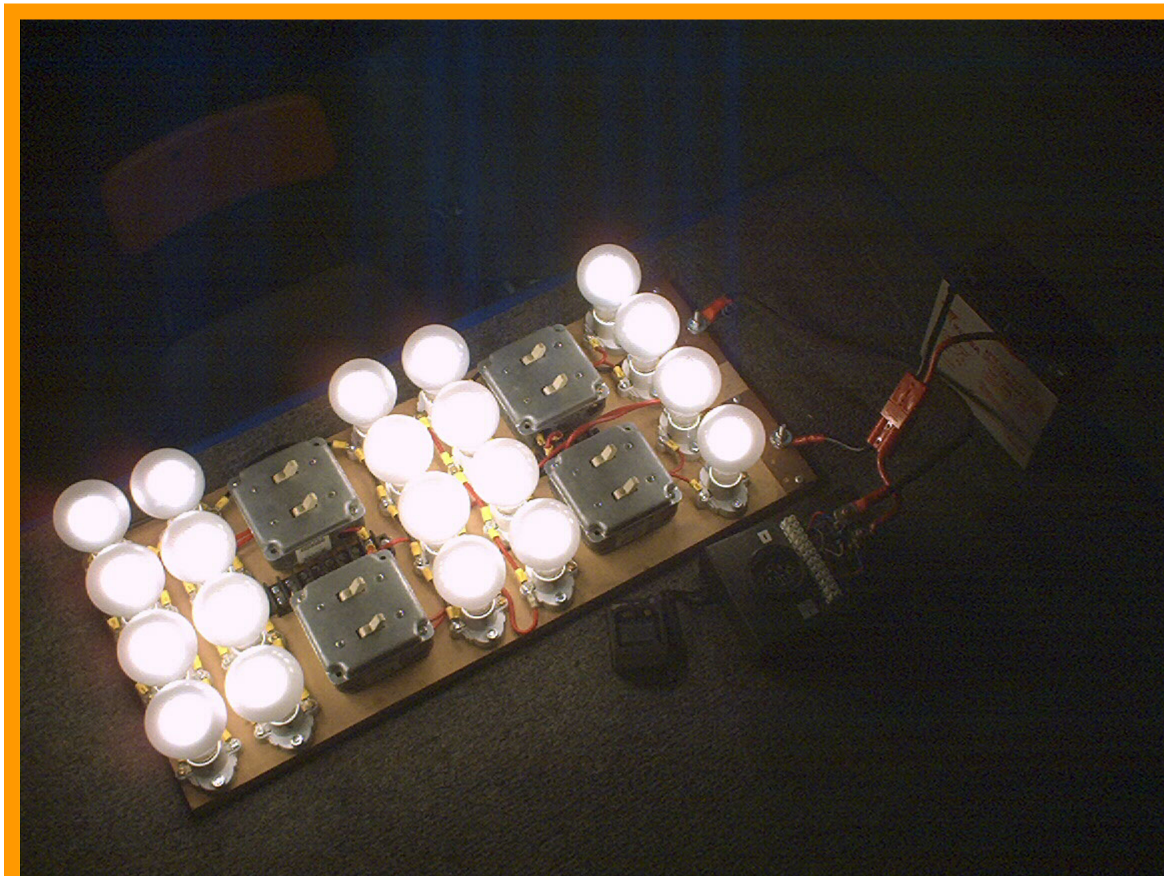
Circular Area = $\pi * r^2$

	#1 Hole Diameter ¼”	#2 Hole Diameter 1”	#1 Hole Area	#2 Hole Area
Drain Time in Seconds				
Drain Rate in Gallons/sec.				

Observations and conclusions:

Test your conclusions: How long will it take to drain 3 gallons of water through a ½” hole? Calculate your answer, then drill a hole and prove it!

Building a Battery Test Board



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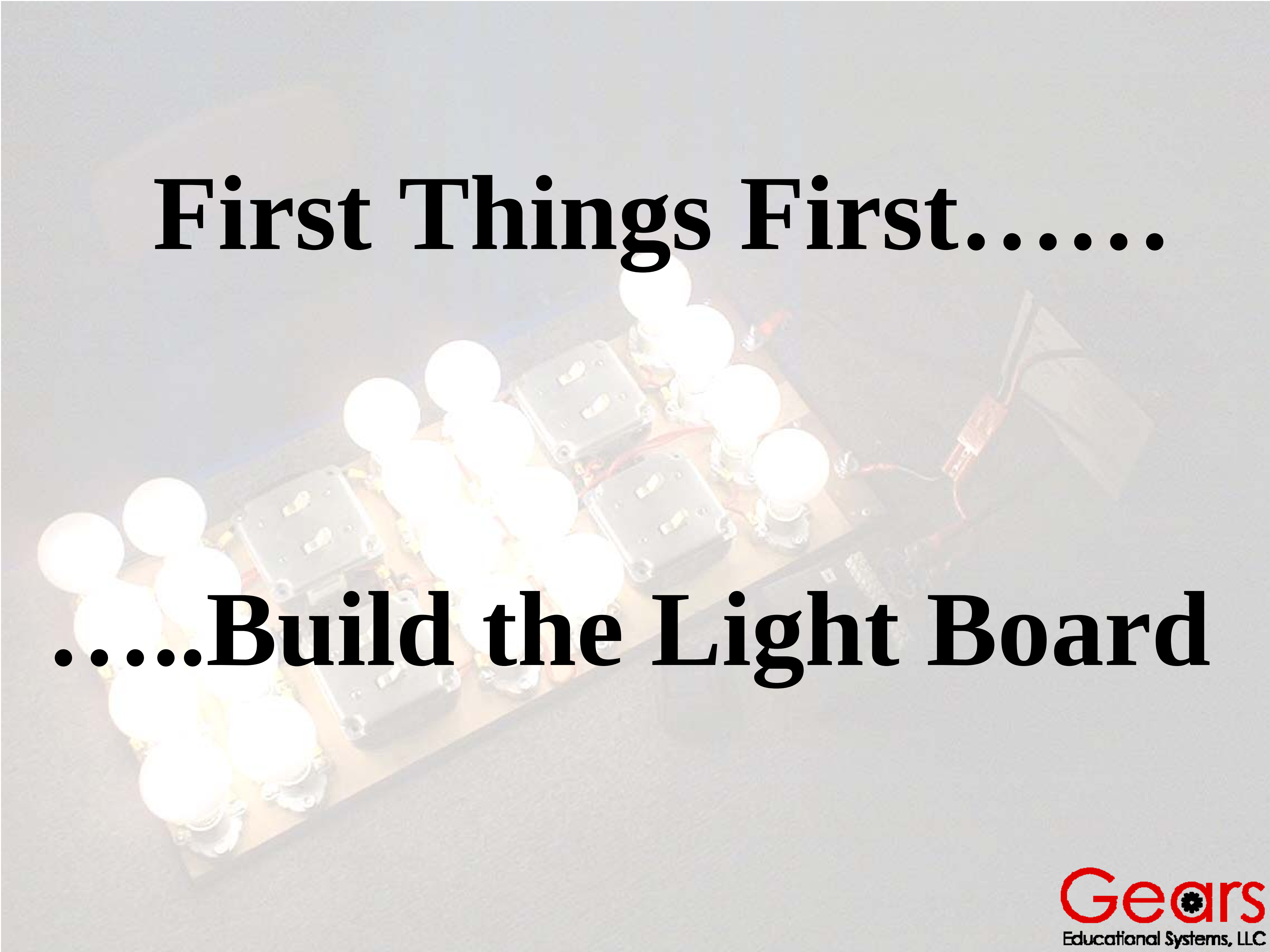
First Things First……
…..Build the Light Board
Gears
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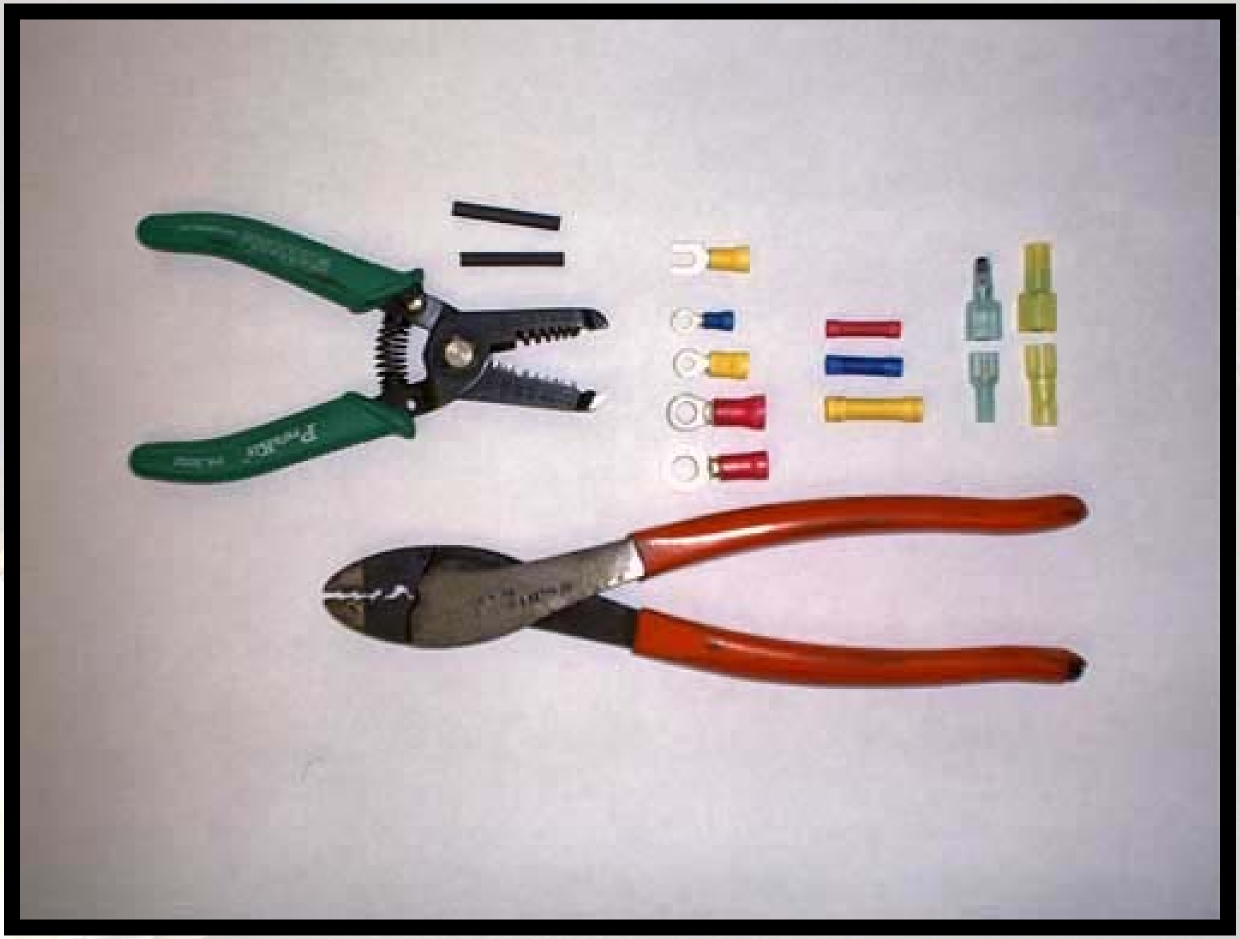
Acquire These Tools



Wire Strippers, Crimps and Solderless Connectors

Gears Educational Systems, LLC

Necessary Hardware

Connectors

10 gauge eyelets (200)

6 gauge eyelets (8 to 10)

Fasteners

 # 10 Sheet Metal Screws (Box 100)

¼-20 x 1" Machine Screws, Nuts, Washers (25 to 30)

4" x 1.5" x 0.057" Copper Sheet (2)

4' x 1' x 0.75" Particle Board

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Necessary Electrical Parts

12 20A/120V Wall Switches

6 4” x 4” metal wall boxes

20 GE 12V/50W Incandescent Light Bulbs

36 250V/660W Free-Standing Light Sockets

1 150Amp/ 50mV Shunt and Meter

2 Anderson 6326-G1 175 Amp Double Pole Battery Connectors for use with #4 Ga wire.

1 Heavy Duty Barrier Strips

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Wiring

#6 gauge wire (6ft.)

#10 gauge wire (15ft.) (red)

#10 gauge wire (15ft.) (black)

#18* gauge wire (5ft.)

***Optional for Shunt/Amp Meter wiring.**

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Instrumentation

This Fluke Clamp on Meter is Available from Radio Shack.

It Measure up to 1000 Amperes DC!

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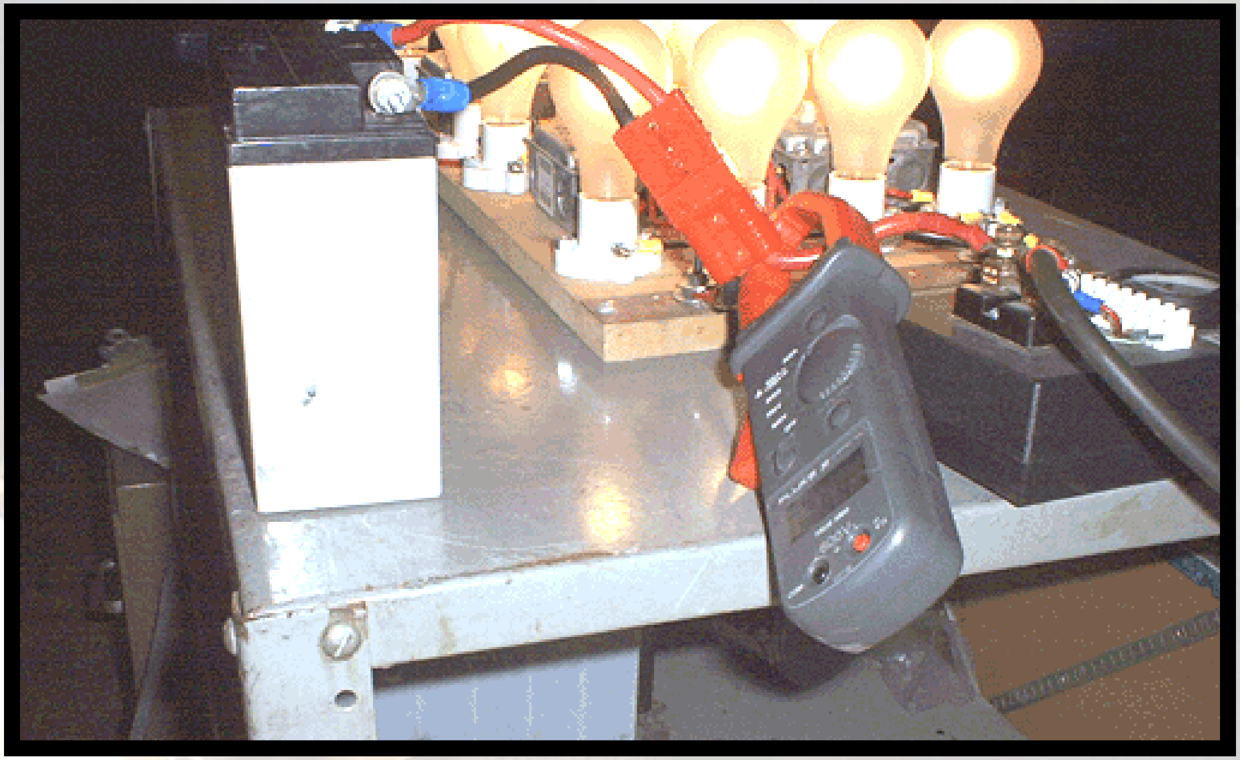
This meter is a great tool for any shop!



The Meter is easy to use, accurate and SAFE!

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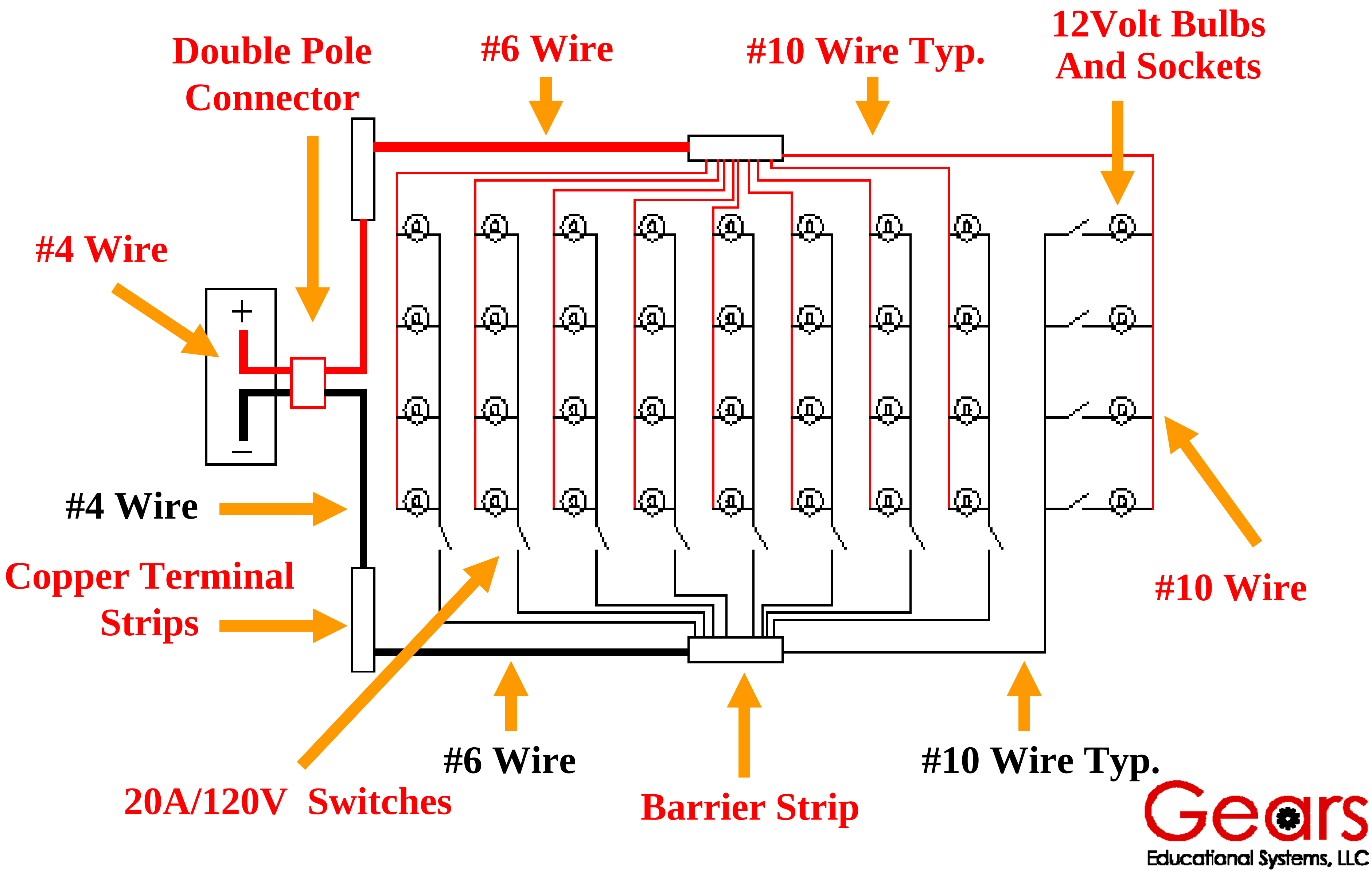
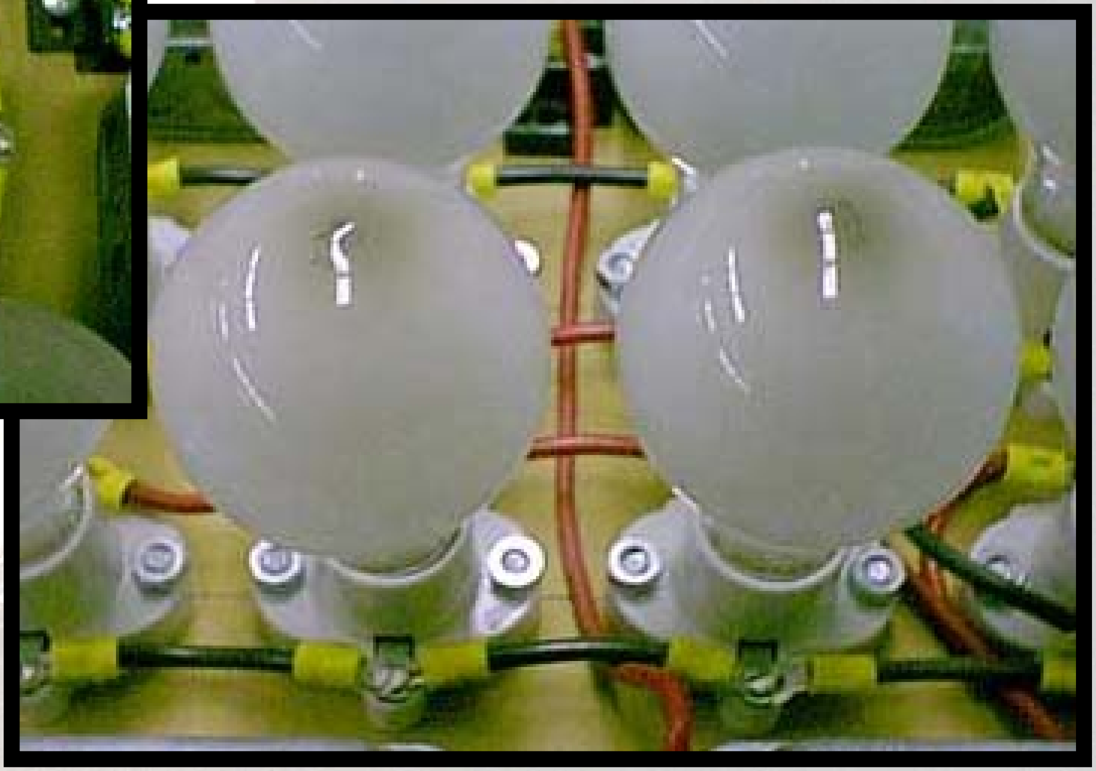
Light Board Wiring Schematic



Some Detail Pictures



Socket Wiring
with
Solderless Terminals

Of the Subassemblies

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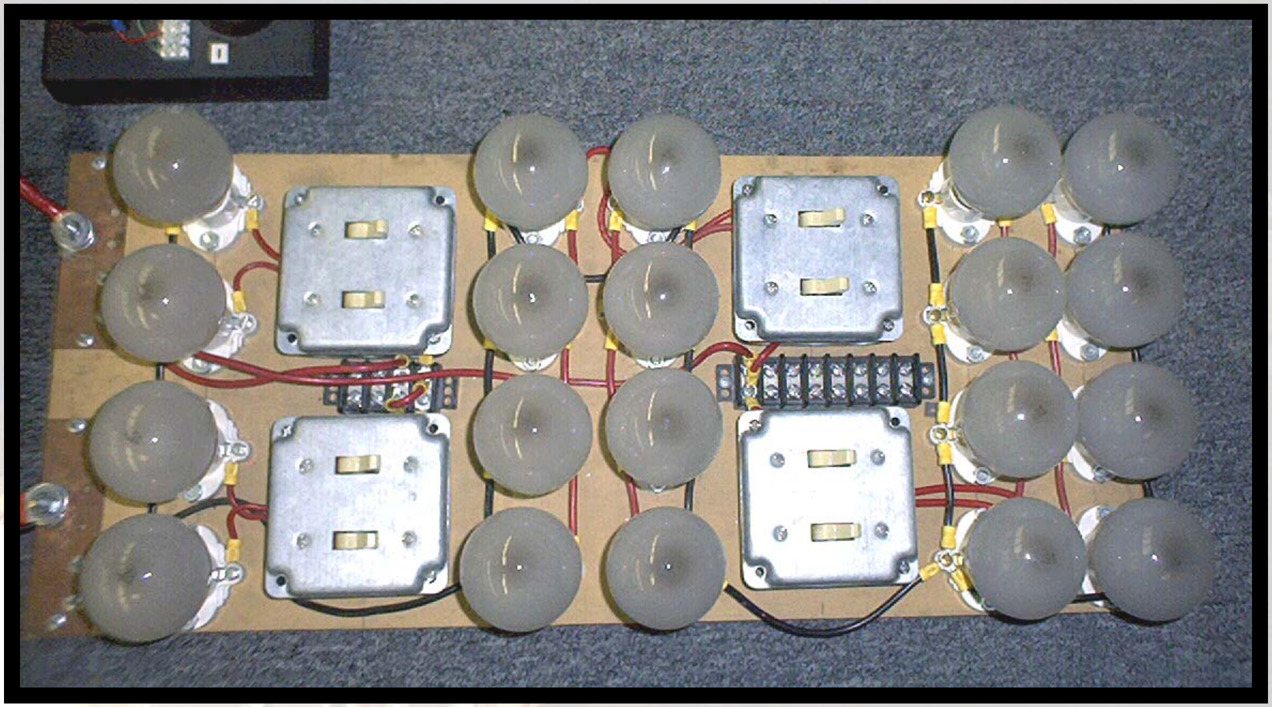
Build the Test Circuit



The board you build does not have to look like this to work well.

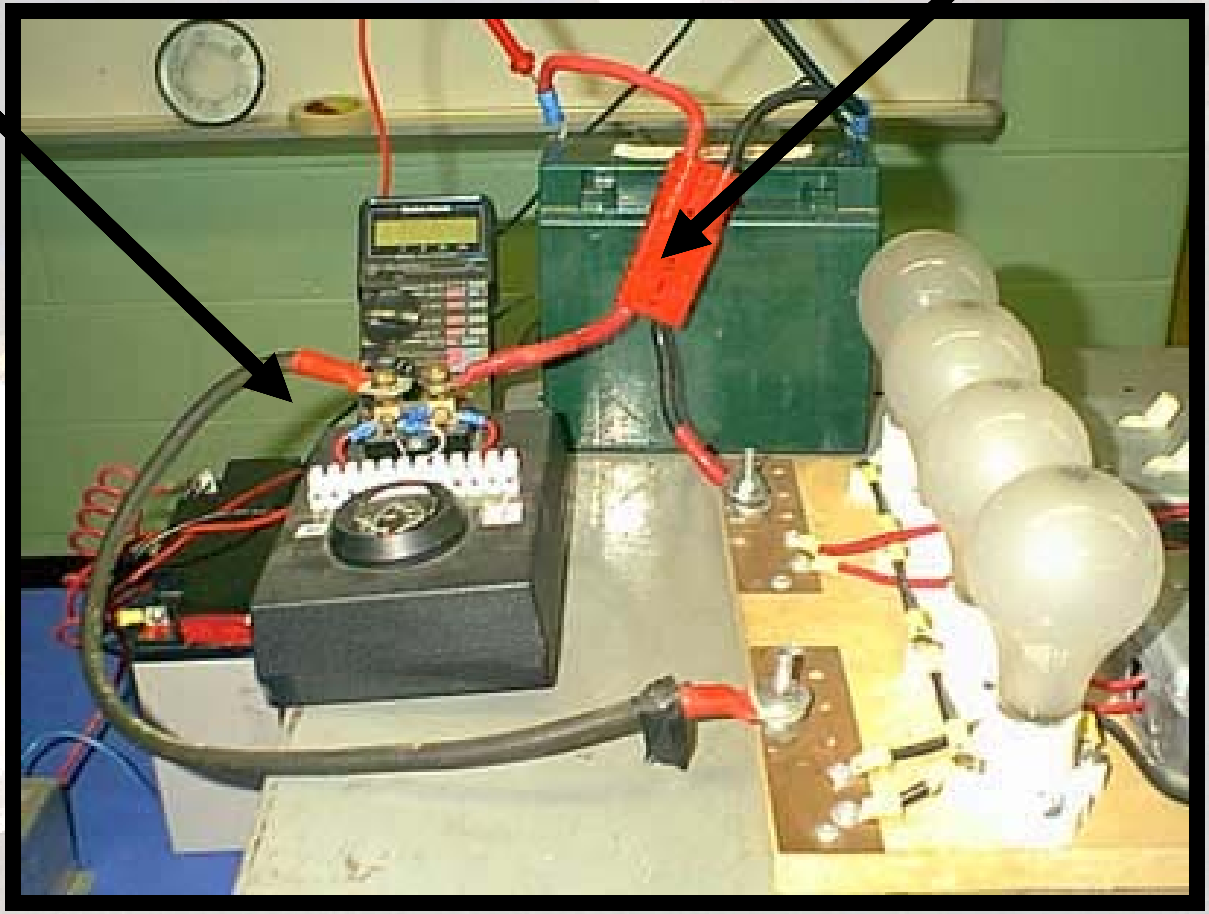
A Finished Setup

150Amp/ 50mV

Shunt and Meter

Not Necessary if you use a clamp on meter!

Anderson 6326-G
175 Amp Double Pole
Battery Connectors



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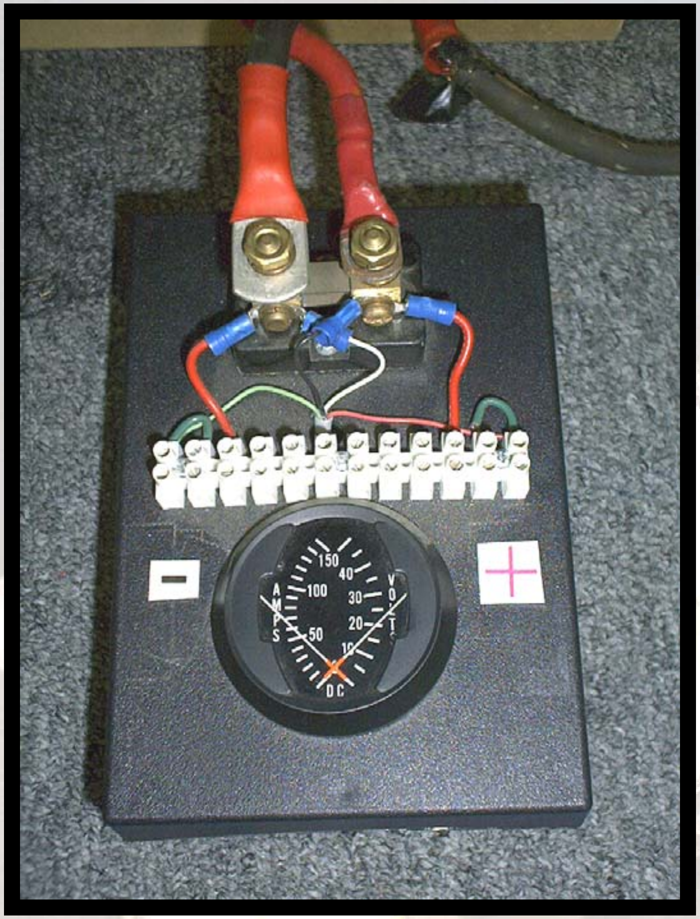
Using Meters and Shunts



Clamp on Ammeters that measure Kilo-amperes are expensive.

With a little research you can construct an affordable shunt/meter combination like the one on the left.

KTA services is a vendor that can supply the parts and know how that will enable you to measure high amperages with low bucks!

www.kta-ev.com

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Technical Notes

A well designed battery test board will perform these functions:

- Provide consistent, repeatable current draws
- Allow for adjustable current draws
- Withstand repeated use without malfunction
- Draw heavy currents safely and reliably
- Be constructed from readily available parts

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Good luck building the Battery Test Board

And we hope you enjoy using it

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