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Estimating Cell Capacity for Multi-Cell Electrical Energy System

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A Thesis Submitted to the College of Engineering, Department of Electrical, Computer, Software & Systems Engineering
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Abstract

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A Multi-Cell Electrical Energy System is a set of batteries that are connected in series. The series batteries provide the required voltage necessary for the contraption. After using the energy that is provided by the batteries, some cells within the system tend to have a lower voltage than the other cells. Also, other factors, such as the number of times a battery has been charged or discharged, how long it has been within the system and many other factors, result in some cells having a lesser capacity compared to the other cells within the system. The outcome is that it lowers the required capacity that the electrical energy system is required to provide. By having an unknown cell capacity within the system, it is unknown how much of a charge can be provided to the system so that the cells are not overcharged or undercharged. Therefore, it is necessary to know the cells capacity within the system. Hence, if we were dealing with a single cell, the capacity could be obtained by a full charge and discharge of the cell. In a series system that contains multiple cells a full charging or discharging cannot happen as it might result in deteriorating the structure of some cells within the system. Hence, to find the capacity of a single cell within an electrical energy system it is required to obtain a method that can estimate the value of each cell within the electrical energy system.

To approach this method an electrical energy system is required. The electrical energy system consists of rechargeable non-equal capacity batteries to provide the required energy to the system, a battery management system (BMS) board to monitor the cells voltages, an Arduino board that provides the required communication to BMS board, and the PC, and a software that is able to deliver the required data obtained from the Arduino board to the PC.

The outcome, estimating the capacity of a cell within a multi-cell system, can be used in many battery related technologies to obtain unknown capacities of different cells; such as the EcoEagle that partially receives its power from the electrical energy system. This thesis was conducted as the theory behind the EcoEagles Electrical Energy System.

Key Words – Electrical Energy System, Cells, ESS, Green Energy, Battery Management System, BMS, Arduino.

Table of Contents

List of Tables

List of Figures

List of Acronyms

A	Amperes
ADC	Analog to Digital Converter
AES	American Electrochemical Society
Ah	Ampere-hours
ANSI	American National Standards Institute
Aq	Aqueous
ARPA	Advanced Research Projects Agency
ARSO	African Organization for Standardisation
BESS	Battery Energy Storage Systems
BMS	Battery Management System
BMSIC	Battery Monitoring/Management System Integrated Circuit
CAFÉ	Comparative Aircraft Flight Efficiency
CANENA	Council for Harmonization of Electrotechnical Standards of the Nations in the Americas
CENELEC	European Committee for Electrotechnical Standardization
COM	Component Object Model
COPANT	Pan American Standards Commission
DC	Direct Current
DMM	Digital Multi-Meter
DOD	Depth of Discharge
EEPROM	Electrically Erasable Programmable Read Only Memory
EFRC	Eagle Flight Research Center
EMF	Electromotive Force
EMI	Electro-magnetic Interference
ESD	Electro Static Discharge
ESS	Electrical Energy Storage System

EV	Electric Vehicles
GFC	Green Flight Challenge
Gnd	Ground
GUI	Graphical User Interfaces
HEV	Hybrid Electric Vehicles
I/O	Input/Output
I/P	Inputs
IATA	International Air Transport Association
IC	Integrated Circuit
ICAO	International Civil Aviation Organization
ICSP	In Circuit Serial Programming
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISO	International Standards Organization
KB	Kilobytes
LiPo	Lithium-ion Polymer Batteries
mAh	milli Ampere Hours
MHz	Mega Hertz
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
ms	milli Seconds
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
OEM	Original Equipment Manufacturer
PASC	Pacific Area Standards Congress
PHEV	Plug-in Hybrid Electric Vehicles
PMIC	Power Management Integrated Circuit

PWM	Pulse-width modulation
Redox	Oxidation-reduction
SOC	State of Charge
SPIB	Serial Peripheral Interface Bus
SRAM	Static Random Access Memory
TTL	Transistor-Transistor Logic
UART	Universal Asynchronous Receiver/Transmitter
UL	Underwriters Laboratories
UN	United Nations
UPS	Uninterruptible Power Supplies
USB	Universal Serial Bus
USNC	United States National Committee
V	Volts
Wh	Watt-hours

Chapter 1: Introduction

Every year many companies and organizations around the world are searching for better energy efficient innovations which would reduce our needs for oil-based products. Climate changes, high oil prices and pollution are disincentives governments and private organizations to take drastic measures to reduce our needs for oil-based products. Many academic and non-academic organizations have hosted or sponsored events to promote this development. Among the supporters the National Aeronautics and Space Administration (NASA) and Google partnered together to support the Green Flight Challenge (GFC).

This event was first announced at AirVenture 2009 in Oshkosh, Wisconsin. The challenge was scheduled to be for July 2011 but later had been rescheduled for September 25 to October 3. The place of competition was at Charles M. Schulz Sonoma County Airport in Santa Rosa, California, hosted by Comparative Aircraft Flight Efficiency (CAFÉ) Foundation Flight Test Center (*2011*).

Fourteen teams had registered, but three teams met the requirements necessary for the competition. The requirements were that the winning aircraft had to fly 200 miles under two hours and use less than one gallon of fuel per passenger or its electrical equivalent. The first two teams had an outstanding achievement of flying 200 miles with just over a half gallon of fuel used per passenger; also, it should be said that they were fully electric-powered aircrafts. First place was awarded to Pipistrel-USA.com from State College, PA and second place was awarded to eGenius from Ramona, CA. The amounts of the prizes were $1.35 million and $120 thousand respectively.

Embry-Riddle Aeronautical University was one of the teams approved for this competition. They had decided to build an aircraft called the EcoEagle. An aircraft which was fully operated by fuel and electrical resources, a hybrid aircraft. The fuel side was used for lift off and landing while the electrical side was used in conjunction for gliding the aircraft through air. The electrical side of the aircraft consisted of multiple battery modules in parallel while each of the battery modules had a battery management system (BMS) connected to a communication data bus controlled by a master controller. This project was put together at the Eagle Flight Research Center (EFRC) and the electrical team was led by Dr. Jianhua Liu.

The hybrid aircraft at Embry-Riddle Aeronautical University consisted of a Rotax 912ULS, a 100 hp internal combustion engine, powered by bio-diesel and a custom-made 40 hp brushless direct current motor powered by a battery system to achieve the fuel efficiency goal. Also, it had an efficient motor glider called the Stemme S10 which was used in the airframe. This hybrid aircraft was the first of its kind denoted by NASA and was its entry into the GFC.

It is known that charging or discharging any battery module decreases the capacity that it contained at the beginning of its use over time, therefore resulting in lower capacity rates. For an aircraft which consists of multiple battery modules which are charged and discharged over time due to flying, testing or any means necessary, we need to be able to estimate its capacity over time. This system will ensure that all our batteries are fully functional according to the specifications needed. Also, this makes it possible for removing and changing the unhealthy batteries from the battery module within the system. Estimating the capacity of the cells is the main focus of this thesis.

The electrical battery system of the aircraft consisted of the following;

1. 4 × 10, 20 Ah Lithium Iron Phosphate cells in series used to provide the needed voltage by the Motor Controller.
2. 4 power management integrated circuit (PMICs) boards to monitor the voltage of each battery cell during charging and discharging as well as balancing the cell voltages during charging. Each board can monitor/balance up to 12 cells.
3. A number of Temperature Sensors to monitor the temperature of the battery cells.
4. Current Sensor to monitor the charging and discharging current of the Battery Module. The discharging current and the total voltage of the batteries can be used to estimate the power of the motor as well as the remaining energy storage.
5. A Relay Pair used to switch the Battery Module on/off for the direct current (DC) power transmission line. Due to the possible voltage difference between the battery modules, a transitional relay, which has a high power resistor in series to it to curb the current, is needed to bring the voltages closer before closing the main relay (contactor). The current reading can be used to determine when the main relay can be closed.
6. Microcontroller board, the controller for the BMS, used to control/read the above PMICs, the Relay Pair, and the current sensor.

See Figure 1 for its configuration.

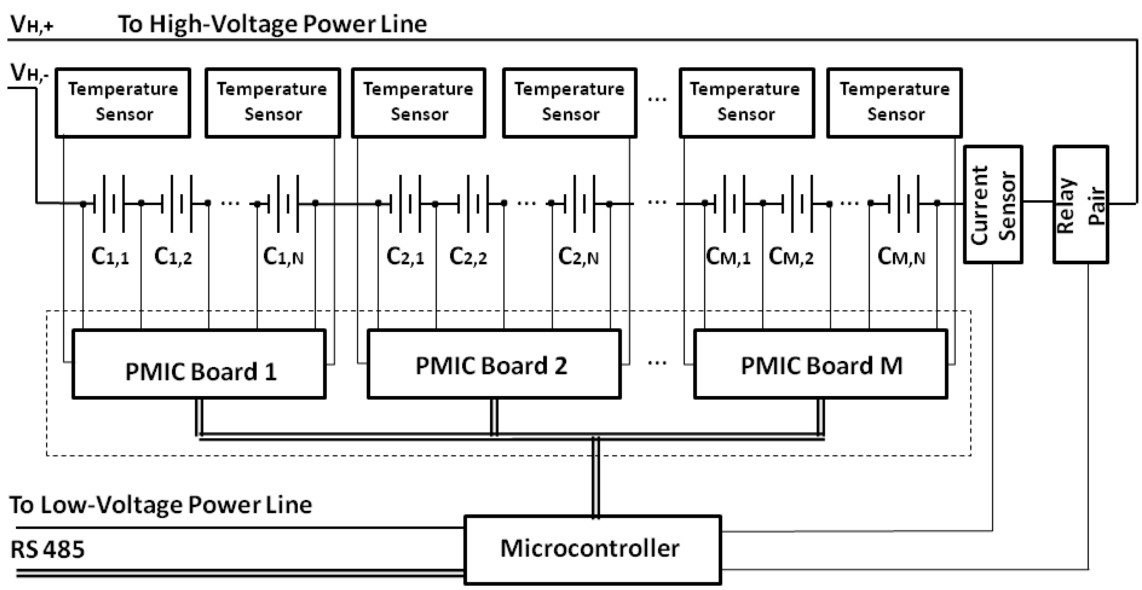

Figure 1. Battery Module Configuration.

The BMS is responsible for the health of the battery cells; it is there to monitor the current, voltage, temperature and state of charge (SOC) of the battery system.

Statement of the Problem

Working with any type of battery it can deliver a specified voltage. It also has a specified capacity indicating on how long it can be consumed. After a certain amount of time of utilizing its charge, it tends to deplete until it cannot give the required output.

There are certain factors to consider for the health of the battery, such as the number of times it was charged or discharged, how long the battery(s) has been used or unused, leakage current that can happen between the batteries and cell specific variations that come from the manufacturer, will result in some cells of the battery system having a lesser capacity compared to the other cells in the system. These phenomena will lower the capacity of the module and therefore the capacity of the system will be reduced. It will lower the output that is required to produce. Depending on the intended application of that certain battery it could have a fatal or non-fatal effect. If the battery is a toy battery and its capacity is unknown after being consumed, it will not put in a lethal effect for its outcome. The only possible outcome is the toy battery cannot deliver the required voltage, either it has been drained or not sufficient enough, therefore the battery will be discarded and a new battery will replace the previous one. If the battery deals with human life or any risky outcome that needs to have a guaranteed solution in operation, being able to have an estimate of how much capacity it contains, is without question, a required fact. Examples can range from the electric system that is onboard the EcoEagle or a small Pacemaker that is implanted in the human chest. It will be necessary to estimate a value for the capacity of that cell or battery.

We are able to mention that estimating the capacity of each cell in a stand-alone process is possible to achieve. By a deep cycle discharging or charging a cell, we are able to estimate its capacity; this method is useful for lead-acid batteries. For Lithium-Ion Polymer Batteries (LiPo) it is recommended to charge or discharge around the nominal voltage value of the battery, therefore not going below the minimum voltage or above the maximum voltage value or this can limit the cells life expectancy. This process is explained throughout this research.

The deep cycle charging or discharging of whether or not for which types of batteries it could be used is based on their internal structures. A deep cycle battery is more robust, it has thicker plates, thicker separators and a higher density paste material which results in a much less corrosion throughout the discharge or charge process.

Due to the GFC and the time constraint to make this aircraft safe in the skies and during operation different parameters were taken into consideration like the location of the fuelling system, the maximum power output of each of the onboard systems and their required efficiency along with many others. The electric system was there to ensure the pilot to fly safely while the gas motor was for providing the aircraft to have the necessary energy for lift off and landing after operation.

For an understanding on how electric power has developed throughout history please refer to Appendix A of this thesis.

Significance of the Study

The results obtained from this research can be used in numerous products that have battery systems among its divisions. It will give projects and battery related technologies an insight on how long can their contraption rely on the batteries energy source. Projects such as the EcoCar or EcoFlight conducted at Embry-Riddle Aeronautcal University. Technologies can have a vast range from portable electronic devices to a simple flashlight.

Modeling the Aircrafts ESS

To estimate the cell capacity of the battery system onboard the EcoEagle a smaller system was modeled to conduct the research. The smaller system is an equivalent model of the aircrafts battery system. It has the following systems;

1. A Turnigy 4000 milli Ampere Hours (mAh) 3S 20C Lipo Pack having 3 cells in series of a nominal voltage of 3.7 Volts (V), a minimum of 3 Volts (V) and a maximum of 4.2 Volts (V).

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   Connecting the 2 battery packs in series, making 6 cells in series, therefore having 6 cells of 3 that are 4000 milli Ampere-hours (mAh) of capacity and 3 that are 5000 milli Ampere-hours (mAh) of capacity.

2. Using a DC1331D Battery Management System (BMS). The LTC6802-1 model is a complete battery monitoring integrated circuit (IC) that has a 12-bit Analog to Digital Converter (ADC). It can measure up to 12 cells in series, with in 13 milli seconds (ms) of voltages received and up to an input voltage of 60 volts (V). The Battery Management System (BMS) also has the following features; each cell input has a relative MOSFET switch for discharging overcharged cells, cell input protection from Zener diodes positioned for enhanced protection to hot-insert stresses and many more features that are elucidated in the following chapters. Although, it ought to be said that the researcher will also be present throughout the charging or discharging process to ensure the safety of the system and it’s surrounding. Also there is a software interface that the researcher can monitor the voltage process of the battery cells. This ensures that the cells are not over charged or under charged.

3. Using the Arduino Mega 2560 model which has 54 digital input/output (I/O) pins, 4 Universal Asynchronous Receiver/Transmitter (UARTs) (hardware serial ports), 16 analog inputs (I/P), 16 Mega Hertz (MHz) crystal oscillators and many other features that are explained in the following chapters.
4. Producing a software capable of reading voltage, time, temperature, current, max cell voltage and min cell voltage values. Also the software will be capable of plotting voltage against time to be able to take measurements from the graphs obtained. (Not all these values that the software will obtain are necessary or needed to conduct this research but it is just a prediction if this software will be used in the future for different research.)

Chapter 2: Overview of Batteries

What is a Battery?

A battery is a component that converts the chemical energy contained in its active materials into electric energy by means of an electrochemical oxidation-reduction (redox) reaction. This kind of reaction involves the transfer of electrons from one material to another through an electric circuit. If the system is also a rechargeable system, the battery is recharged by a turnaround of the process. While the term “battery” is often used among the common public, the actual term is the “cell” which is the primary electrochemical unit of the battery. A cell is the source for electrical energy by directly converting chemical energy to electrical energy; it is the primary electrochemical unit of the battery pack. The cell involves an assembly of electrodes separated by separators among a solution of electrolyte within distinct container and terminals. In day to day matters the product which is provided or sold to the user is commonly referred to as the “battery” and not the “cell”.

A cell consists of a cathode, anode and an electrolyte. The cathode is where reduction takes place and an anode is where oxidation takes place. When the process of discharge is happening the ions are traveling through the electrolyte, otherwise stated, the electrolyte conducts the current inside the cell. The most beneficial amalgamation of the anode and cathode materials are the ones that will have the lightest in weight and give a great cell voltage and/or capacity. Such mixtures may not always be practical, nonetheless, because of its reactivity to other cell components it might have, difficulty in handling, polarization, high cost of materials and other deficiencies.

In a practical system, the anode is selected with the following features;

1. Good conductivity
2. High columbic output
3. Competence as a reducing agent
4. Simplicity of production
5. Solidity
6. The most important; low cost

Hydrogen is a chemical element with an atomic number of 1; it plays an important role in chemistry considering acid base materials. Many of its reactions are switching protons amid soluble molecules. When ionic compounds are present Hydrogen can be as H-, a negative charge known as Hydride (generally an anion), or it can be a cation, a positive charge if it loses its one electron making it a single proton. Hydrogen as a cation happens in more complex ionic compounds. Hydrogen, when used as an anode, is an attractive material, therefore it must be controlled by some processes, which inherently reduces its electrochemical equivalence. In metal-hydride anodes hydrogen is the active material. In general, metals are primarily used as the anode material. A predominant anode in electrochemical cells is Zinc because of its favorable properties. Lithium, one of the lightest metals, having a high value of electrochemical equivalence, has become a very charismatic anode as compatible electrolytes, appropriate and many cell schemes have been developed to contain its activity. With the production of intercalation electrodes, charged carbons are locating many applications in lithium-ion technology. Intercalation electrodes are one of the branches of secondary cells. Their electrodes are layered and regularly made out of graphite or metal oxides. Their operation is by storing positive charged ions between the crystal layers of the electrode. As an example, when one of the cells is being charged the lithium ions forms an intercalation compound around a graphite electrode. When it is being discharged, the ions move back through electrolyte to the previous electrode that they had a tighter bound; it is usually made out of manganese oxide. When the cells are being charged again the ions move back to the positions they had on the graphite electrode. Basically said this process is called the “Rocking Chair Cells”. The values that Rocking Chair Cells have in compared with Lead-Acid Cells are the following;

1. Minor deterioration happen to the electrodes while charging or discharging
2. The electrolyte sustains a more healthier life and is not decomposed quickly
3. The electrolyte only acts as a bridge between the two electrodes and does not contribute too much in the process
4. Intercalation cells (Lithium Cells) have a higher charge/discharge life cycle compared to lead-acid cells so they are more considered in applications where charging and discharging is highly used, examples are camcorders, cell phones and electric vehicles

Lithium alloys are also being researched for use as anodes in lithium-ion batteries. Practicality of one type of lithium-ion battery is explained in further chapters. It will be seen how Li-Po cells function according to voltage against time.

On the other hand the cathode must be perpetual while it is surrounded by the electrolyte also be an efficient oxidizing agent when be used during the process and have a useful working voltage. Oxygen can be applied directly from ambient air being drawn into the cell, as in the zinc/air battery case. On the other hand, most of the known cathode materials are metallic oxides. Other cathode materials like halogens and oxyhalides, sulfur and its oxides are also used for special battery systems.

The electrolyte must have good ionic conductivity, but not itself be electronically conductive because if this happens it would be causing internal short-circuiting. This would damage the cells structure instantaneously.

Other important characteristics of the electrolyte are;

1. No reactivity with the electrode materials
2. Secure handling
3. Little change in its properties with the change in temperature
4. The most important; low cost

Many electrolytes are aqueous (aq) solutions (solvable in water), but there are important exceptions as, for example, in batteries having lithium and thermal anodes, where the electrolyte is made out of molten salt and not an aqueous solution, so this keeps the electrolyte not having any chemical reactions with the anode. In general, the cathode and anode electrodes are isolated electronically in the cell to avert internal short-circuiting. It is good to keep in mind that the anode and cathode are enclosed by the electrolyte. In practical cell designs, a separator material is used to separate the cathode and anode electrodes mechanically. The separator is pervious to the electrolyte that allows for it to keep an acceptable level of the ionic conductivity required. In some cases, the electrolyte is restrained for a no spill design. Electrically conducting grid materials or structures may also be added to the electrodes to reduce the internal resistance.

The cell itself can be built in many forms and configurations – flat, cylindrical, button, and prismatic. The cell constituents are manufactured to accommodate the particular cell shape. The cells are airtight and/or watertight in a variety of ways to prevent leakage and dry-out happening to the cells. Some cells are provided with venting devices, these devices assist the gases that are piled up within the cell to leave and avoid explosion or degradation of the cell. For the final stages of the cell production an appropriate case or receptacle is designed for its terminal connection and labeling are added to complete the fabrication of the cell and the full battery. The lithium-ion cells can be either cylindrical batteries or prismatic. Cylindrical batteries will almost have the appearance of AA cells. Prismatic batteries are made to have a boxed-like shape such as a square structure or a rectangle structure. LiPo batteries researched in this project or the batteries used on the EcoFlight are batteries of prismatic shape. Figure 2 shows two different types of battery cells.

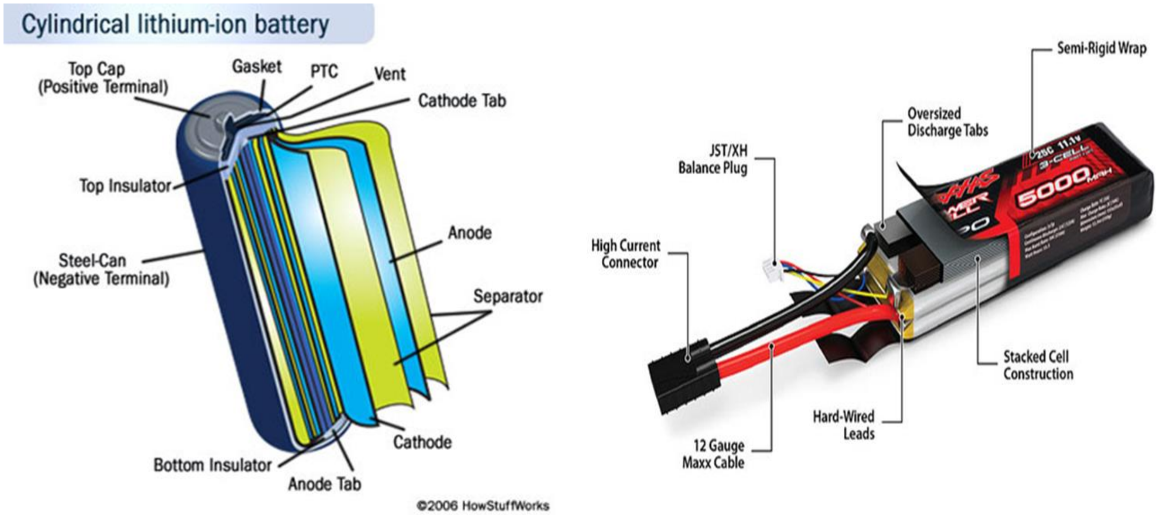

Figure 2. Cells showing internal structure. (*HowStuffWorks*)

Types of Batteries

Electrochemical cells and batteries are identified as primary (no rechargeable) or secondary (rechargeable), depending on their capability of being electrically recharged or not. Within this classification, other classifications are used to identify particular structures or designs.

Primary batteries, according to their internal structures and their applications, are not efficient enough of being recharged effectively, so once the voltage has been depleted they are discarded. Primary cells, cells that the electrolyte among them is contained by a separator material (there is no free liquid electrolyte) are termed “dry cells.” The primary battery is usually inexpensive, convenient, lightweight source of packaged energy for electronic and electric devices; as we could mention flash lights, toys, lighting, digital cameras, memory backup, Global Positioning System devices and other applications. The general advantages of primary batteries are a good shelf life, a very high energy density at low to moderate discharge rates, little, if any maintenance, and easy to use. However large high-capacity primary batteries are used in military applications, whereas, biomedical applications, signaling, and standby power are also under consideration. The vast majority of primary batteries are the familiar single-cell cylindrical (like the AA batteries) and flat button batteries or multicellular batteries using these component cells.

Secondary batteries can be recharged electrically and again being discharged, to their original condition by passing current through them in the opposite direction to that of the charge current. They are storage devices for electric energy and are known also as “accumulators” or “storage batteries”.

The applications of secondary batteries are considered into two main categories; the first category is what we are mainly concerned in this thesis;

1. Practical applications in that the secondary battery is used as an energy-storage device, generally being electrically connected to and charged by a prime energy unit. Its power is delivered to the load on its intended use. These type of batteries have a range of applications such as the automotive industry, aircraft systems, emergency no-fail and standby uninterruptible power supplies (UPS), power sources, hybrid electric vehicles (HEV’s), and battery energy storage systems (BESS’s) for electric utility load leveling.

2. Applications in which the secondary battery is used or discharged essentially as a primary battery source, however, it is recharged again after it is used completely or partially. These batteries usually do not get discarded unless their health is not sufficient enough to provide the required power. Examples for this type of a battery are mobile consumer electronics such as cell phones, laptop computers,

power tools and etc. For cost savings (they can be recharged rather than replaced) and in applications requiring power drains beyond the capability of primary batteries. Electric vehicles (EV's) and plug-in hybrid electric vehicles (PHEV's) also fall into this category.

Another classification for secondary batteries are their ability of being able to be discharged by high discharge rate curve or flat discharge or its capability of being recharged by a high power density rate. The charging and discharging of the battery should have a good low-temperature performance, unlike the Boeing 787 Dreamliner. Their energy densities are generally lower than those of primary batteries. Their charge retention is also poorer than that of most primary batteries; however the benefit of the secondary batteries compared to primary batteries is that the capacity of the secondary battery which degrades over time can be reinitiated by recharging the battery.

Certain types of batteries exist that are known as "mechanically rechargeable brands". They are recharged by the replacement of the discharged or depleted electrode, usually the metal anode with a new one.

Capacity of a Battery

The theoretical capacity of a cell can be determined by the amount of active materials within the cell. It is expressed as the accumulated amount of electricity involved in the electrochemical reactions and is defined in terms of coulombs or ampere-hours (Ah). The "ampere-hour capacity" of a battery or generally its capacity is directly associated with the amount of electricity obtained from the active materials within the cells. By theory, l gram or its equivalent weight of material and/or active material will hand over an equivalent energy of 26.8 Ah or 96,487 C. (A gram-equivalent weight is the atomic or molecular weight of the active material in grams divided by the number of electrons participating in the reaction.)

The capacity of a cell can also be determined by its energy in watt-hours (Wh) basis by taking the voltage and then multiplying it by the amount of electricity that is generated. This theoretical energy value or its electromotive force (EMF) is the maximum value that can be delivered by a specific electrochemical system:

Watt-hour (Wh) = voltage (V) x ampere-hour (Ah)

In an actual system due to the internal resistance which is located within the cells the theoretical voltage value or its electromotive force value will be reduced and therefore a voltage (V) value will be its output. Therefore the maximum energy that can be delivered by an electrochemical system is based on the brands of active materials that are used (this contributes to the electromotive force (EMF) which then contributes to the voltage (V)) and for the second term the amount of the active materials that are used (this determines ampere-hour capacity). Generally said, the more amount of active material and the better quality of the active materials the better the capacity and in return its energy delivered in Watt-hour (Wh). However, we are restricted by the size of the battery and how its physical dimensions can be located in the area of use. Also on certain cases, like the EcoFlight the weight of the electrical energy storage system is also under consideration because we have to limit ourselves to a certain amount of energy from the system or the weight of the batteries will affect the outcome of the flight.

In practice, only a section of the theoretical energy or the capacity of the battery is useable. This is due to the need for electrolytes and nonreactive components such as containers, separators and electrodes that add to the weight and volume of the battery making it heavier and restricted for use.

Another contributing factor is that the battery does not discharge at the theoretical voltage given (thus lowering the average voltage), or it is not discharged completely to zero volts (thus reducing the delivered ampere-hours). This depends on whether the battery of use is a primary or a secondary. Furthermore, the active materials in a practical battery are usually not balanced. This entitles that its specific energy is being reduced because in the process of charging or discharging one of the active elements is being used more than the other, meaning one of the active elements is overindulging in the process therefore less energy is obtained as a product. These attributes of the batteries will be seen in the upcoming chapters.

There is another important factor that strongly affects the performance or rate capability of any cell, as mentioned before it is the internal impedance (resistance) of the cell. It is the main source of a voltage drop during the charge or discharge operation. The internal impedance is a main factor that consumes part of the useful energy that can be delivered by the cell. The energy that is consumed is usually dissipated as wasted heat. The voltage drop that usually occurs due to the internal impedance of the cell is mainly referred to as the “ohmic polarization” or “IR drop” (because according to “Ohm’s Law” which mentions that the potential difference (voltage (V)) across a component is the current (I) passing through and the resistance (R) of the component), and is proportional to the current drawn from the system. To understand what actually the internal resistance of a battery is, it is the total internal impedance of a cell; it is the sum of the ionic resistances of the electrolyte within the porous electrodes and the separator. The electronic resistances of the current collectors, the active mass, the electrical tabs of both electrodes and the contact resistance between the active mass and the current collector. These resistances are generally ohmic in nature, and follow Ohm's law as mentioned before, with a linear relationship between current and voltage drop. Its internal resistance will be the inverse of the slope obtained.

Standards of Batteries

Note: The performance of the cells in a multicellular battery will usually be different than the performance of the individual cells. Also when the batteries fall in series their performance will differ than when they are isolated.

The cells cannot be manufactured identically even though they are aligned in a single pack and, although cells are selected to be balanced at the beginning, they each encounter a somewhat different environment in the battery pack. The specific design of the multi cell battery and the hardware that is used such as the container materials, fuses, packaging techniques, spacing between the cells, insulation, potting compound, and other electronic controls, will influence the performance as they effect the environment and temperature of the individual cells whether stand alone or in the process of charging or discharging. Obviously, the energy density or specific energy of a battery will be lower than the components of each of the cells due to the battery materials that add to its weight and size. As a result, when comparing values like the specific energy of a cell, in addition to being aware of the conditions such as the temperature, current discharge rate and etc., under which these values were determined, it should be ascertained whether the values given are for a cell, a number of cells, a single cell battery (batteries), or multicellular battery (batteries).

Battery designs that retain the heat dissipated at low temperatures can improve the performance of the cells. On the other hand, unnecessary buildup of heat can be a significant danger to the battery's performance, life cycle and safety. As much as possible, batteries should be thermally designed to maintain a uniform internal temperature and avoid hot spots. In the case of rechargeable batteries, cycling could cause the individual cells within a battery pack to become unbalanced and their capacity or voltage or their other characteristics could become significantly different. This could definitely result in poorer performance or major safety problems, and end-of-charge or discharge control may be necessary to prevent this. Therefore as a result, cell balancing techniques are employed with some systems, such as lithium-ion batteries.

Battery Performance Factors

It should be noted that because of the many possible interactions that each cell could have, these effects can be presented only as generalities and the influence of each of the factors is usually more immense under the more stringent operating conditions. For example, if we consider the effect of storage, it is more exceptional with long storage periods and high storage temperatures. After a given storage time, the diminished capacity of a battery in compared to a fresh battery will usually be greater under heavier discharge conditions rather than under a light discharge condition. Concordantly, the diminished capacity of a battery at low temperatures in compared to a fresh battery with normal temperature discharges will be greater than at light or moderate discharge loads. Specifications and standards for batteries are usually listed with the operational conditions or specific tests, which the specifications or standards are based on, because of the influence of these conditions that effects the battery performance.

Furthermore it should be noted that even within a given cell or battery design, there will be performance differences from manufacturer to manufacturer and between different versions of the same batteries such as if it is a premium, standard or a heavy duty battery. There are also different performance variables such as performance factors within a production lot and from production lot to production lot that are inherent to any manufacturing process. How far this variability can go to, depends on the extent of the process controls as well as the application and use of the battery. Manufacturer's data should be seen to obtain specific performance characteristics regarding the battery in use or its application in the system.

There are many ways of referencing the voltage of a cell inside a battery:

1.The theoretical voltage or the Electromotive Force (EMF) is a function of the anode with the cathode materials considering the composition of the electrolyte at a given temperature (usually stated at 25°C).

2.The open-circuit voltage is the voltage under a no-load condition and is usually a close approximation of the theoretical voltage.

3.The closed-circuit voltage is the voltage under the load condition.

4.The nominal voltage is one that is generally accepted as typical of the operating voltage of the battery as, for example, 1.5 V for a zinc-manganese dioxide battery.

5.The working voltage is more representative of the actual operating voltage of the battery under the load and will be lower than the open-circuit voltage.

6.The average voltage is the voltage averaged during the discharge.

7.The midpoint voltage is the central voltage during the discharge of the cell or battery.

8.The end or cutoff voltage is designated as the end of the discharge. Usually it is the voltage above which most of the capacity of the cell or battery has been delivered. The end voltage may also be dependent on the application requirements.

It will be seen that the voltage value of a cell is lower than its EMF after being discharged. This difference is caused by the IR (the product of the discharge current (I) and the internal resistance (R) losses due to cell resistance). Another factor that contributes to the lower voltage is when the active materials become polarized under the discharge process. From this event we can conclude that the specific energy that can be delivered by the battery in its application will always be lower than the theoretical specific energy measured (by a voltmeter) due to its active materials. The reason is:

1. The LiPo battery is not fully discharged to zero volts therefore all of its available ampere-hour capacity is not used.
2. The average voltage during the discharge process is lower than the theoretical voltage.

A common way for representing the discharge, as well as the current charging the battery is the C-Rate and E-Rate. Discharge current is usually defined as the C-rate in order to have a normalized value versus the battery capacity that is always very diverse between different batteries. A C-rate is the quota of the rate that the battery is discharged in compared to its maximum capacity. As an example if we say a battery has a 1 C-rate, it means that the discharge current will discharge the entire battery in 1 hour. For a battery with a capacity of 100 Amp-hours (Ah) this entails that the discharge current will be 100 Amps. Therefore a 20 C rate for this battery obviously would be 2000 Amps and a C/2 rate would mean 50 Amps. The E-rate of a battery defines its discharge power. Therefore just like the C-rate, 1 E rate is the discharge power to discharge an entire battery in 1 hour and obviously E/2 rate would mean to the discharge the complete battery would take 30 minutes.

Another major parameter that is used as battery performance factors is the State of Charge (SOC) and Depth of Discharge (DOD). These two factors imply the present battery capacity as a percentage of its maximum capacity. To obtain the State of Charge (SOC) you would have to integrate the current and this is due that the battery capacity varies over time. For the Depth of Discharge (DOD) it is the percentage of the battery capacity that has been discharged and is stated as a percentage of the maximum capacity over time. If you discharge a battery almost to 20% of its maximum capacity then this process is referred as a deep discharge. If a battery is (continuously) charged or discharged its life performance or life cycle will generally be reduced, therefore the operating life of a battery is mainly affected by the State of Charge (SOC) and Depth of Discharge (DOD).

For a complete understanding on how batteries are standardize according to specifications, organizations and international regulations please refer to Appendix B of this thesis.

Mathematical Model of a Battery

A mathematical model of a battery is an equation or set of equations that represent that certain battery according to its applied performance. It can be a unique equation that represents the battery model for predicting the capacity of the battery versus the current discharged from that battery over time. The level on how detail we want our mathematical model of a battery be depends on its envisioned use. For example a battery model having a set of electrode sets can be represented by a complex three dimensional model showing three spatial coordinates versus time for researching the thermal characteristics of the electrode sets that the battery cells are constructed from.

Finding a mathematical model appropriate for the battery in use comprises of identifying the physical processes that happen during the applied operation of the battery and how does each of its components contribute to those processes. There are basically two ways that can be approached for identifying a mathematical model for a battery;

1. Identify the physical processes that happen across the materials once the battery is connected to the charger/discharger. This involves the chemical reactions that happen across the active materials and among the electrodes of the cells. This process is not the method we want to approach because it deals with identifying the chemical processes of the battery which we cannot have access to and we don’t have the required instruments for measuring these parameters.
2. Identify the general rules that help us to quantify each of these phenomena, which in our case is the method we want to approach. The phenomena that we are looking for is how much the capacity of the cell or battery would be after a certain amount of charge/discharge over time by taking its voltage values. By taking

several measurements while the battery is connected to the battery management system (BMS) and the PC, also while connected to the charger and isolated from the battery management system (BMS) and PC, we will be able to identify the characteristic behavior change of the battery and its cell by cell configuration.

The next task in being able to obtain the mathematical model of the battery is by taking several measurements while the battery is connected to the charger and the battery management system (BMS) and the PC, also while connected to the charger and isolated from the battery management system (BMS) and PC. We will then be able to identify the characteristic behavior change of the battery and its cell by cell characteristic configuration. The main objective of this entire procedure is to develop a mathematical model for a battery (or its cells) to be able to predict its capacity that happens when the battery is in its operation. The intricacy of the mathematical model depends on how accurate we want our model to be and the number of the physical processes we want it to portray. One of the popular objectives nowadays is while having the state of charge (SOC) function of a given battery model, be able to predict the cell voltage(s) of that battery model.

Chapter 3: Battery Management System (BMS)

1. Arduino

Arduino is an easy to use hardware that can be built by obtaining a kit or purchasing and having it already preassembled. It also comes with an open source software that can be downloaded from the Arduino website. It is capable of many tasks from prototyping to simulating real life engineering environments. It can be used by engineers, non-engineers and anyone interested in programming or hardwiring a special type of project. It basically is a single board microcontroller, open source electronics platform.

Arduino according to how its board is setup and the purpose for the usage of the board can have a variety of sensors for sensing the environment it's been put in. It can have a range of sensors from sensing the current to the thermal activity of its ambient. It also has the ability to affect its environment which it has been put in. It can be the controlling of the rotation of a servo to changing the light intensity of its ambient or any other means necessary. The microcontroller that is located on the board is programmed by using the Arduino programming language, which currently is based on "Wiring". Wiring is an open source programming structure for any type of a microcontroller. It can control devices attached to the microcontroller in use. The Arduino programming development environment is based on "Processing". Processing is very easy to use and an open source programming environment that is capable of creating structures, images, animation and etc. The projects associated to Arduino can be stand alone or they can interact with a variety of software's such as Flash, Processing, MaxMSP, Labview and Matlab. To the extent of my experience if the programming language is chosen to be Labview, communicating with the Arduino board and completing different projects can somewhat be easier.

The Arduino board which was used in this thesis was the Arduino Mega 2560 model. This model has the following features;

1. 54 digital input/output pins that 15 of them can be used as Pulse-width modulation (PWM outputs)
2. 16 analog inputs
3. 4 Universal Asynchronous Receiver/Transmitter (UARTs) hardware serial ports
4. 16 MHz crystal oscillator
5. A Universal Serial Bus (USB) connection
6. A power jack
7. An In Circuit Serial Programming (ICSP) header
8. 256 kilobytes (KB) of flash memory for storing code that 8 KB of it is used for the bootloader
9. 8 KB of Static Random Access Memory (SRAM)
10. 4 KB of Electrically Erasable Programmable Read Only Memory (EEPROM)
11. And last but not least a reset button

This board has everything and/or anything needed or wanted to support the microcontroller. Just by simply connecting it to a computer using a Universal Serial Bus (USB) cable or by powering it with an AC to DC adapter or battery, you can get started.

The Arduino Mega 2560 model is an update to its predecessor the Arduino Mega board.

The Arduino Mega 2560 model has the following specifications according to Table 1;

Table 1. Arduino Mega 2560 Specifications

Microcontroller	**ATmega2560**
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Note. Adapted from “*Arduino*.”

As previously mentioned the Arduino Mega 2560 can be powered by a Universal Serial Bus (USB) connection or with an external power supply. Whichever power source is selected to be used, this board can automatically configure it with its processes. External or a non-Universal Serial Bus (USB) power can either come from an AC-to-DC adapter; wall-wart or a battery. If an adapter is chosen for the method to power the board, it can be connected by the center positive plug and the board's power jack. If a battery is chosen the leads can be inserted in the ground (Gnd) and the voltage input (Vin) pin headers of the power connector. The board’s operational region with an external power supply is 6 to 20 volts. If the board is supplied with less than 7 volts it should be noted that the 5V pin can supply less than five volts of power but the board will become unstable. If it has to use more than 12 volts then the voltage regulator can overheat and cause damage to the board. The suggested range to supply power to the board is between 7 to 12 volts.

The Arduino Mega 2560 has a number of facilities for communicating with a computer, another Arduino, or any other microcontrollers. It can have the following specifications for communications;

1. Provides four hardware Universal Asynchronous Receiver/Transmitter (UARTs) for Transistor-Transistor Logic (TTL) 5 volts serial communication
2. An ATmega16U2 is on the board channels; one of these is over the Universal Serial Bus (USB) and provides a virtual Component Object Model (COM) port to the software on the computer.

   Note:

   Windows based platforms will need an .inf file, but OSX and Linux based platforms will recognize the board as a Component Object Model (COM) port automatically.
3. The Arduino software comes with a serial monitor that allows simple text data to be sent to and from the board.
4. The RX and TX LEDs on the board will flash when data is being transmitted by the ATmega16U2 chip and USB connection to the computer but not for the serial communications on pins 0 and 1.

   Note:

   In obtaining the measurements in this thesis the Arduino software was not used to communicate with the Battery Management System (BMS) or the board itself, instead Matlab was used in obtaining the results.
5. The Arduino board has a resettable poly-fuse that can protect the computer's USB ports from being short circuited or overcurrented. Considering that most

computers already offer their own internal protection, the fuse offers an extra layer of protection. Therefore if more than 500 mA of current starts flowing through the port, the fuse will automatically break the connection in use, until the short circuited or overloaded current is over.

The dimensions of the Arduino Mega 2560 model are as the following; the maximum length is 4 inches and the maximum width is 2.1 inches for the PCB. The USB connector and the power jack extend beyond the dimensions mentioned. There are three screw holes which allow the board to be fastened to a case or surface. Just to keep in mind the spacing between the digital pins of 7 and 8 is 160 mm which is not the regular spacing method used on the board that is a multiple of the 100 mm of spacing between the other pins.

Figure 3 shows the top view of the Arduino Board used during the measurements. Figure 4 shows the bottom view of the Arduino Board used during the measurements.

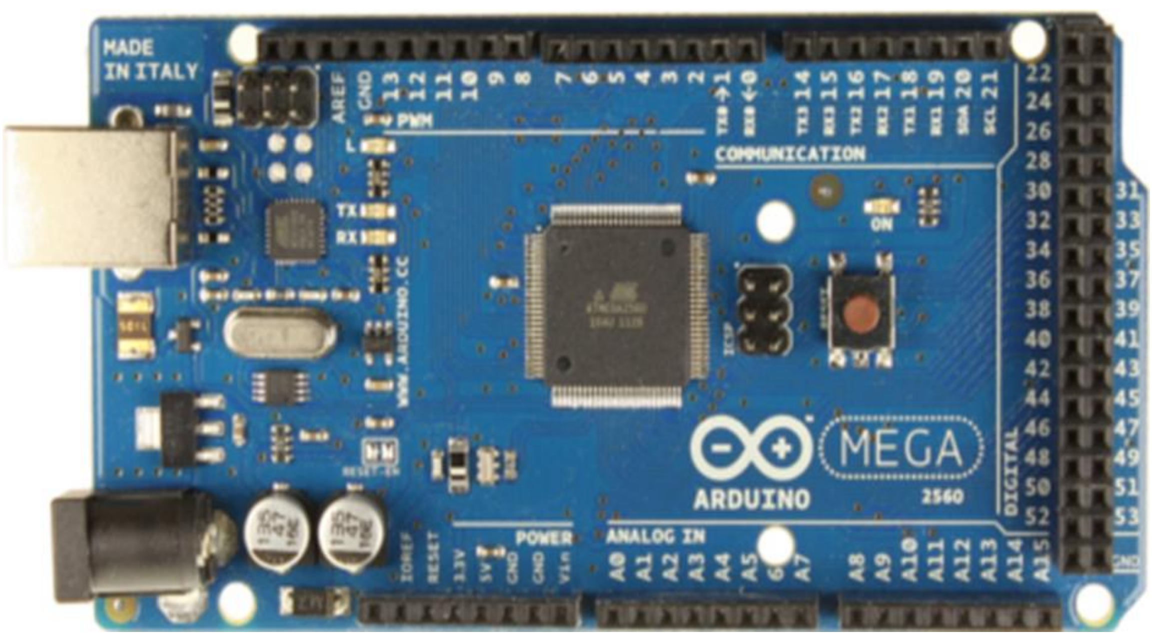

Figure 3. Arduino Mega 2560 Front. (*Arduino*)

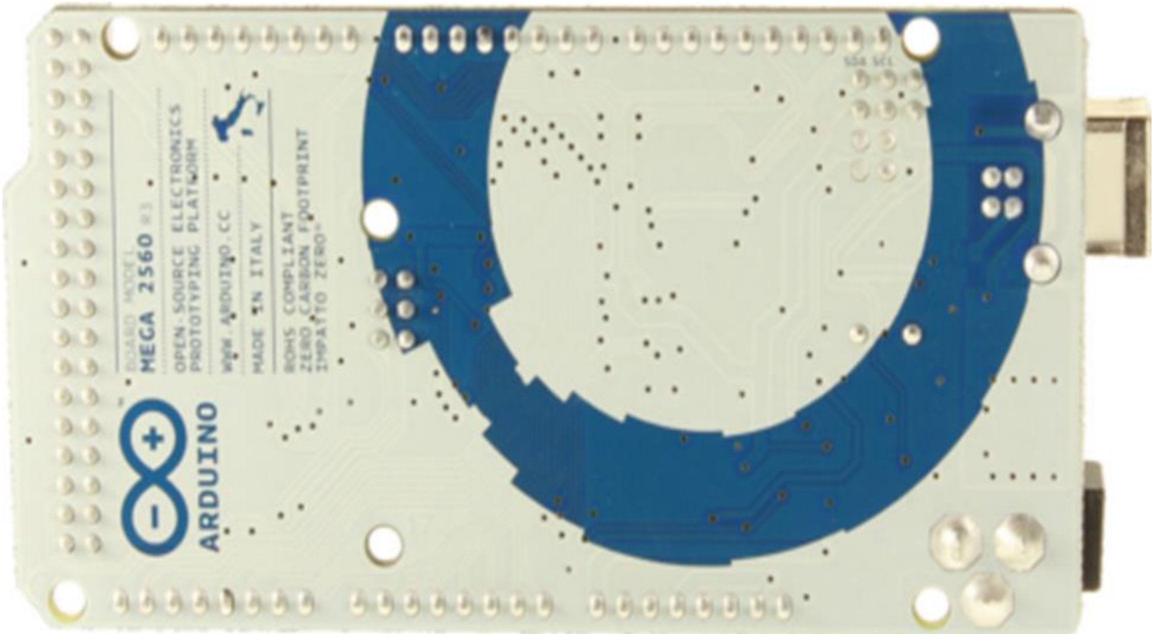

Figure 4. Arduino Mega 2560 Back. (*Arduino*)

The communication protocol for sending and receiving data is through the Arduino Board. Every voltage data, time data and any other types of data that is shown on the software has been sent by the serial communication from the Arduino board. It basically is the interface between the BMS board and the Interface Slave Board that connects to the BMS.

2. Battery Management System Board

The Battery Management System (BMS) board was used as the interface between the batteries and the Arduino board. Its main objective is to monitor the health of the batteries i.e. the voltage, current, temperature and etc. The LTC6802-1 board is a complete battery monitoring/management system integrated circuit (BMSIC) that comes with the following features;

1. Includes a 12-bit Analog to Digital Converter (ADC)
2. A precision voltage reference
3. A high voltage input multiplexer and a serial interface
4. Measures up to 12 series of battery cells an input common mode of voltage for up to 60 volts
5. Multiple LTC6802-1 devices can be positioned in series to monitor the voltage of each cell in a long battery sequence
6. The unique level-shifting serial interface permits the serial ports of these devices to be daisy-chained without the need for any isolators or optocouplers
7. When a number of LTC6802-1 devices are connected in series they can function simultaneously, allowing all cell voltages in the stack to be measured within 13 ms
8. To minimize the power usage, the LTC6802-1 offers a measure mode that can simply monitor each of the cells for over voltage or under voltage situations. Also a standby mode comes with the board
9. Each cell has an input that is associated with a Metal Oxide Semiconductor Field Effect Transistor (MOSFET) switch for discharging over charged cells.

In summary the DC1331D (LTC6802-1) model features are as below;

1. Programmable ability to measure 12 cells in 13 ms, 10 cells in 11 ms or any one specified cell in 2 ms

2. Options in measuring cell voltages and performing an open wire detection with or without the cell discharge transistor activated

3. Thermal shutdown built in and flagged
4. 0.25% Maximum Total Measurement Error
5. Functionality self-test commands for cell voltage and temperature data registers
6. Increased daisy chain Serial Peripheral Interface Bus (SPIB) interface current
7. Silicon revision code provided
8. Permanently activated watchdog feature
9. Added protection circuitry to maintain energetic Electro Static Discharge (ESD)
10. Cell input protection; Zener diodes are relocated for boosted robustness to hot insert stresses
11. Stackable structural design enables greater than a 1000 volt system
12. 1 MHz daisy chainable serial interface
13. Two thermistor inputs plus on board temperature sensor
14. Delta sigma converter with built in noise filters
15. Open wire connection fault detection
16. High electro-magnetic interference (EMI) immunity

Figure 5 shows the top image of the Battery Management System (BMS) board used during the measurements;

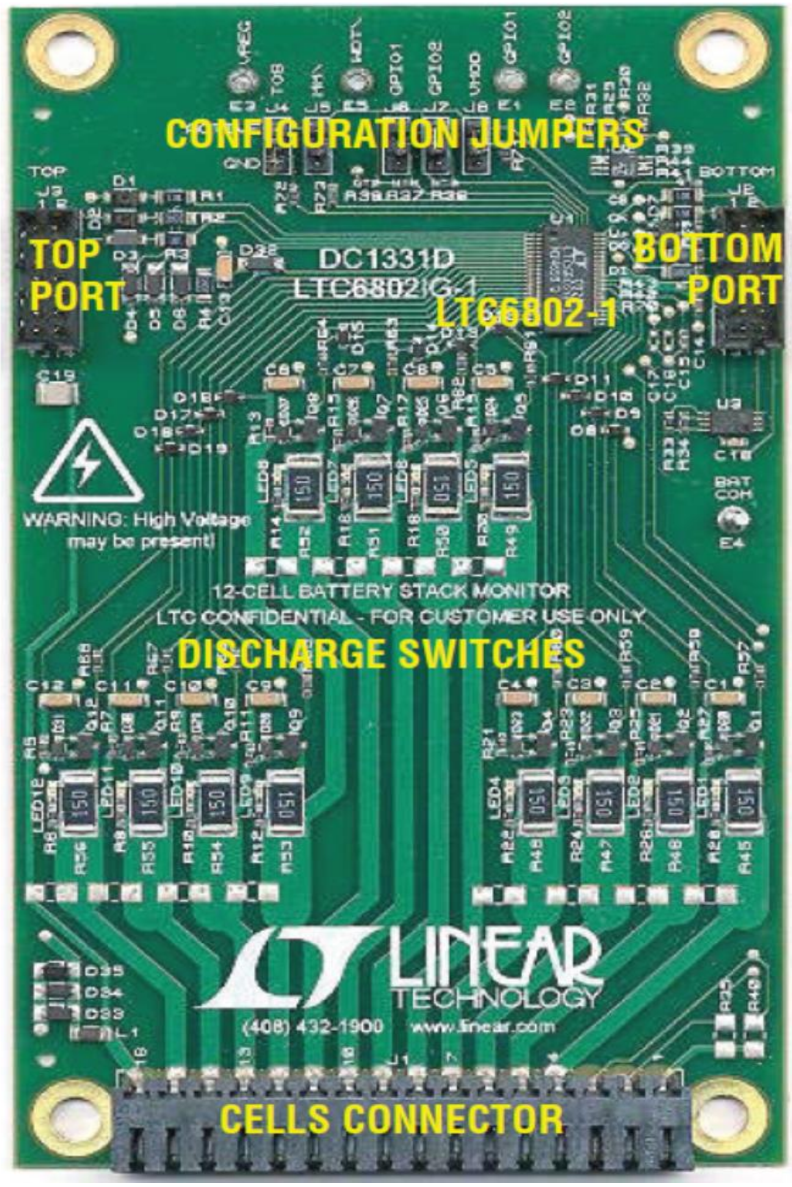

Figure 5. Image of the DC1331D BMS. (*Hardware/Software Users Guide*)

3. Charger

Some rechargeable batteries have memory effect which is the residual capacity if a battery is not fully discharged. This phenomenon will cause the battery to be charged from the remaining capacity it has. For NiCd and NiMH batteries it is better to fully discharge especially NiCd batteries which have a higher memory effect compared to

NiMH batteries. For Lithium batteries it is not recommended to fully discharge the battery instead to partially discharge below the nominal voltage.

The charger that was used in discharging the LiPo battery was the “HobbyKing Quattro 4x6S Lithium Polymer Multi Charger”

Hobby King Quattro 4x6 has the ability of charging four battery packs at the same time, regardless of what battery is in use. The Quattro 4x6 is furnished with 4 high performance isolated microprocessors that correspond to each battery. The microprocessors regulate the charge or discharge flown in or out of the battery. Its effective cooling system provides a safe operation throughout the charge or discharge cycle. The Quattro 4x6 permits the use of a balance charge on a LiPo pack on one of the ports while series charging a LiFePo4 or NiMH battery on another port.

The specifications of the charger are as below;

1. Operating voltage range: 11~15 V DC
2. Power source: 12 V DC
3. Charge power: 50 watts, current is regulated accordingly
4. Discharge power: 5 Watts, current is regulated accordingly
5. Dimensions: 225.4x158.6x62.4 mm
6. Net weight: 1.09 kg

The image of the charger can be seen in Figure 6;

Figure 6. HobbyKing Quattro 4x6S Lithium Polymer Multi Charger (*HobbyKing*)

At the final stages of the conducting the research, during the process of discharging, the charger’s main MOSFET was burned out. This channel led directly to the 4 levels of charging/discharging. The charger was opened, and it was seen the rest of the circuitry was fine but due to the main channel it couldn’t be fixed or relied on. At this moment a new charger came into order and the final stage was completed when the new charger arrived.

4. Li-Po Batteries

The Li-Po batteries that were used had a capacity 4000 mAh and 5000 mAh. These battery packs consist of three cells in series with a nominal voltage of 3.7 volts each. The maximum charge to charge each cell is suggested 4.2 volts. To discharge each cell is suggested to go as minimum of 3.0 volts. The specifications of each battery pack are as below;

Turnigy 5000mAh 3S 20C Lipo Pack

1. Minimum Capacity: 5000 mAh
2. Configuration: 3S1P/11.1 v/3 Cell
3. Constant Discharge: 20 C
4. Peak Discharge (10 sec): 30 C
5. Pack Weight: 412 g
6. Pack Size: 145 x 49 x 26 mm
7. Charge Plug: JST-XH

Turnigy 4000mAh 3S 20C Lipo Pack

1. Minimum Capacity: 4000 mAh
2. Configuration: 3S1P/11.1 v/3 Cell
3. Constant Discharge: 20 C
4. Peak Discharge (10sec): 30 C
5. Pack Weight: 337 g

6. Pack Size: 151 x 50 x 21 mm

7. Charge Plug: JST-XH

Figure 7 shows the images of both of the battery packs;

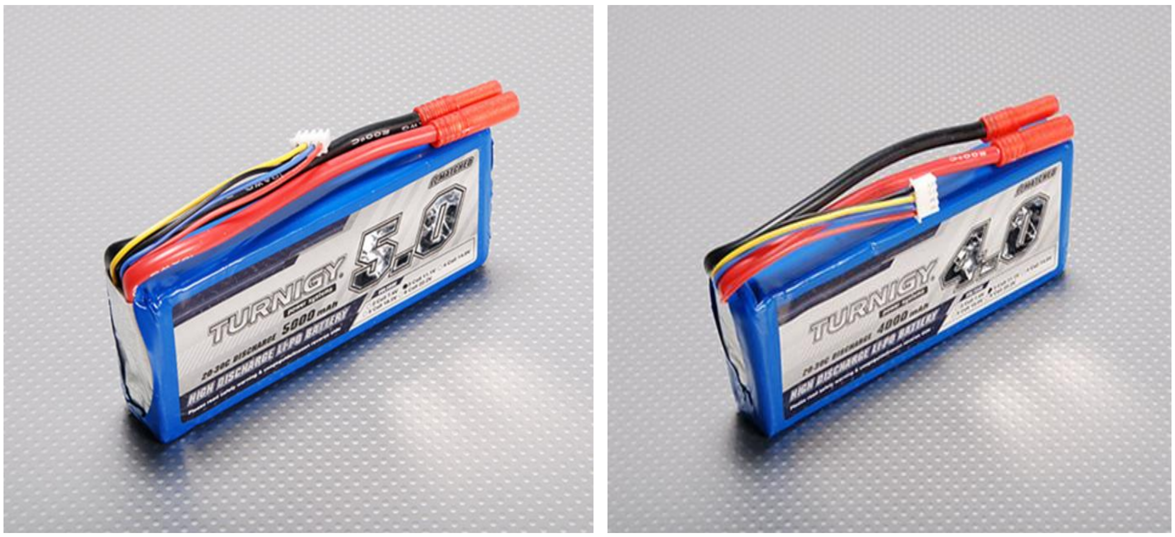

Figure 7. Turnigy 5000mAh 3S 20C Lipo Pack (left), Turnigy 4000mAh 3S 20C Lipo Pack (right) (*Turnigy*)

5. Software

Introduction

The software that was chosen to conduct the research is Matlab. It has the following detriments and benefits in compared to other languages;

1. Matlab in compared to C or C++ is harder to interact with devices to establish a sound communication, therefore the time necessary to find the proper code to be able to communicate in an acceptable format might require a longer time. However on the other hand not all branches of engineering have a solid

background in C or C++ and Matlab offers various toolboxes and Simulink that make a better visual experience of performing calculations compared to C or C++.

2. Matlab in compared to Labview has lesser ability to show advanced Graphical User Interfaces (GUI's) for controlling or communicating between a device or devices. However, Labview is not a common language between all engineers, making its use limited to a certain range of engineers.

Consequently, we chose Matlab as the leading language to carry out this thesis.

Software Rundown

The software, is a complete lines of code that can read all the data necessary in carrying out the estimation process, and plot the required graph. It was also updated in various situations to have the optimum results and minimum flaws. It has also been designed to administer future research if desired. The breakdown of the software is as follow;

1. Start Up Procedure (Initializing Parameters)

   In this block of code we initialize the parameters necessary in order to continue with obtaining the data.

```
voltage_matrix = zeros(1, 12);
voltage_time_history = zeros(1,1);
current_array = zeros(1,1);
current_time_history = zeros(1,1);
min_cell_array = zeros(1,1);
max_cell_array = zeros(1,1);
temp_voltage_matrix = zeros(1,2);
```

This code will basically zero out all voltage, time, current, minimum cell voltage, maximum cell voltage and the temperature cell values at the beginning in order to have a clean and clear set of data coming into the computer, thus initializing all incoming data.

```
voltage_channel_array = [1, 2, 3, 4, 5, 6];
```

This code is there for if we want to pick our channels of incoming data. At the current setting it will read the data channels coming in from channels 1 to 6 of the Battery Management System (BMS) to be allowed through. If the user desires instead of executing this line he or she can input 2, 3 and 5. This will allow the data channels of 2, 3 and 5 of the Battery Management System (BMS) and block the rest.

The advantage of adding this line is if we have one of the channels of the Battery Management System (BMS) not operating correctly, we could disregard that channel and have the rest of the correct data to flow in.

Troubleshooting Note

How do we know if our Battery Management System (BMS) is monitoring the cell voltages correctly?

Each cell should be connected to the voltmeter to see their values, later it should be connected to the computer through the BMS to also see the values obtained from the software, then the following would occur;

1. The values are less than a maximum of 0.5 voltage difference; the values are accurate and the difference is because of the IR drop. The IR drop is the total internal impedance of a cell.
2. The values are more than a maximum of 0.5 voltage difference; the values are inaccurate therefore they need to be disregarded from the measurements or the Battery Management System (BMS) needs to be changed

What happens if we are reading random values on the computer? Which of the systems are not functioning properly and needs to be changed?

The values that are shown on the PC come from the serial communication associated with the Arduino board. If the values shown on the PC are seen randomly changing with no sequence, this indicates that the Arduino board is faulty and the sensor associated with gathering that special type of data has malfunctioned. Therefore to solve this matter, we need to switch that sensor onboard the Arduino, if not replace the board with an error free board.

2. Create Serial Object

In this part of the code we need to address the Arduino board with the proper code and assign it a name, the reasons are;

1_ We are dealing with a cyber-physical system therefore regular coding methods cannot be applied in obtaining the data.

2_ No values or incorrect values will be obtained with regular coding methods.

To solve this issue we need to address this system and give it a name. Hence;

```
arduino = serial('COM8','BaudRate',57600)
```

has a name of arduino and will be communicating with us through com port 8 with a baud rate of 57600.

3. Create Voltage Versus Time Plot

```
voltage_plot = figure('KeyPressFcn', @quitKeyPress);
hold on
plot(voltage_time_history, voltage_matrix, 'XDataSource',...
    'voltage_time_history', 'YDataSource', 'voltage_matrix')
linkdata on
refreshdata(voltage_plot);
hold off
```

This part of the code prepares a graph to be ready to be displayed, a graph that consists of voltage values on the Y-axis and time values on the X-axis. The significance of this part of the code is since our data needs to be monitored in real time and will be monitored in real time we have to have a graph that constantly updates while receiving new data points.

When a value is plotted each time in Matlab, the new plotted value will replace the previous plotted value. In a real time system like this one, the Battery Management System (BMS) will be sending data values almost every 10 ms therefore the graph displayed will be constantly updating almost every 10 ms and each time the previous value will be lost. The key to solve this matter is using the Matlab functions of "hold on" and "hold off" which allows the graph to be constantly updated in real time, without losing its previous value and refreshing it as necessary to receive new data points.

4. Open Serial Port to Arduino

```
fopen(arduino);
```

This part of the code allows the COM port of the computer to establish connections with the arduino (named object).

5. Wait Until Arduino is Calibrated

```
calibrated = false;
while(~calibrated)
    nextLine = fscanf(arduino);
        if (strfind(nextLine,'Current calibrated'))
        disp('Start Up Complete')
        calibrated = true;
    end
```

```
    pause(0.2);
end
disp('Sending Input to Arduino')
fprintf(arduino, '+');
```

This part of the code communicates with the Arduino to see how is its status, it is a startup check to see if the Arduino is calibrated as required, if the Arduino responds giving that it is calibrated, the software will then send a message on the screen to the user that the startup is complete (Start Up Complete). After the software has made sure of this process is complete it will then automatically send an input to the Arduino telling it that to send the data values. It will show a message of “Sending Input to Arduino” notifying the user that the software is now ready to accept the data values.

6. Data Collection

```
number_voltage_samples = size(voltage_matrix,1);
number_current_samples = size(current_array,1);
number_min_voltage_samples = size(min_cell_array,1);
number_max_voltage_samples = size(max_cell_array, 1);
number_temp_voltage_samples = size(temp_voltage_matrix, 1);

disp(['Voltage Values | Time Values | Current Values |',...
    ' Temperature Values | Min Cell Voltage | Max Cell Voltage'])
```

This segment of the code starts building matrices according to the data values that are needed and starts displaying them on the screen as “Voltage Values | Time Values | Current Values | Temperature Values | Min Cell Voltage | Max Cell Voltage”. The only data which is needed from these parameters are the voltage and time values. The rest is extra if needed in another research.

7. Cell Voltages are found

Since the Battery Management System (BMS) is capable of measuring up to 12 cells the program was built according to read 12 cells. However, in this thesis not more than 6 cells were used therefore only 6 of the channels of the BMS were needed and the rest were not shown (because it will only display a value of zero).

```
if(strfind(nextLine,'Cell voltage'))
        cellVoltages = fscanf(arduino,...
            '%f %f %f %f %f %f %f %f %f %f %f %f')';
        if(size(cellVoltages,2) == 12)
            voltage_matrix = [voltage_matrix; cellVoltages];
            voltage_time_history = [voltage_time_history; toc];
        end
```

In this part of the code it will look for the desired cell voltage and turn it to a number.

```
if(strfind(nextLine, 'Min cell voltage'))
```

```
        currentString = strrep(nextLine, 'Min cell voltage (V):
', '');
        min_cell_voltage = str2double(currentString);
        min_cell_array = [min_cell_array; min_cell_voltage];
        number_min_voltage_samples = size(min_cell_array,1);
    end
```

In this part of the code it will look for the desired min cell voltage and turn it to a number.

```
    if(strfind(nextLine, 'Max cell voltage'))
        currentString = strrep(nextLine, 'Max cell voltage (V):
', '');
        max_cell_voltage = str2double(currentString);
        max_cell_array = [max_cell_array, max_cell_voltage];
        number_max_voltage_samples = size(max_cell_array, 1);
    end
```

In this part of the code it will look for the desired max cell voltage and turn it to a number.

```
    if(strfind(nextLine, 'Temp voltages'))
        tempVoltages = fscanf(arduino, '%f %f');
        if(size(tempVoltages,2) == 2)
            temp_voltage_matrix = [temp_voltage_matrix;
tempVoltages];
```

```
            number_temp_voltage_samples =
size(temp_voltage_matrix, 1);
        end
    end
```

In this part of the code it will look for the desired temperature and turn it to a number.

```
    if(strfind(nextLine, 'Current'))
        currentString = strrep(nextLine, 'Current (A): ', '');
        current = str2double(currentString);
        current_array = [current_array; current];
        current_time_history = [current_time_history; toc];
        number_current_samples = size(current_array,1);
    end
```

In this part of the code it will look for the desired current and turn it to a number.

```
if(number_voltage_samples ~= size(voltage_matrix,1))
        number_voltage_samples = size(voltage_matrix,1);
        disp([num2str(voltage_matrix(number_voltage_samples,...
            voltage_channel_array),...
            '%.3f\t'),'    |    ',...

num2str(voltage_time_history(number_voltage_samples),...
            '%.3f\t'), '    |    ', ...
            num2str(current_array(number_current_samples,1),...
```

```
            '%.3f\t'), '    |    ', ...

num2str(temp_voltage_matrix(number_temp_voltage_samples,:),...
            '%.3f\t'), '    |    ', ...

num2str(min_cell_array(number_min_voltage_samples,1),...
            '%.3f\t'), '    |    ', ...

num2str(max_cell_array(number_max_voltage_samples,1),...
            '%.3f\t')])
        refreshdata(voltage_plot)
    end
```

In this segment of the code it will put the voltage, time, current, temperature, min cell voltage and max cell voltage values which are recognized as a number now into a column matrix. The advantage of this step is that the number values have a three decimal value which gives us the following;

1. Providing a nice and comprehensible screen for understanding the data obtained and for the user to monitor the data and the system to have a flaw free milieu
2. Making an accurate measurement of the voltage values and the time it was obtained in millivolts and milliseconds, respectively
3. When saving the data in Excel or any other spreadsheet the data can fall in the required columns and therefore not have a shambolic spreadsheet

Chapter 4: Measurements

The measurements that were taken are in three categories;

1. Measurements of charging and discharging each of the battery pack while measuring the capacity with the charger, i.e. measurements that came from the screen of the charger showing the capacities.

2. Measurements of charging and discharging each of the battery pack connected to the BMS, i.e. measurements taken while the 4000 mAh and 5000 mAh were connected to the BMS but with different inputs from the charger (these measurements were taken only to ensure the accuracy of the measurements taken in step 1 and are not part of this thesis).

3. Measurements of charging and discharging the battery packs connected in series to the charger while connected to the BMS.

Battery Pack Capacity Values

For the measurements obtained from step number 1 we have obtained Table 2 which from left to right consists of the following, (to see the full measurements obtained from Table 2 please refer to Appendix C);

1. Batt. Type; This first column explains the capacity of the battery used during operation which in our case could have been a 4000 mAh or 5000 mAh.

2. Date; The time/date the measurement was taken.

3. Wire Color; The wire color represents which wires were connected to the charger during operation which could consist of Red/Blue (first or third cell, depending on which side you consider first and/or connected to the charger). Blue/Yellow which is the second cell of the battery pack (direction does not matter). Yellow/Black is the last or first cell depending on how the connection is. It should be noted, if the charging was a balanced charging, all three cells were used and the connection established was by connecting all four wires (JST/XH Balance Plug) and the high current connector.

4. Type of Charge; This is according to the display of the charger that was used which could be single, balanced, fast, storage or discharged. The type of charging or discharging that was used in our measurements was the single, balanced and discharged. Fast and storage were not used just to be able to take more accurate measurements.

    1. Single Charge; This type of charging charges each cell within the battery pack almost in a balanced matter, so the resulting voltages at the end of the charge cycle have different values considering all cells had equal voltages at the beginning. Vis-a-vis, this type of charging is the most accurate because it deals with each cell within the battery pack. However, it takes the most time in charging and/or discharging a battery pack.

    2. Balanced Charge; This type of charging charges all cells within the battery pack in a balanced matter, so the resulting voltages at the end

of the charge cycle have similar values considering all cells had equal voltages at the beginning. Vis-a-vis, this type of charging is not the most accurate because it does not deal with each cell within the battery pack. However, it takes the minimum time in charging and/or discharging a battery pack.

3. Discharge; This type of discharging discharges all cells or a single cell within the battery pack almost in a unbalanced matter, so the resulting voltages at the end of the charge cycle may have dissimilar values considering all cells had equal voltages at the beginning.

5. Charge/Discharge; If the notation is written as CHG it means a charge cycle has been depicted if not then the notation would be DSC meaning that a discharge cycle has been depicted. The 1st, 2nd and 3rd notations show how many times was it needed to reach from the maximum to the minimum or vice-versa in the charge or discharge process. The “start, cont. (continued), final or end” show at what stage is the battery pack at.

6. Mov_Name; This shows the corresponding data that is on the graph was recorded to what attestation.

7. # of Batt.; This column shows the number of cells which are used in the process. The Li stands for the type of battery used which in our case is the “Turnigy 4000mAh or 5000 mAh 3S 20C Lipo Pack”.

8. Amp Shown (A); This is the current number shown on the screen at the time the value was recorded in Amperes.

9. Voltage Shown (V); This is the voltage number shown on the screen at the time the value was recorded in Volts.

10. Time Shown (min); This is the time value in minutes at the time the value was recorded.

11. Current Charged/Discharged; This is the amount of charge which has been accumulated during the moment that the measurement was taken.

12. DMM Reading; This is the value that the Digital Multi-Meter (DMM) was showing before or after the battery charging or discharging process was started. If it contains a letter "B" after the numerical value it indicates that this value is the reading before the discharge process was started. If there is no "B" next to the numerical value it indicates this is the value after the measurement was taken by the DMM.

An example of the recorded values of the capacity of the battery packs have been indicated in the Table 2.

Table 2. Recorded values of the capacity measured by the charger during discharge and charge process.

Batt. Type	Date	Wire Color	Type of Charge	Charge/ Discharge	Mov_ Name	# of Bat.	Amp. Shown (A)	Voltage Shown (V)	Time Shown (min)	Current Charged/Discharged (mAh)	DMM Reading
4.0	**5:15 - 5:25**	**Yellow/Black**	**Single**	**CHG (End)**	**MOV_0227-8**	**Li 1S**	**0.0**	**4.20**	**120**	**02966**	**3.98**
5.0	**10:49**	**All three cells**	**Balance**	**DSC (End)**	**MOV_0253-6**	**Li 3S**	**0.0**	**11.16**	**120.00**	**00999**	**11.31**

4.0	**12:17**	**Red/Blue**	**Single**	**DSC (START)**	**MOV_0257-8-9**	**Li 1S**	**1.0**	**3.48**	**0.11**	**00001**	**3.8 B**
5.0	**12:17**	**Yellow/Black**	**Single**	**DSC (START)**	**MOV_0258-9**	**Li 1S**	**1.0**	**3.64**	**0.10**	**00001**	
5.0	**1:19**	**Yellow/Black**	**Single**	**DSC (Cont.)**	**MOV_0260**	**Li 1S**	**1.0**	**3.50**	**66.29**	**01106**	
5.0	**1:44**	**Yellow/Black**	**Single**	**DSC (Final)**	**MOV_0261-2**	**Li 1S**	**0.0**	**2.99**	**85.36**	**01425**	**3.19**
4.0	**1:44**	**Red/Blue**	**Single**	**DSC (Cont.)**	**MOV_0261**	**Li 1S**	**1.0**	**3.19**	**85.30**	**01440**	
5.0	**1:48**	**Blue/Yellow**	**Single**	**DSC (START)**	**MOV_0263**	**Li 1S**	**0.9**	**3.64**	**0.10**	**00001**	
4.0	**1:48**	**Red/Blue**	**Single**	**DSC (Cont.)**	**MOV_0263**	**Li 1S**	**1.0**	**3.07**	**9.37**	**01508**	
4.0	**2:50**	**Red/Blue**	**Single**	**DSC (Final)**	**MOV_0264-5**	**Li 1S**	**0.0**	**2.99**	**92.22**	**01538**	**3.35**

Note. For full table refer to Appendix C.

Results from Table 2;

From the obtaining table the following results were obtained;

1. The start discharge is at 1.0 A but would go down to 0.2-0.3 A.

    a. This depends on the strength of the charger that is in use because some chargers are not powerful enough therefore it cannot handle a big discharge current resulting in a lower discharge rate.

2. The end discharge would show 0.0 A at 120 minutes.

3. The discharge start and end after 120 minutes either for the 4000 mAh or 5000 mAh had the same capacity shown.

4. The values shown on the Digital Muti-Meter are usually lower than the values shown on the screen of the charger in the charging process. Also the values shown on the Digital Muti-Meter are usually higher than the values shown on the screen of the charger in the discharging process. This is due to the internal resistance that has been explained in the previous chapters.

5. The capacity of each cell is the addition of the individual capacity of each cell by the number of times it has been charged or discharge.

6. For every 3 seconds, 1 mAh of charge or discharge would occur, according to the capacity remaining.

7. The first discharge is at 9-10 seconds.

8. The first charge is at 1 second.

Battery Pack Characteristics

The second part is measuring the values for each of the cells within the battery pack while the battery packs are connected in series, connected to the Battery Management System (BMS). This is step 3 of the three categories for the “measurements”.

The values obtained in this section are when our battery system is also connected to the PC to see the characteristic behavior of the cells over time.

In Figure 8 the graph of the discharging of 2 battery packs of 5000 mAh's and 4000 mAh's are shown, respectively. For the data table please refer to the Appendix C section of this thesis.

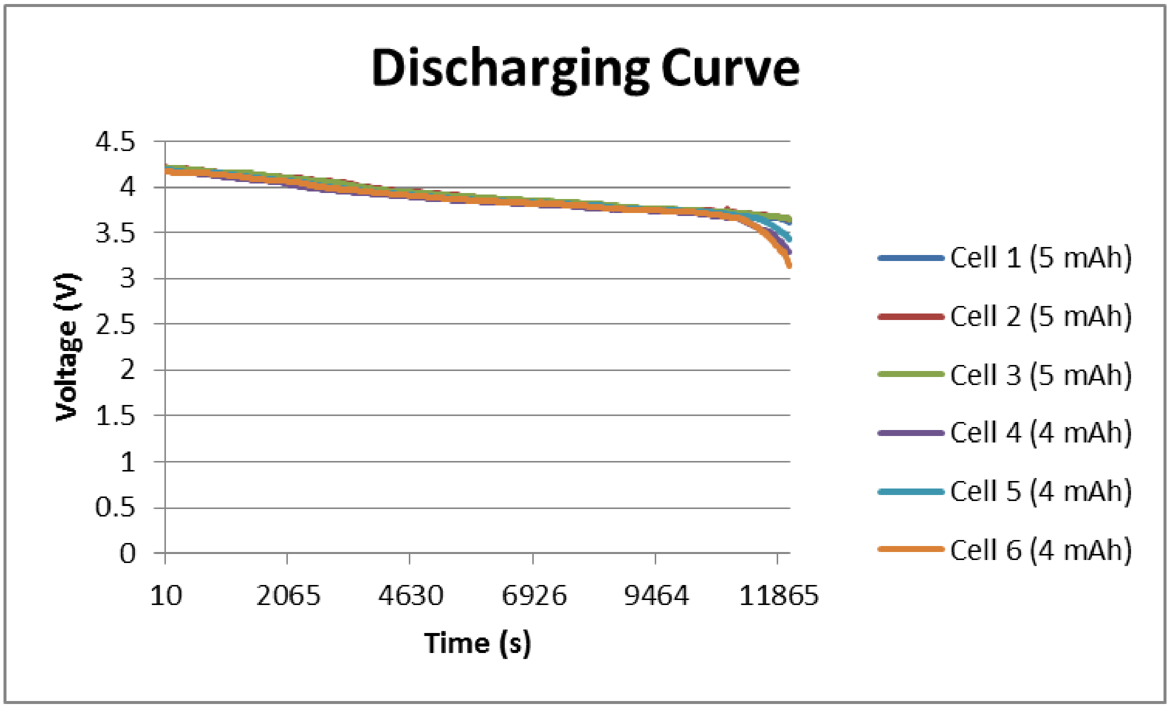

Figure 8. "Voltage vs. Time". Discharging curves of the 2 battery packs connected in series.

As can be seen the Lipo batteries start a discharge from 4.2 volts to 3 volts. Below 3 volts is not recommended because it can damage the internal structure of a LiPo battery. Therefore when a cell in a battery system reached the lowest voltage value that is 3 volts the discharging process was stopped to ensure the safety of the cells.

Recommendations

1. Always keep an eye for the lower capacity battery pack because the system will follow according to the lower capacity battery pack during charge or discharge.

2. Always the end cells of a battery pack show a lower voltage and capacity value compared to the cell in the middle after a full charge or full discharge and is non-dependent on the battery capacity but it is dependent on its internal structure. (LiPo voltage range 3 - 4.2 volts of full discharge/charge)

In Figure 9 the charging curves of the same battery pack system can be seen.

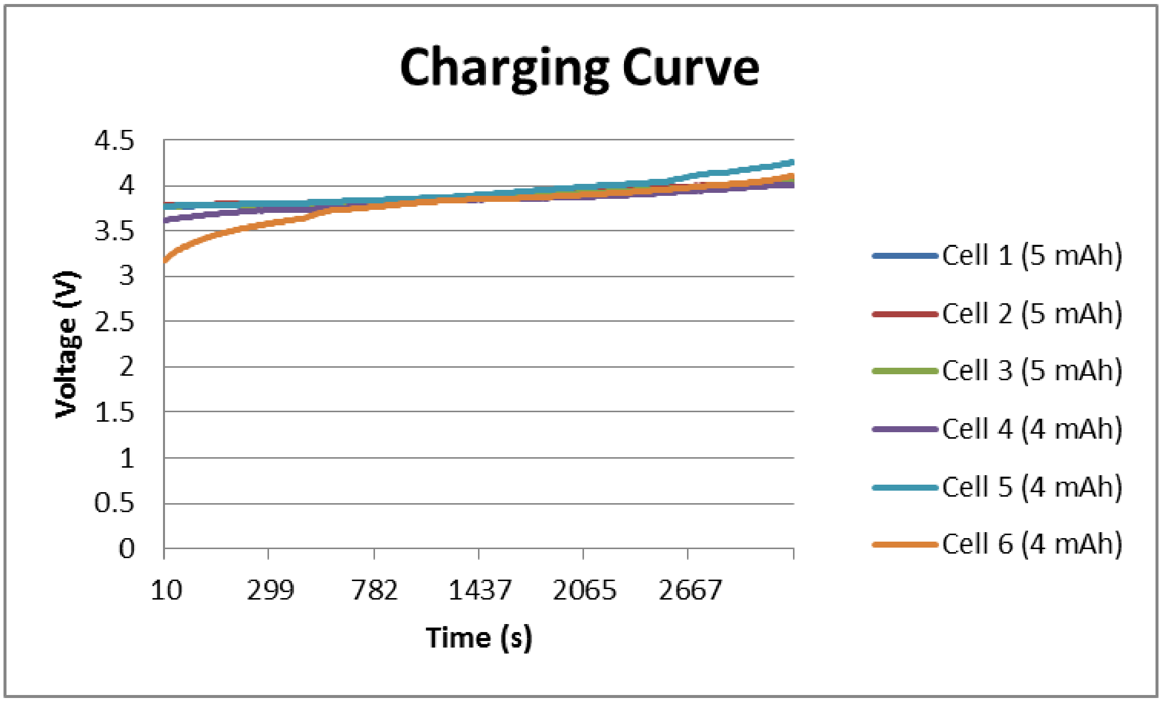

Figure 9. “Voltage vs. Time”. Charging curves of the 2 battery packs connected in series.

As can be seen the maximum is around a 4.2 volts value because a value more than 4.2 volts is overcharging the cells and can lead to explosion of the battery pack. For the data table please refer to the Appendix C section of this thesis.

Errors

In practice the capacity value of a given battery is different from its standard value. This returns back to the internal structure of the battery and its active components. Now, if noise is to be considered in the signal, such as it being induced into the voltage signal over time, the effects it can produce on the capacity of the cell or cells will be shown in the Matlab simulation. Therefore, for the surplus of the analysis, Matlab is referred to complete our estimation.

Chapter 5: Analysis

How to Approach

According to the data that has been obtained, we have charging curves (Figure 2) and discharging curves (Figure 1) of “Voltage against Time”, that each curve among the 6 curves contains a certain cell capacity.

Now a question appears, if two curves are given with the same specifications, such as the curves are voltage values plotted at the time instant they are measured and their capacities are known unequal values (these capacities represent the cell capacities that have been charged or discharged over time in mAh), if an unknown curve is given between these two curves can it be possible to obtain its capacity of the cell value it represents and/or if an unknown capacity is given between the first two known capacities is it possible to obtain the required curve for the capacity aforementioned?

The answer to the question mentioned above relies on simulating the curves in a near manner as the actual data and obtaining the capacity from the simulated data. Also, the effect of noise can be induced within the signal to see the corresponding values that noise can affect the data and obtaining the errors associated.

Capacity vs. Curve

Error-free Capacity

Now we will simulate graphs similar to Figure 1 to continue with the estimation.

c=rand

The “c” value is to generate a random “c” value that is between zero and one, which will in return give a function value that is, “Xc”, which is “V4 < Xc <V5”.

```
Voltage_Data = xlsread('first discharge final.xlsx',1,'A2:G1021');
```

“Voltage_Data” reads the entire spread sheet from excel and brings the data into Matlab for further processing.

```
V5 = Voltage_Data(:,3);
V4 = Voltage_Data(:,6);
T = Voltage_Data(:,7);
```

“V5” and “V4” are the required columns within the excel spreadsheet to continue with the estimation technique. The “T” column, is the associated time value with each sample voltage taken.

```
L = length (V5)
```

“L” will represent how many data points are read from the excel sheet into Matlab for further processing.

```
X4 = (1-c).* V4;

X5 = c.* V5;

Xc = X4 + X5;
```

“V4” and “V5” are the functions simulated as just as if we had discharging batteries of 4.0 mAh and 5.0 mAh respectively. “Xc” is a function generated between “V4” and “V5” that has an unknown capacitance we are seeking to find.

```
r = ((Xc-V4)./(V5-V4));

r = mean(r)

est.error = abs(r-c)
```

“r” is the capacitance that function “Xc” holds that we are seeking to find. Therefore, the “r” will give us the capacitance for any unknown generated “c” value. Consequently, to see how far the “r” value is compared to the “c” value, “est.error” will give the absolute value of the difference between “r” and “c”. The error is given in a new line along with the numeric value.

```
hold on

plot (T,V5,'g');

plot (T,V4,'g');

plot (T,Xc,'r');

hold off
```

These are the functions “V4”, “V5” and “Xc” plotted against any capacitance that “Xc” holds, showing that for any number of iterations this code is executed, “Xc” always is between “V4” and “V5”. The “g” and the “r” are there to make a distinction between the actual data and the simulated data.

```
ylabel ('Voltage (V)')
xlabel ('Time (s)')
```

This part of the code is to label our axis’s showing why these plots are used for.

Figure 10 shows the graphs obtained from executing the code and figure 11 shows an example of the code executed in the command window of Matlab.

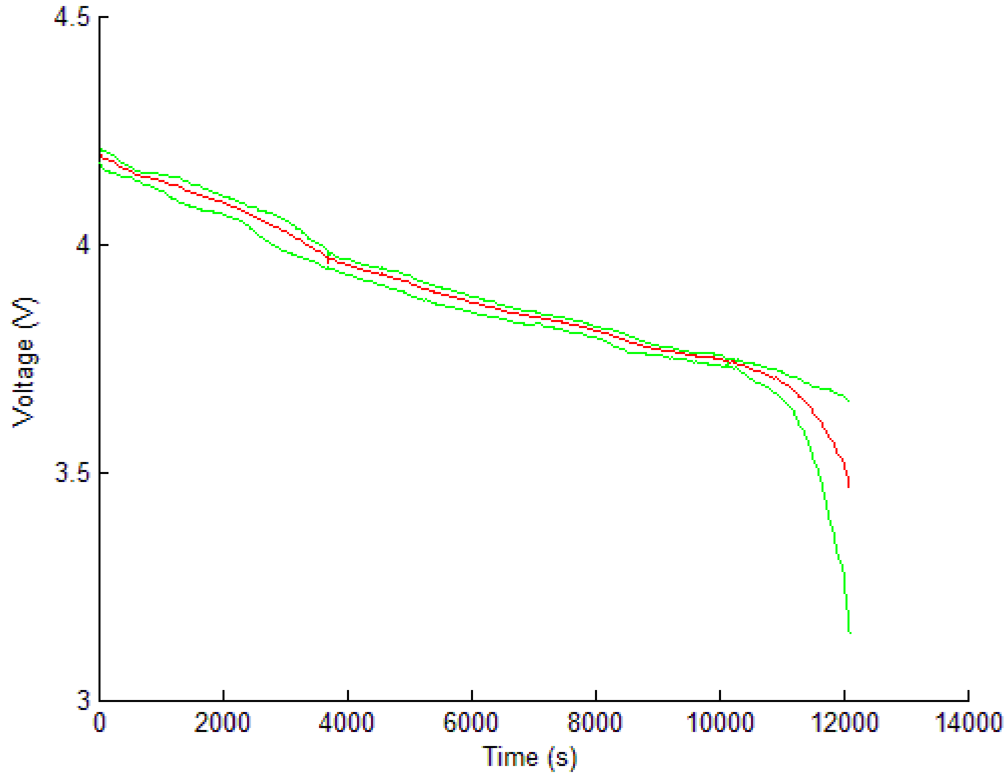

Figure 10. “Simulated Voltage vs. Time”. Plot of the graphs of “V4”, “V5” and “Xc”.

```
c =

    0.6324


L =

        1020


r =

    0.6324


est =

    error: 2.9976e-15

>>
```

Figure 11. Display of the code executed in the command window.

According to our code, and generated “c” and calculated “r”, we are able to obtain the actual values. We now need to see how the values will change when error is included. Error is being induced in the next part of the code to see the affects it can have within different ranges of data points. This will show, if noise is to be induced within the data range, which ranges will have more effect compared to the other sets.

Non Error-free Capacity

This section will now show the error values that can be obtained, the maximum error that might occur during calculations and the total range that can affect the outcome. In the following section, that is, the next part of the code shall contain the error simulated data.

The code that is now generated is as follow;

```
c=rand
n = 0.2/100
```

The “c” value is to generate a random “c” value that is between zero and one, which will in return give us a function value that “Xc” is “V4 < Xc < V5”. However, in this case we are not able to achieve the actual “c” value that was obtainable from the signal “Xc”. Signal “Xc” is now corrupted with the different error values “n”, that are induced into the signal of “Xc”.

```
Voltage_Data = xlsread('first discharge final.xlsx',1,'A2:G1021');
```

“Voltage_Data” reads the entire spread sheet from excel and brings the data into Matlab for further processing.

```
V5 = Voltage_Data(:,3);
V4 = Voltage_Data(:,6);
T = Voltage_Data(:,7);
```

“V5” and “V4” are the required columns within the excel spreadsheet to continue with the estimation technique. The “T” column, is the associated time value with each sample voltage taken.

```
L = length (V5)
```

“L” will represent how many data points are read from the excel sheet into Matlab for further processing.

```
X4 = (1-c).* V4;
X5 = c.* V5;
Xc = X4 + X5 + n;
```

“V4” and “V5” are the functions simulated as just as if we had discharging batteries of 4.0 mAh and 5.0 mAh respectively. “Xc” is a function generated between “V4” and “V5” that has an unknown capacitance we are seeking to find.

```
r = ((Xc-V4)./(V5-V4));

r = mean(r)

est.error = abs(r-c)
```

“r” is the capacitance that function “Xc” holds that we are seeking to find. “r” will give the capacitance containing the error values when the signal “Xc” was generated by the linear combination of “V4” and “V5”. Therefore, the “r” will give the capacitance for any unknown generated “c” value and the possible noise effect “n” has within the signal. Consequently, to see how much difference the “r” value has compared to the “c” value, “est.error” will give the absolute value of the difference between “r” and “c”. The error is given in a new line along with the numeric value.

```
hold on

plot (T,V5,'g');

plot (T,V4,'g');

plot (T,Xc,'r');

hold off
```

These are the functions “V4”, “V5” and “Xc” plotted against any capacitance that “Xc” holds, showing that for any number of iterations this code is executed, “Xc” always is between “V4” and “V5”. The “g” and the “r” are there to make a distinction between the actual data and the simulated data. The “g” represents the measured data with the known capacitance and the “r” represents the simulated data with the unknown capacitance.

```
ylabel ('Voltage (V)')

xlabel ('Time (s)')
```

This part of the code is to label our axis’s showing why these plots are used for.

Figure 12 shows the graphs obtained from executing the code and figure 13 shows an example of the code executed in the command window of Matlab.

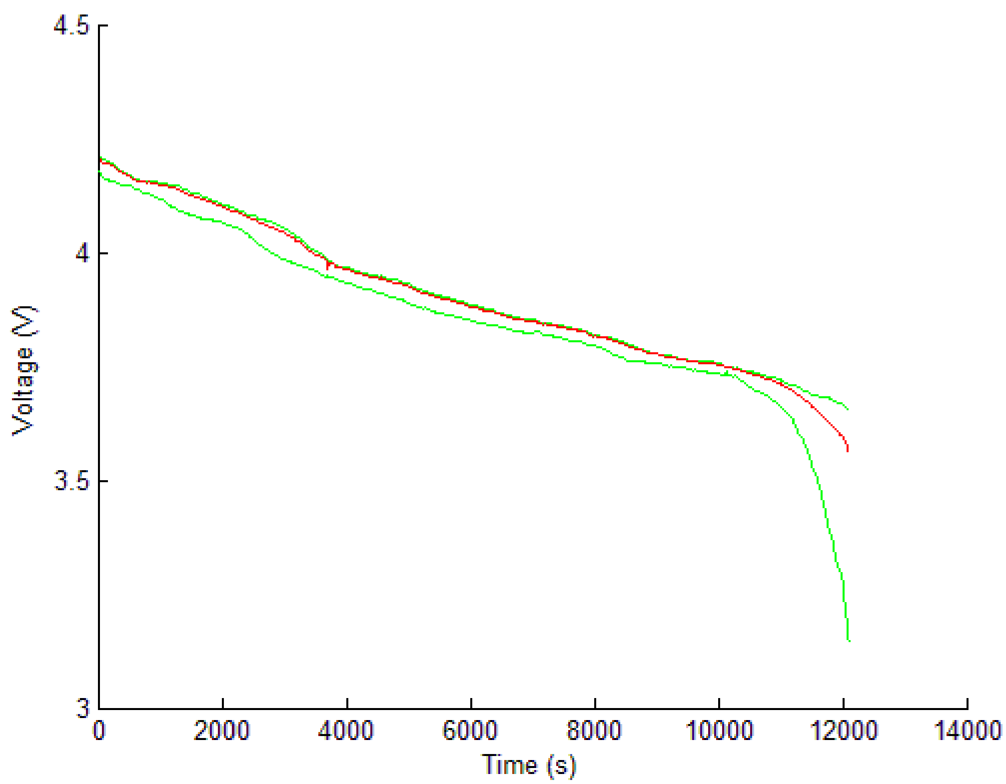

Figure 12. “Simulated Voltage vs. Time”. Plot of the graphs of “V4”, “V5” and “Xc”.

```
c =

    0.8147


n =

    0.0020


L =

        1020


r =

    0.8721


est =

    error: 0.0574

fx >> |
```

Figure 13. Display of the code executed in the command window.

Now, if we consider the various cases, such as taking different intervals and inducing random errors to the signal “Xc”, to see the effect it can produce on the estimated “r”, Table 3 is the result of this experiment that shows how diverse “r” can be compared to the actual “c” values. According to signal plus noise, for any “c” value the error would be the same. Therefore, to see the effect, the “c” value for example is chosen as “0.5”. Different ranges of voltage will be taken with the “c” value to see what the “r” value is. To see the full table refer to Appendix C of the Appendices.

Table 3. Estimated Capacity Values for Random Noises.

Range	Noise	"r" value obtained	Error
First 100 data values	0.05%	0.5160	0.0160
First 100 data values	0.1%	0.5320	0.0320
First 100 data values	0.5%	0.6598	0.1598
First 100 data values	1%	0.8195	0.3195
First 500 data values	0.05%	0.5128	0.0128
First 500 data values	0.1%	0.5256	0.0256
First 500 data values	0.5%	0.6278	0.1278
First 500 data values	1%	0.7555	0.2555
First 1000 data values	0.05%	0.5146	0.0146
First 1000 data values	0.1%	0.5292	0.0292
First 1000 data values	0.5%	0.6460	0.1460
First 1000 data values	1%	0.7920	0.2920
Full data range	0.05%	0.5143	0.0143
Full data range	0.1%	0.5287	0.0287
Full data range	0.5%	0.6434	0.1434
Full data range	1%	0.7868	0.2868

As seen from the Table, the maximum error that can occur is 0.3195 or 31.95% and the minimum error value is 0.0128 or 1.28%. Therefore the maximum and minimum values of error fall between the interval of 1.28%< error < 31.95%. The "full data range" is considered with 1020 data points.

Chapter 6: Conclusion

According to the formula used to obtain the capacity value “c” in the error free section of Chapter 5, it was seen it had the most accurate method of obtaining the “c” value. The formula would demonstrate an “r” value that had the same value as if “c” was the unknown capacity of the curve generated. Concordantly, there was no deviation from the actual “c” value, leaving the “r” value, to whatsoever error that comes from its ambient. The formula that the “r” value was calculated from is;

$$r = ((Xc - x4)/(x5 - x4)) \qquad (1)$$

The formula of (1) was obtained from simulated curves of “X5”, “X4” and “Xc”. The “r” value confirms the unknown capacity of “Xc”. Therefore it can be said, for any values of capacity of two known curves, a third curve can be generated and to obtain the capacity of that curve by formula (5.2).

$$capacity = (Xcapacity - Xminimum)/(Xmaximum - Xminimum) \qquad (2)$$

Whereas each of the terms in formula (2) represent;

Capacity: The unknown capacity required.

Xcapacity: The linear combination of the curves of Xmaximum and Xminimum.

Xmaximum: The maximum capacity value of the corresponding “Voltage against Time Curve” given.

Xminimum: The minimum capacity value of the corresponding “Voltage against Time Curve” given.

Suggestions

Some of these suggestions have been pointed throughout this thesis but as a reminder and to complement the other suggestions it is mentioned again.

1. Working with Labview is highly recommended as it can broaden the aspects of this research and it can save time in conducting different aspects to approach.
2. The Arduino board or any other interface in use needs to have a shielded protection from noise, as this can affect the outcome of the measurements. The effect came to an extent that the measurement needed to be retaken, because there were spike values seen in the graphs obtained that showed a high level of noise interference from its surrounding.
3. Always run a standard checkup of all the devices that are going to be used during the measurement. This ensures that the readings obtained are as accurate it can be. This was done by measuring the voltages of the cells before or after the charge or discharge and comparing them with values shown on the software.
4. LiPo batteries are highly explosive therefore never leave your workspace unattended for any reason and also to ensure that any electric breakdown does not occur.
5. If by any reason an electric breakdown occurs with the charger is in use, never use that same channel, if you’re using an n-channel multi-charger charger. Always switch it to another channel for testing, if the same result occurs this highly indicates that it has a burned out chip at the input of the charger. However, if it is

a single channel charger and an electric breakdown occurs remove the battery connections from the charger, AFTER you have turned off the power supply, then the charger. Connect the batteries to another charger to see whether the batteries have deteriorated or the charger has malfunctioned.

6. The JST/XH Plugs on the LiPo batteries are internally highly sensitive, as if, after multiple checks with the voltmeter, abrasion tends to peel off the inner layer making it prepared for a short-circuit, therefore always observe the connection before connecting it to a voltmeter, when measuring cell by cell of the battery pack.
7. If a week passes by from the last charge or discharge the value that you would start with has almost a 0.1 volt difference from the last measurement.

According to the steps above, the results came as accurate as possible with the instruments at hand. The algorithm obtained is simple and yet, a very comprehensive formula solvable for many applications of different cell capacities of various batteries. It can be used for any non-LiPo batteries and any other battery applications necessary. Other methods of approach that I perceived interesting in different research, are finding the values by “Kalman Filtering”. Many researches, which dealt with the chemical reactions of the cells, were based on this type of filtering. Other types of cell capacity estimation are also used, such as estimating the cell capacity based on the internal mechanical-pressure difference or charge integration of the cell over time. However, the required apparatus is also required to conduct an accurate estimation.

Lithium-ion batteries have advanced throughout the years from the time they became well known in the 1990’s. Their technology is also rapidly advancing to unknown fields yet to be discovered. One of their main advantages compared to other types of batteries were that lithium-ion batteries do not experience memory effect. Memory effect is when a rechargeable battery, after charging and discharging many times, withholds a residue amount of charge that cannot be used. This effect will lower the actual amount of charge that can be used from a battery. It has been suggested to be able to remove this memory effect; a rechargeable battery should be full recharged and discharged, so the residue charged is omitted. The memory effect was discovered by the scholars “Tsuyoshi Sasaki”, “Yoshio Ukyo” and “Petr Novák” at the Paul Scherrer Institute and the Toyota Research Laboratories in Japan. This discovery was published on April 2013; for the positive cathode of the “LiFePO4 battery”.

An overview of their capabilities can be seen in figure 14. Figure 15 is what till now many have accepted and still do. However, in my opinion I respect the work at the Toyota Laboratories and the Paul Scherrer Institute.

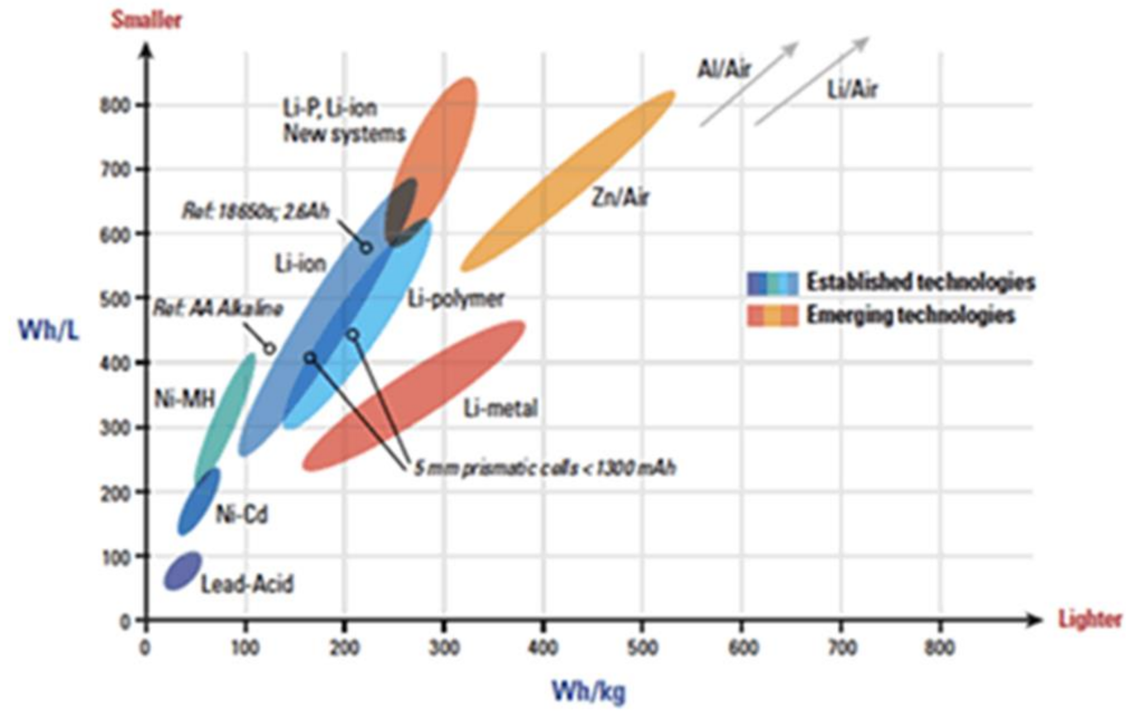

Figure 14. Battery technologies and applications.

	Lead Acid	Ni-Cd	Ni-MH	Li-Ion	Li-Poly	LiFe
Voltage	2V	1.2V	1.2V	3.6-3.7V	3.6-3.7V	3.3V
Energy Density (Wh/Kg)	35	45	70	167	110	100
Cycle Life	400	500-1000	400-1000	300-1000	300-1000	>1000
Life (Yrs) @ one charge/day	1	2	2	1+	1+	3
Self Discharge Rate (%/mo)	10%	30%	30%	3%	3%	3%
Charging Time	8 hrs	1.5 hrs	4 hrs	2-6 hrs	2-6 hrs	1-3 hrs
Safety	No BMS	Good	Good	Poor	Average	Good
High Temp Performance	Good	Good	Good	Average	Average	Good
Cold Temp (0°F) Charge	Good	Fair	Fair	0-45degC	0-45degC	0-45degC
Cold Temp (0°F) Discharge	Good	Good	Poor	Avg-Good	Avg-Good	Good
Memory Effect	No	Yes	Little	No	No	No

Figure 15. Comparison of different battery types.

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Appendices

A The Idea of Electric Propulsion

The idea of electric propulsion system being used onboard an aircraft started with the Tissandier Brothers in 1881. Albert Tissandier was a French architect and archaeologist. Among his other hobbies were editing and illustrating. He later was also known as an aviator along with his brother Gaston Tissandier. Gaston Tissandier was a French chemist and meteorologist. Among his other hobbies were editing, alike his brother Albert. He later was also known as an adventurer and especially an aviator. He and his brother were able to escape the blockade of Paris during the Franco-Prussian War by one of the first mail balloons on October 14, 1870. Among their passenger they had carried 1000 lb. of mail and dispatches from 100 families to outside the city of Paris. Due to Albert’s bravery he later on received the Medaille Militaire award. In April of 1875 Gaston took his most adventurous trip along with Theodore Sivel and Joseph Croce-Spibelli. They were able to reach an altitude of 8,600 meters on a balloon. Unfortunately Gaston’s two companions suffocated from breathing thin air, he did survive but became deaf. On 1881 the Tissandier brothers showed the world’s first electric powered aircraft at an exposition by attaching a Siemens electric motor to a dirigible. Their first flight took on October 8, 1883 with an electric dirigible aerostat; the blue prints were designed by Albert. On their second attempt which occurred on September 26, 1884 they obtained the results they had wished for.

After the accomplishment by the Tissandier brothers another two French nationalities by the names of Arthur Constantin Krebs who was an innovator in automotive engineering and an officer along with Charles Renard who was a military engineer started to work on designs of an airship in the Aeronautical Department at the French Army. Charles with Arthur and his brother built the La France which was the first fully controlled free-flight. The La France had its maiden flight on August 9, 1884 at Chalais Meudon. It was a French Army Airship electrically powered with a 435 kilogram battery, measuring 170 foot and 66,000 cubic feet. The flight had covered 23 minutes over 5 miles, and it was one of the first airships that was able to land on the starting point it had taken off making a major pivot point in the history of aviation. It was able to do so five out of seven times it had taken off. Due to their contribution to aviation Arthur and Charles received the 1886 Ponti Prize of the French Academie Des Sciences. Jules Verne was inspired by the accomplishment of these two prodigies that he wrote a novel "Robur The Conqueror" elucidating the accomplishments of "Captain Krebs and Captain Renard".

Electric powered engines became the most popular demand for the industry during that period. Their efficiency was much greater than their rival the steam engine. When gasoline engines came along electric powered engines got less attention for almost a century and more engineers focused their work on gas engine products. Electric powered aircrafts were noticed once again on June 30, 1957 when a national from the United Kingdom by the name of Colonel H. J. Taplin documented an electric powered radio controlled flight by the name of "Radio Queen". Its internal structure consisted of a permanent magnet motor with a silver zinc battery. Regrettably, this was how far his experiments with the aircraft had gone. In 1957 a German enthusiast and pioneer by the name of Fred Militky improved the electric engine model. On October 1957 Fred's success came when he was able to fly a free flight model. From there on after, electric motors came back to the attention of engineers to be operated in the aviation industry.

Before the experiments of Taplin and Militky, in 1954 at the Bell Telephone Laboratories in the U.S. photovoltaic technology was produced. The first silicon photovoltaic cell was capable of converting solar energy to electrical energy to run everyday equipment. Its efficiency started at 4%, later on was improved to 11%. This innovation was done by our prodigies Gerald Pearson, Daryl Chapin and Calvin Fuller. The technology that was introduced in 1954 found its way into aviation on November 4, 1974 when the very first solar powered aircraft was flown over the skies at the dry lake Camp Irwin, California. Its name was “Sunrise 1” designed by R. J. Boucher. This magical moment that became true had been a contract between Advanced Research Projects Agency (ARPA) and Astro Flight Inc. “Sunrise 1” weighed 12.25 kilograms, its wing span was 9.76 meters, weighing 12.25 kilograms and flying for an altitude of 100 meters for 10 minutes on its initial flight. Its power output was 450 Watts that was generated from 4,096 solar cells.

Solar power aircrafts are capable of flight during day time. They convert solar energy to electrical energy for power throughout the flight. A major concern was how can a solar power aircraft be able to fly during night time without receiving energy from the sun. Research went on for decades until NASA designed “Helios” (other names also used are NASA Pathfinder (Plus), NASA Helios Prototype and NASA Centurion). It was the last prototype of its kind which was capable of storing electric energy converted from solar energy to be used during night time. NASA had set two goals for this project;

1. Unremitting flight of an altitude of 100,000 feet
2. A nonstop flight of at least 24 hours (14 hours of the flight needed to be above 50,000 feet)

Helios in 2001 remarkably accomplished its first objective with an altitude of 96,863 feet near Hawaii and flying above an altitude of 96,000 feet. Unfortunately, it didn't succeed to accomplish its second objective. Due to its internal structural failure on June 26, 2003 it fell into the Pacific Ocean.

Although, history has not stopped here, it has still continued. "Solar Impulse" a fully solar powered aircraft that received a great amount of funding from "Bayer MaterialScience" will fly around world in 2015. Bayer announced on September 28, 2012 that it has provided 30 engineers working to advance many of the ultra-lightweight materials of the aircraft and to support it both technically and financially. This aircraft has a wing span of an A320 while only weighing of a family car. The new materials that have been developed since the project being introduced in 2003, can also be used in many different industries such as automotive, construction, military, medical and etc.

Basically aircraft propulsion can be categorized to the following;

1. Shaft Engines
    a. Internal Combustion Engines
        i. Piston Engine
        ii. Wankel Engine
        iii. Turbines
            1. Turboprop

            2. Turboshaft

    b. External Combustion Engines

        i. Steam-Powered

2. Reaction Engines

    a. Turbines

        i. Turbojet

        ii. Turbofan

        iii. Propfan

    b. Rocket-Powered

    c. Motorjet

    d. Pulsejet

    e. Ramjet

        i. Scramjet

3. Other Types

    a. Hydrogen

    b. Human Powered

    c. Electric

    d. Nuclear

Explanation of each of these systems is out of the scope of this thesis and will be left to the reader.

B The Dawn of Standardization

Standardization of batteries started in 1912, when the committee of the American Electrochemical Society (AES) came together to establish standard methods for testing dry cells. This event later on led to the first national publication in 1919, it was issued as an appendix to a circular from the National Bureau of Standards (NBS). It further evolved and became into the present American National Standards Institute (ANSI) Accredited Standards Committee CI8 on portable batteries and portable cells. Since then many other professional associations have emerged and have been advancing the fundamental standards of batteries that are used in the industry. Many battery standards were also issued by international, national, military and many leading federal organizations. Manufacturer associations, trade associations and individual manufacturers have also published their own standards. The Underwriters Laboratories (UL), the International Electrotechnical Commission (IEC) and other organizations that cover battery-operated equipment have also published standards that cover the specifications of batteries and their related application.

The International Electrotechnical Commission (IEC) is the designated organization responsible for standardization in the fields of electricity, electronics, and other related technologies. Its basic mission is promoting international cooperation on all questions of electrotechnical standardization and its related matters. This organization was created in 1906 and consists of over 70 national committees that represent 95% of the world's production and consumption of electricity and electrical matters. The International Electrotechnical Commission (IEC) also represents more than 80% of the world's population. The International Standards Organization (ISO) is responsible for international standards in fields other than electrical whether food manufacturers to restaurants that provide food. International Electrotechnical Commission (IEC) and International Standards Organization (ISO) are gradually adopting equivalent development and documentation modus operandi's therefore closer relations are being established between these two international organizations.

The American National Standards Institute (ANSI) is the sole U.S. representative of the International Electrotechnical Commission (IEC) throughout the United States under the United States National Committee (USNC). This committee coordinates all International Electrotechnical Commission (IEC) activities within the United States. It also is considered as the U.S. representative with emerging regional standards developing bodies such as European Committee for Electrotechnical Standardization (CENELEC), Pacific Area Standards Congress (PASC), Council for Harmonization of Electrotechnical Standards of the Nations in the Americas (CANENA), Pan American Standards Commission (COPANT), African Organization for Standardisation (ARSO) and other foreign and national groups. American National Standards Institute (ANSI) does not itself develop standards; it actually facilitates development by establishing unanimity among accredited and well qualified groups. These standards are published as the U.S. National Standards to be used in public or private firms.

On the international case for transportation protocols, transport is policed by organizations such as the International Civil Aviation Organization (ICAO), the International Air Transport Association (IATA), and the International Maritime Organization (IMO). Their regulations are guided by the United Nations (UN) via their committee of experts on the transport of dangerous goods, which consequently, has developed recommendations for the transportation of hazardous goods. These recommendations, which include tests and criteria are addressed to governments and international organizations concerned with regulating the transport of various products. Currently, the United Nations (UN) committee of experts has developed strategies embracing the transport of lithium primary and secondary based batteries. The quantity of the lithium or lithium equivalent content in each cell and battery determines which specific rules and regulations are applied concerning the packaging, mode of shipment, marking, and other special provisions.

It is the inherent nature of batteries and its contents, particularly, primary batteries that replacements will at some time be necessary. For replacing its contents according to international standards a third party end user of the equipment is typically chosen to handle this matter. It is therefore essential that certain characteristics of the battery be specified by standard values such as size, shape, temperature, capacity and voltage. It is obvious without a rational match of at least these basic parameters there can be no interchangeability between suppliers and consumers or traders. These characteristics are the absolute minimum requirements in order to assure the proper provided voltage, the proper appliance receptacle and to make the proper contact with the receptacle. Other than the end-user's manual and the need for replacement information, the original equipment manufacturer (OEM) appliance designer must have a consistent source of reliable information about these parameters in order to design a battery compartment and the corresponding circuits that will accommodate the tolerances on the battery products available for purchase by the end-user. The International Electrotechnical Commission

(IEC) nomenclature system for primary batteries that became effective in 1992 is based on the electrochemical system and the shape and size of the battery unit. It is necessary to keep in mind that the documentation for standardization of rechargeable batteries is not as complete as the documentation for the primary batteries. Most of the primary batteries are used in a variety of portable applications that the user is able to replace the battery upon its usage, therefore the need for primary battery standards to ensure its interchange-ability can be seen. Developing standards like these have been the active projects by both the International Electrotechnical Commission (IEC) and the American National Standards Institute (ANSI) for many years.

C Tables

Table 4. Recorded values of the capacity measured by the charger during discharge and charge process.

Batt. Type	Date	Wire Color	Type of Charge	Charge/ Discharge	Mov_ Name	# of Bat.	Amp. Shown (A)	Voltage Shown (V)	Time Shown (min)	Current Charged/Discharged (mAh)	DMM Reading
4.0	Oct. 19	All three cells	Balance	DSC (End)	MOV_ 0191	Li 3S	0.0	11.23	120	00999	
4.0	Oct. 19	All three cells	Balance	DSC (Start)	MOV_ 0193	Li 3S	0.5	11.29	0.0	00000	
4.0	Oct. 19	All three cells	Balance	DSC (End)	MOV_ 0195	Li 3S	0.0	10.64	120	00999	
4.0	Oct. 19	All three cells	Balance	DSC (Start)	MOV_ 0196	Li 3S	0.5	10.71	0.0	00000	
4.0	Oct. 19	All three cells	Balance	DSC (Final)	MOV_ 0197	Li 3S	0.0	8.98	19.25	00165	
4.0	Oct. 26, 1:05	Yellow/ Black	Single	CHG (START -End)	MOV_ 0218-9	Li 1S	1.5- 1.4	4.20	0.04- 3.09	00001- 00075	
4.0	Oct. 26	Yellow/ Black	Single	DSC (START)	MOV_ 0219	Li 1S	1.0	3.47	0.10	00001	
4.0	Oct. 26	Yellow/ Black	Single	DSC (START Cont.)	MOV_ 0220	Li 1S	1.0	3.46	7.30	00123	
4.0	Oct. 26	Yellow/ Black	Single	DSC (START Cont.)	MOV_ 0221	Li 1S	1.0	3.45	12.03	00199	
4.0	Oct. 26	Yellow/ Black	Single	DSC (START Cont.)	MOV_ 0222	Li 1S	1.0	3.43	21.36	00359	
4.0	Oct. 26	Yellow/ Black	Single	DSC (START Cont.)	MOV_ 0223	Li 1S	1.0	3.37	75.18	01253	

4.0	Oct. 26	Yellow/Black	Single	DSC (End)	MOV_0224	Li 1S	1.0	3.18	120.00	01998	
4.0	Oct. 26	Yellow/Black	Single	DSC (Start)	MOV_0224	Li 1S	1.0	3.19	0.10	00001	
4.0	Oct. 26, 3:15	Yellow/Black	Single	DSC (Final)	MOV_0225	Li 1S	0.0	3.00	6.14	00102	
4.0	3:15	Yellow/Black	Single	CHG	MOV_0226	Li 1S	3.2	4.20	0.02	00001	
4.0	5:15-5:25	Yellow/Black	Single	CHG (End)	MOV_0227-8	Li 1S	0.0	4.20	120	02966	3.98
4.0	6:35	Blue/Yellow	Single	DSC (Start)	MOV_0230	Li 1S	1.0	3.51	0.12	00001	
4.0		Blue/Yellow	Single	DSC (START Cont.)	MOV_0231	Li 1S	1.0	3.42	61.00	01015	
4.0	8:55	Blue/Yellow	Single	DSC (End)	MOV_0232-3	Li 1S	0.0	3.10	120.00	01998	3.44
4.0		Blue/Yellow	Single	DSC (START)	MOV_0234	Li 1S	1.0	3.07	0.13	00002	
4.0		Blue/Yellow	Single	DSC (START Cont.)	MOV_0234	Li 1S	1.0	3.03	1:13	00018	
4.0		Blue/Yellow	Single	DSC (Final)	MOV_0235-6	Li 1S	0.0	3.00	1.59	00031	3.37
4.0	Oct 26, 8:47	Blue/Yellow	Single	CHG (Start)	MOV_0251	Li 1S	3.1	4.20	0.02	00001	
5.0	9:27	All three cells	Balance	DSC (START)	MOV_0252	Li 3S	0.4	11.44	0.04	00000	
5.0	10:49	All three cells	Balance	DSC (End)	MOV_0253-6	Li 3S	0.0	11.16	120.00	00999	11.31
4.0	10:49	Blue/Yellow	Single	CHG (End)	MOV_0253-5	Li 1S	0.0	4.20	120.00	02522	3.98
4.0	12:17	Red/Blue	Single	DSC (START)	MOV_0257-8-9	Li 1S	1.0	3.48	0.11	00001	3.8B

5.0	12:17	Yellow/Black	Single	DSC (START)	MOV_0258-9	Li1S	1.0	3.64	0.10	00001	
4.0	1:19	Red/Blue	Single	DSC (Cont.)	MOV_0260	Li1S	1.0	3.36	66.22	01104	
5.0	1:19	Yellow/Black	Single	DSC (Cont.)	MOV_0260	Li1S	1.0	3.50	66.29	01106	
5.0	1:44	Yellow/Black	Single	DSC (Final)	MOV_0261-2	Li1S	0.0	2.99	85.36	01425	3.19
4.0	1:44	Red/Blue	Single	DSC (Cont.)	MOV_0261	Li1S	1.0	3.19	85.30	01440	
5.0	1:48	Blue/Yellow	Single	DSC (START)	MOV_0263	Li1S	0.9	3.64	0.10	00001	
4.0	1:48	Red/Blue	Single	DSC (Cont.)	MOV_0263	Li1S	1.0	3.07	9.37	01508	
4.0	2:50	Red/Blue	Single	DSC (Final)	MOV_0264-5	Li1S	0.0	2.99	92.22	01538	3.35
5.0	2:50	Blue/Yellow	Single	DSC (Cont.)	MOV_0264	Li1S	1.0	3.61	1.54	00030	
4.0	1:54	Red/Blue	Single	CHG (Start)	MOV_0266	Li1S	3.5	4.20	0.02	00001	
5.0	3:19	Blue/Yellow	Single	DSC (Final)	MOV_0267-8	Li1S	0.0	2.99	89.48	01495	3.19
5.0		Blue/Yellow	Single	DSC (Start)	MOV_0269	Li1S	0.9	3.64	0.10	00001	
4.0	3:55	Red/Blue	Single	CHG (End)	MOV_0270-1	Li1S	0.0	4.20	120.00	03044	4.01
4.0		Red/Blue	Single	CHG (Start Cont.)	MOV_0272	Li1S	0.9	4.20	0.05	00001	
4.0	4:50	Red/Blue	Single	CHG (Final)	MOV_0273-4	Li1S	0.0	4.20	49.45	00457	4.12
5.0		Blue/Yellow	Single	DSC (End)	MOV_0273-5	Li1S	0.0	2.99	86.22	01438	3.20
5.0		Blue/Yellow	Single	DSC (Start)	MOV_0276	Li1S	0.9	3.07	0.10	00001	
5.0		Blue/Yellow	Single	DSC (Final)	MOV_0276-7	Li1S	0.0	2.99	00.38	00009	3.17
4.0		Blue/Yellow	Single		MOV_0278	Li1S					3.98B
5.0		Red/Blue	Single		MOV_0279	Li1S					3.20B
4.0	5:04	Blue/Yellow	Single	CHG (Start)	MOV_0280	Li1S	1.0	4.20	00.05	00001	
5.0	5:04	Red/Blue	Single	CHG (Start)	MOV_0280	Li1S	3.5	3.37	00.02	00001	

4.0	5:37	Blue/Yellow	Single	CHG (Start Cont.)	MOV_0281	Li 1S	0.6	4.20	33.40	00423	
5.0	5:37	Red/Blue	Single	CHG (Start Cont.)	MOV_0281	Li 1S	3.5	3.99	32.21	01883	
4.0	Oct. 26, 6:02	Blue/Yellow	Single	CHG (Final)	MOV_0282-3	Li 1S	0.0	4.20	57.43	00608	4.13
4.0	Oct. 26	Yellow/Black	Single		MOV_0284	Li 1S					3.97 B
4.0	Oct. 26	Yellow/Black	Single	CHG (Start)	MOV_0285	Li 1S	1.0	4.20	00.05	00001	
5.0	Oct. 26, 6:51	Red/Blue	Single	CHG (Final)	MOV_0287-8	Li 1S	0.0	4.20	105.47	04976	4.18
4.0	7:08-12	Yellow/Black	Single	CHG (Final)	MOV_0289-90	Li 1S	0.0	4.20	60.54	00660	4.13
4.0	Nov.2 10:40	Yellow/Black	Single		MOV_0306	Li 1S					4.11 B
4.0	Nov.2	Blue/Yellow	Single		MOV_0306	Li 1S					4.11 B
4.0	Nov.2	Red/Blue	Single		MOV_0306	Li 1S					4.11 B
5.0	Nov.2	Red/Blue	Single		MOV_0306	Li 1S					4.16 B
5.0	Nov.2	Blue/Yellow	Single		MOV_0306	Li 1S					3.41 B
5.0	Nov.2	Yellow/Black	Single		MOV_0306	Li 1S					3.40 B
4.0	Nov.2 10:48	Red/Blue	Single	DSC (Start)	MOV_0307	Li 1S	0.9	3.77	00.10	00001	
5.0	Nov.2 10:14	Blue/Yellow	Single	CHG (Start)	MOV_0307	Li 1S	3.7	3.58	00.01	00001	

4.0	**Nov.2**	**Red/Blue**	**Single**	**DSC (Start Cont.)**	**MOV_0308**	**Li 1S**	**1.0**	**3.46**	**91.54**	**01530**	
5.0	**Nov.2**	**Blue/Yellow**	**Single**	**CHG (Start Cont.)**	**MOV_0308**	**Li 1S**	**0.9**	**4.20**	**91.44**	**04806**	
5.0	**12:35**	**Blue/Yellow**	**Single**	**CHG (Final)**	**MOV_0309-10**	**Li 1S**	**0.0**	**4.20**	**105.12**	**04938**	**4.18**
5.0	**12:39**	**Yellow/Black**	**Single**	**CHG (Start)**	**MOV_0311**	**Li 1S**	**3.7**	**3.57**	**00.02**	**00001**	
4.0	**12:50**	**Red/Blue**	**Single**	**DSC (End)**	**MOV_0312-3**	**Li 1S**	**0.0**	**3.43**	**120.00**	**01998**	**3.80**
4.0		**Red/Blue**	**Single**	**DSC (Start)**	**MOV_0314**	**Li 1S**	**0.0**	**3.45**	**00.10**	**00001**	
5.0	**2:36**	**Yellow/Black**	**Single**	**CHG (Final)**	**MOV_0315-6**	**Li 1S**	**0.0**	**4.20**	**106.24**	**04893**	**4.18**
4.0	**2:36**	**Red/Blue**	**Single**	**DSC (End)**	**MOV_0315-6**	**Li 1S**	**0.0**	**3.00**	**93.50**	**01562**	**3.38**
5.0		**Red/Blue**	**Single**		**MOV_0316**	**Li 1S**					**4.16B**
4.0		**Red/Blue**	**Single**	**DSC (Start)**	**MOV_0317**	**Li 1S**	**0.9**	**3.07**	**00.10**	**00001**	
5.0		**Red/Blue**	**Single**	**DSC (Start)**	**MOV_0317**	**Li 1S**	**1.0**	**4.03**	**00.10**	**00001**	
4.0		**Red/Blue**	**Single**	**DSC (Final)**	**MOV_0317-8**	**Li 1S**	**0.0**	**2.99**	**00.43**	**00010**	**3.37**
4.0		**Red/Blue**	**Single**	**CHG (Start)**	**MOV_0319**	**Li 1S**	**3.3**	**4.20**	**0.03**	**00001**	
5.0	**4:36 Nov 2**	**Red/Blue**	**Single**	**DSC (End)**	**MOV_0320-1**	**Li 1S**	**0.0**	**3.71**	**120.00**	**01998**	**3.86**
5.0	**4:40**	**Red/Blue**	**Single**	**DSC (Start)**	**MOV_0322**	**Li 1S**	**0.9**	**3.73**	**00.10**	**00001**	**3 sec 1 mili charge**
4.0	**4:44**	**Red/Blue**	**Single**	**CHG (End)**	**MOV_0323-4**	**Li 1S**	**0.0**	**4.20**	**120.00**	**02883**	**3.98**
5.0		**Red/Blue**	**Single**	**DSC (End)**	**MOV_0324**	**Li 1S**	**0.0**	**3.70**	**3:49**	**00062**	
4.0		**Red/Blue**	**Single**	**CHG (Start)**	**MOV_0325**	**Li 1S**	**0.9**	**4.20**	**00.05**	**00001**	
5.0		**Red/Blue**	**Single**	**DSC (Start)**	**MOV_0325**	**Li 1S**	**0.9**	**3.72**	**00.10**	**00001**	
4.0	**5:47**	**Red/Blue**	**Single**	**CHG (Final)**	**MOV_0326-7**	**Li 1S**	**0.0**	**4.20**	**59.55**	**00589**	**4.12**

5.0	**5:48**	**Red/Blue**	**Single**	**DSC (End)**	**MOV_0328-9**	**Li 1S**	**0.0**	**3.58**	**120.00**	**01998**	**3.73**
5.0	**6:50**	**Red/Blue**	**Single**	**DSC (Start)**	**MOV_0330**	**Li 1S**	**1.0**	**3.59**	**00.10**	**00001**	
5.0	**7:50**	**Red/Blue**	**Single**	**DSC (Final)**	**MOV_0331-2**	**Li 1S**	**0.0**	**3.00**	**57:11**	**00951**	**3.19**
5.0	**Check**	**Red/Blue**	**Single**	**DSC (Start)**	**MOV_0333**	**Li 1S**	**0.9**	**3.05**	**00.10**	**00001**	
5.0	**Check**	**Red/Blue**	**Single**	**DSC (Final)**	**MOV_0333-4**	**Li 1S**	**0.0**	**2.99**	**00.30**	**00006**	**3.17**
5.0	**7:55**	**Red/Blue**	**Single**	**CHG (Start)**	**MOV_0335**	**Li 1S**	**3.7**	**3.35**	**00.01**	**00001**	
5.0	**9:43**	**Red/Blue**	**Single**	**CHG (Final)**	**MOV_0336-7**	**Li 1S**	**0.0**	**4.20**	**106.34**	**04959**	**4.18**
5.0	**Dec. 24, 1:40**	**Red/Blue**	**Single**		**MOV_0366**	**Li 1S**					**4.14B**
5.0	**Dec. 24**	**Blue/Yellow**	**Single**		**MOV_0367**	**Li 1S**					**4.14B**
4.0	**Dec. 24**	**Red/Blue**	**Single**		**MOV_0368**	**Li 1S**					**4.09B**
4.0	**Dec. 24**	**Blue/Yellow**	**Single**		**MOV_0369**	**Li 1S**					**4.09B**
4.0	**Dec. 24, 1:47**	**Blue/Yellow**	**Single**	**DSC (Start)**	**MOV_0370**	**Li 1S**	**0.9**	**3.79**	**00.10**	**00001**	
5.0	**Dec. 24, 1:47**	**Blue/Yellow**	**Single**	**DSC (Start)**	**MOV_0370**	**Li 1S**	**0.9**	**4.01**	**00.10**	**00001**	
4.0	**Dec. 24, 3:48**	**Blue/Yellow**	**Single**	**DSC (End)**	**MOV_0371-2**	**Li 1S**	**0.0**	**3.42**	**120.00**	**01998**	**3.79**
5.0	**Dec. 24, 3:48**	**Blue/Yellow**	**Single**	**DSC (End)**	**MOV_0371-3**	**Li 1S**	**0.0**	**3.69**	**120.00**	**01998**	**3.85**

4.0*	Dec. 24, 3:50	Blue/Yellow	Single	DSC (Start)	MOV_0374	Li1S	0.9	3.48	00.10	00001	
5.0*	Dec. 24, 3:50	Blue/Yellow	Single	DSC (Start)	MOV_0374	Li1S	0.9	3.72	00.10	00001	
4.0	Dec. 24, 5:25	Blue/Yellow	Single	DSC (Final)	MOV_0375-6	Li1S	0.0	3.00	92:43	01543	3.37
5.0	Dec. 24, 5:25	Blue/Yellow	Single	DSC (Final)	MOV_0375	Li1S					
4.0	Dec. 24	Blue/Yellow	Single	DSC (Start)	MOV_0377	Li1S	0.9	3.04	00.10	00001	
4.0	Dec. 24	Blue/Yellow	Single	DSC (Final)	MOV_0377	Li1S	0.0	2.99	00.15	00002	
4.0	Dec. 24, 5:37	Blue/Yellow	Single		MOV_0366 - Copy	Li1S					3.39 B
4.0*		Blue/Yellow	Single	CHG (Start)	MOV_0367 - Copy	Li1S	3.1	4.20	00.03	00001	
5.0		Blue/Yellow	Single	DSC (End)	MOV_0368-9 - Copy	Li1S	0.0	3.56	120.00	01998	3.72
5.0	Dec. 24, 5:55	Blue/Yellow	Single	DSC (Start)	MOV_0370 - Copy	Li1S	0.9	3.58	00.10	00001	
5.0	Dec. 24, 6:48	Blue/Yellow	Single	DSC (Final)	MOV_0371-2 - Copy	Li1S	0.0	2.99	52:42	00876	3.20
5.0		Check	Single	DSC (Start - Final)	MOV_0373 - Copy	Li1S	0.9-0.0	3.05-2.99	00.10-00.30	00001-000006	3.15-3.18

5.0	6:51	Blue/Yellow	Single	CHG (Start)	MOV_0374 - Copy	Li 1S	3.5	3.37	00.02	00001	
4.0	7:42	Blue/Yellow	Single	CHG (End)	MOV_0366 – 7 Copy(2)	Li 1S	0.0	4.20	120.00	02894	3.98
4.0		Blue/Yellow	Single	CHG (Start)	MOV_0367 - Copy(2)	Li 1S	0.9	4.20	00.04	00001	
4.0	8:41	Blue/Yellow	Single	CHG (Final)	MOV_0369 - Copy(2)	Li 1S	0.0	4.20	55.51	00571	4.12
5.0	8:45	Blue/Yellow	Single	CHG (Final)	MOV_0369 - Copy(2)	Li 1S	0.0	4.20	109.04	04931	4.18
5.0	Dec. 25, 12:45	Yellow/Black	Single		MOV_0366 - Copy(3)	Li 1S					4.14B
4.0	Dec. 25,	Yellow/Black	Single		MOV_0367 - Copy(3)	Li 1S					4.09B
4.0	Dec. 25, 12:50	Yellow/Black	Single	DSC (Start)	MOV_0368 - Copy(3)	Li 1S	0.9	3.79	00.10	00001	
5.0	Dec. 25, 12:50	Yellow/Black	Single	DSC (Start)	MOV_0368 - Copy(3)	Li 1S	0.9	4.01	00.10	00001	
4.0	Dec. 25, 2:50	Yellow/Black	Single	DSC (End)	MOV_0369 - Copy(3)	Li 1S	0.0	3.43	120.00	01998	3.79
5.0	Dec. 25, 2:50	Yellow/Black	Single	DSC (End)	MOV_0369 - Copy(3)	Li 1S	0.0	3.68	120.00	01998	3.85

4.0	**Dec. 25, 4:30**	**Yellow/ Black**	**Single**	**DSC (Start-Final)**	**MOV_ 0370 - Copy(2)**	**Li 1S**	**0.0**	**3.00**	**95.28**	**01589**	**3.39**
4.0	**Dec. 25, 4:30**	**Check**	**Single**	**DSC (Start-Final)**	**MOV_ 0370 - Copy(2)**	**Li 1S**	**0.0**	**2.99**	**00.33**	**00007**	**3.37**
4.0	**Dec. 25, 4:32**	**Yellow/ Black**	**Single**	**CHG (Start)**	**MOV_ 0371 - Copy(2)**	**Li 1S**	**3.2**	**4.20**	**00.02**	**00001**	
5.0	**Dec. 25, 4:55**	**Yellow/ Black**	**Single**	**DSC (End)**	**MOV_ 0372 - Copy(2)**	**Li 1S**	**0.0**	**3.55**	**120.00**	**01998**	**3.71**
5.0		**Yellow/ Black**	**Single**	**DSC (Start)**	**MOV_ 0372 - Copy(2)**	**Li 1S**	**1.0**	**3.56**	**00.12**	**00001**	
5.0	**Dec. 25, 5:41**	**Yellow/ Black**	**Single**	**DSC (Final)**	**MOV_ 0373 - Copy(2)**	**Li 1S**	**0.0**	**2.99**	**47.34**	**00791**	**3.18**
5.0	**Dec. 25, 5:48**	**Yellow/ Black**	**Single**	**CHG (Start)**	**MOV_ 0366 - Copy(4)**	**Li 1S**	**3.7**	**3.38**	**00.01**	**00001**	
4.0	**Dec. 25, 6:33**	**Yellow/ Black**	**Single**	**CHG (End)**	**MOV_ 0367 - Copy(4)**	**Li 1S**	**0.0**	**4.20**	**120.00**	**02949**	**3.98**
4.0	**Dec. 25, 6:33**	**Yellow/ Black**	**Single**	**CHG (Start)**	**MOV_ 0367 - Copy(4)**	**Li 1S**	**0.9**	**4.20**	**00.06**	**00001**	**4.06**
4.0	**Dec. 25, 7:36**	**Yellow/ Black**	**Single**	**CHG (Final)**	**MOV_ 0368 - Copy(4)**	**Li 1S**	**0.0**	**4.20**	**59.09**	**00598**	**4.12**

5.0	**Dec. 25, 7:37**	**Yellow/ Black**	**Single**	**CHG (Final)**	**MOV_0368 - Copy(4)**	**Li 1S**	**0.0**	**4.20**	**108.53**	**04866**	**4.19**

Table 5. Data Table for the Discharging Graph in Figure 8.

Voltage Values						Time Values
4.207	4.217	4.211	4.184	4.194	4.178	10
4.205	4.215	4.211	4.184	4.191	4.178	16
4.205	4.214	4.208	4.182	4.191	4.176	22
4.205	4.214	4.208	4.181	4.191	4.176	28
4.203	4.211	4.208	4.179	4.191	4.176	33
4.203	4.211	4.208	4.179	4.19	4.175	39
4.2	4.211	4.206	4.179	4.188	4.173	45
4.2	4.211	4.208	4.179	4.188	4.17	51
4.199	4.209	4.206	4.176	4.186	4.167	56
4.199	4.208	4.206	4.176	4.184	4.167	62
4.199	4.208	4.206	4.175	4.184	4.166	68
4.199	4.208	4.205	4.172	4.184	4.163	74
4.199	4.206	4.205	4.172	4.182	4.163	79
4.197	4.208	4.205	4.172	4.181	4.161	85
4.197	4.206	4.203	4.17	4.179	4.161	91
4.197	4.206	4.205	4.17	4.179	4.161	97
4.197	4.206	4.205	4.167	4.178	4.161	102
4.196	4.205	4.203	4.167	4.176	4.16	108
4.194	4.205	4.203	4.166	4.176	4.16	114
4.196	4.205	4.203	4.163	4.176	4.16	120
4.193	4.203	4.203	4.163	4.175	4.16	126
4.194	4.205	4.202	4.161	4.173	4.16	131
4.191	4.205	4.202	4.16	4.172	4.16	137
4.191	4.202	4.2	4.16	4.172	4.158	143
4.191	4.203	4.2	4.16	4.172	4.158	149
4.191	4.202	4.2	4.158	4.17	4.158	154
4.188	4.202	4.2	4.158	4.17	4.158	160
4.188	4.202	4.2	4.158	4.167	4.158	166
4.188	4.202	4.199	4.158	4.167	4.157	172
4.188	4.2	4.199	4.158	4.166	4.157	177

4.187	4.199	4.199	4.157	4.163	4.157	183
4.187	4.199	4.199	4.157	4.163	4.158	189
4.187	4.199	4.197	4.155	4.161	4.157	195
4.187	4.199	4.197	4.155	4.161	4.157	201
4.184	4.199	4.197	4.155	4.161	4.157	206
4.184	4.199	4.197	4.154	4.161	4.155	212
4.184	4.199	4.197	4.154	4.16	4.157	218
4.182	4.199	4.197	4.154	4.16	4.155	224
4.181	4.197	4.196	4.152	4.16	4.155	229
4.179	4.197	4.196	4.152	4.16	4.155	235
4.179	4.197	4.196	4.152	4.16	4.155	241
4.178	4.197	4.196	4.151	4.16	4.154	247
4.176	4.197	4.196	4.151	4.158	4.154	253
4.176	4.196	4.193	4.151	4.158	4.154	258
4.176	4.194	4.194	4.151	4.158	4.154	264
4.175	4.196	4.194	4.149	4.158	4.154	270
4.173	4.193	4.194	4.149	4.158	4.154	276
4.172	4.194	4.194	4.149	4.157	4.154	282
4.172	4.191	4.191	4.148	4.157	4.154	287
4.172	4.191	4.191	4.148	4.157	4.152	293
4.17	4.19	4.19	4.149	4.158	4.152	299
4.17	4.19	4.19	4.149	4.157	4.152	305
4.167	4.19	4.19	4.148	4.157	4.152	310
4.167	4.188	4.188	4.148	4.157	4.152	316
4.166	4.187	4.187	4.148	4.155	4.151	322
4.164	4.187	4.187	4.146	4.157	4.152	328
4.163	4.185	4.184	4.146	4.155	4.151	333
4.163	4.185	4.184	4.145	4.155	4.151	339
4.163	4.185	4.184	4.145	4.155	4.151	345
4.161	4.184	4.182	4.143	4.155	4.151	351
4.16	4.184	4.181	4.143	4.154	4.149	357
4.158	4.184	4.179	4.143	4.154	4.149	362
4.158	4.182	4.179	4.142	4.154	4.149	368
4.158	4.181	4.179	4.14	4.154	4.149	374
4.157	4.179	4.179	4.14	4.154	4.149	380
4.155	4.179	4.179	4.14	4.154	4.149	385
4.154	4.179	4.178	4.139	4.154	4.148	391
4.154	4.179	4.178	4.137	4.154	4.148	397
4.151	4.179	4.176	4.137	4.152	4.149	411
4.151	4.178	4.176	4.136	4.152	4.149	421

4.151	4.178	4.176	4.136	4.152	4.148	431
4.149	4.176	4.175	4.136	4.152	4.148	443
4.148	4.176	4.173	4.134	4.152	4.148	453
4.148	4.176	4.172	4.134	4.151	4.146	463
4.148	4.175	4.172	4.134	4.152	4.146	482
4.148	4.173	4.172	4.133	4.151	4.146	491
4.148	4.172	4.17	4.131	4.151	4.146	501
4.148	4.172	4.17	4.13	4.151	4.146	511
4.145	4.172	4.167	4.13	4.151	4.146	529
4.145	4.17	4.167	4.128	4.149	4.145	542
4.143	4.17	4.166	4.128	4.149	4.145	551
4.143	4.167	4.163	4.128	4.149	4.143	552
4.142	4.167	4.163	4.127	4.149	4.143	562
4.142	4.166	4.161	4.127	4.149	4.143	572
4.142	4.164	4.161	4.125	4.149	4.142	583
4.14	4.164	4.161	4.125	4.148	4.14	593
4.139	4.164	4.161	4.124	4.148	4.14	604
4.139	4.164	4.16	4.122	4.149	4.14	624
4.137	4.163	4.16	4.122	4.149	4.139	635
4.136	4.163	4.16	4.121	4.148	4.137	642
4.136	4.163	4.16	4.118	4.148	4.137	654
4.134	4.161	4.16	4.116	4.148	4.136	655
4.133	4.161	4.16	4.116	4.146	4.136	666
4.133	4.161	4.158	4.115	4.146	4.136	676
4.133	4.161	4.158	4.113	4.145	4.134	687
4.13	4.161	4.158	4.112	4.145	4.134	687
4.13	4.16	4.158	4.109	4.143	4.134	697
4.13	4.16	4.158	4.107	4.143	4.133	698
4.128	4.16	4.157	4.107	4.143	4.131	709
4.128	4.16	4.157	4.106	4.142	4.131	730
4.128	4.158	4.157	4.104	4.14	4.131	741
4.125	4.158	4.158	4.104	4.14	4.13	753
4.125	4.158	4.157	4.104	4.14	4.13	767
4.125	4.158	4.157	4.103	4.139	4.13	777
4.124	4.158	4.157	4.103	4.137	4.13	790
4.124	4.157	4.155	4.101	4.137	4.13	803
4.122	4.157	4.157	4.1	4.136	4.128	828
4.124	4.157	4.155	4.1	4.136	4.128	842
4.122	4.157	4.155	4.1	4.136	4.128	851
4.122	4.155	4.155	4.1	4.134	4.127	863

4.122	4.154	4.155	4.101	4.134	4.127	875
4.122	4.154	4.154	4.1	4.134	4.125	888
4.121	4.151	4.154	4.098	4.133	4.125	890
4.121	4.151	4.154	4.098	4.131	4.124	901
4.121	4.151	4.154	4.097	4.131	4.122	911
4.121	4.149	4.154	4.097	4.131	4.122	934
4.119	4.148	4.154	4.095	4.13	4.121	946
4.119	4.148	4.154	4.094	4.13	4.121	956
4.119	4.148	4.154	4.094	4.13	4.119	967
4.119	4.145	4.152	4.094	4.13	4.118	980
4.119	4.145	4.152	4.092	4.13	4.118	991
4.118	4.143	4.152	4.092	4.128	4.118	1019
4.116	4.143	4.152	4.091	4.128	4.116	1028
4.116	4.142	4.152	4.089	4.128	4.116	1053
4.116	4.142	4.151	4.089	4.127	4.115	1065
4.115	4.142	4.152	4.089	4.127	4.112	1075
4.115	4.14	4.151	4.088	4.125	4.11	1084
4.115	4.139	4.151	4.088	4.125	4.109	1099
4.115	4.139	4.151	4.086	4.124	4.107	1111
4.115	4.137	4.151	4.086	4.122	4.107	1121
4.115	4.136	4.149	4.086	4.12	4.106	1141
4.113	4.136	4.149	4.085	4.118	4.103	1143
4.113	4.134	4.149	4.083	4.118	4.101	1157
4.112	4.133	4.149	4.085	4.116	4.1	1167
4.113	4.133	4.149	4.083	4.116	4.101	1179
4.112	4.131	4.149	4.082	4.115	4.1	1191
4.11	4.13	4.148	4.082	4.112	4.098	1205
4.112	4.13	4.148	4.08	4.11	4.098	1216
4.11	4.13	4.149	4.082	4.109	4.097	1243
4.112	4.128	4.149	4.08	4.107	4.097	1252
4.11	4.128	4.148	4.079	4.107	4.095	1265
4.112	4.128	4.148	4.079	4.106	4.094	1273
4.11	4.128	4.148	4.079	4.104	4.094	1286
4.11	4.128	4.146	4.079	4.104	4.094	1297
4.109	4.128	4.146	4.077	4.104	4.092	1321
4.109	4.128	4.145	4.077	4.103	4.092	1331
4.109	4.127	4.145	4.076	4.103	4.091	1340
4.109	4.127	4.143	4.076	4.101	4.089	1350
4.109	4.127	4.143	4.074	4.1	4.089	1361
4.107	4.127	4.14	4.076	4.101	4.089	1376

4.107	4.127	4.139	4.074	4.1	4.088	1388
4.107	4.125	4.137	4.074	4.098	4.088	1397
4.106	4.125	4.137	4.074	4.098	4.086	1408
4.107	4.125	4.136	4.073	4.097	4.086	1421
4.106	4.125	4.136	4.073	4.097	4.086	1431
4.103	4.124	4.136	4.073	4.095	4.085	1442
4.103	4.125	4.134	4.073	4.094	4.083	1455
4.101	4.125	4.134	4.07	4.094	4.085	1467
4.101	4.125	4.134	4.071	4.094	4.083	1480
4.101	4.124	4.133	4.07	4.092	4.082	1500
4.1	4.124	4.131	4.07	4.092	4.082	1511
4.098	4.124	4.131	4.068	4.091	4.08	1524
4.098	4.122	4.131	4.068	4.089	4.082	1537
4.097	4.121	4.13	4.068	4.089	4.08	1548
4.095	4.122	4.13	4.067	4.089	4.079	1558
4.097	4.121	4.13	4.067	4.088	4.079	1567
4.097	4.121	4.13	4.067	4.088	4.079	1580
4.095	4.121	4.13	4.067	4.086	4.079	1593
4.094	4.119	4.128	4.065	4.086	4.077	1605
4.094	4.118	4.128	4.064	4.086	4.077	1628
4.094	4.118	4.128	4.064	4.085	4.076	1640
4.092	4.118	4.127	4.062	4.083	4.076	1648
4.092	4.118	4.127	4.062	4.085	4.074	1661
4.091	4.118	4.125	4.061	4.083	4.076	1670
4.091	4.118	4.125	4.061	4.082	4.074	1683
4.091	4.118	4.124	4.059	4.082	4.074	1695
4.089	4.118	4.122	4.059	4.08	4.074	1705
4.089	4.118	4.122	4.059	4.082	4.073	1719
4.088	4.116	4.121	4.058	4.08	4.073	1730
4.088	4.116	4.121	4.058	4.079	4.073	1755
4.088	4.116	4.119	4.056	4.079	4.073	1767
4.089	4.116	4.118	4.056	4.079	4.071	1779
4.088	4.116	4.118	4.056	4.079	4.071	1791
4.086	4.115	4.118	4.055	4.077	4.071	1804
4.086	4.115	4.116	4.053	4.077	4.071	1815
4.086	4.115	4.116	4.052	4.076	4.071	1827
4.086	4.115	4.115	4.052	4.076	4.07	1841
4.086	4.115	4.113	4.049	4.074	4.071	1855
4.085	4.113	4.113	4.049	4.076	4.07	1866
4.083	4.115	4.112	4.049	4.074	4.07	1876

4.083	4.113	4.112	4.046	4.074	4.068	1897
4.083	4.113	4.112	4.046	4.074	4.068	1918
4.082	4.113	4.11	4.044	4.073	4.068	1927
4.08	4.113	4.109	4.043	4.073	4.067	1940
4.082	4.112	4.107	4.041	4.073	4.067	1966
4.08	4.112	4.107	4.041	4.073	4.067	1991
4.079	4.11	4.106	4.041	4.071	4.067	2003
4.079	4.11	4.104	4.04	4.071	4.065	2028
4.077	4.11	4.104	4.038	4.07	4.064	2040
4.079	4.109	4.104	4.035	4.068	4.064	2053
4.077	4.109	4.103	4.034	4.068	4.062	2065
4.077	4.107	4.103	4.032	4.068	4.062	2078
4.076	4.107	4.101	4.032	4.067	4.061	2088
4.076	4.106	4.1	4.031	4.067	4.061	2097
4.074	4.106	4.101	4.028	4.067	4.059	2108
4.076	4.104	4.1	4.028	4.067	4.059	2120
4.074	4.104	4.098	4.026	4.065	4.059	2135
4.074	4.104	4.098	4.025	4.064	4.058	2143
4.073	4.104	4.097	4.022	4.064	4.058	2155
4.073	4.103	4.097	4.022	4.062	4.056	2181
4.073	4.103	4.095	4.02	4.062	4.056	2194
4.071	4.104	4.094	4.017	4.061	4.056	2207
4.071	4.103	4.094	4.017	4.061	4.055	2217
4.071	4.101	4.094	4.017	4.059	4.053	2256
4.07	4.101	4.092	4.016	4.059	4.052	2267
4.07	4.1	4.092	4.014	4.059	4.052	2279
4.07	4.1	4.091	4.013	4.058	4.049	2289
4.07	4.098	4.089	4.011	4.058	4.049	2301
4.07	4.098	4.089	4.01	4.056	4.049	2322
4.068	4.098	4.089	4.01	4.056	4.046	2333
4.068	4.097	4.088	4.008	4.056	4.046	2342
4.068	4.097	4.088	4.008	4.055	4.044	2354
4.068	4.097	4.086	4.005	4.053	4.043	2355
4.068	4.097	4.086	4.005	4.052	4.041	2364
4.067	4.095	4.086	4.004	4.052	4.041	2378
4.065	4.094	4.085	4.002	4.049	4.041	2404
4.065	4.095	4.083	4.001	4.049	4.04	2418
4.062	4.094	4.085	4.001	4.049	4.038	2431
4.062	4.094	4.083	4.001	4.046	4.035	2432
4.062	4.092	4.082	3.999	4.046	4.034	2446

4.062	4.092	4.082	3.999	4.044	4.032	2460
4.061	4.091	4.08	3.997	4.043	4.032	2472
4.059	4.091	4.082	3.997	4.041	4.031	2484
4.059	4.091	4.08	3.997	4.041	4.028	2498
4.059	4.089	4.079	3.994	4.041	4.028	2515
4.058	4.086	4.079	3.994	4.04	4.026	2526
4.058	4.085	4.079	3.993	4.038	4.025	2540
4.058	4.085	4.079	3.993	4.035	4.022	2552
4.056	4.083	4.076	3.992	4.034	4.022	2562
4.056	4.083	4.074	3.99	4.032	4.02	2563
4.055	4.08	4.076	3.989	4.032	4.017	2574
4.055	4.08	4.074	3.987	4.031	4.017	2585
4.052	4.079	4.074	3.987	4.028	4.017	2608
4.052	4.077	4.074	3.986	4.028	4.016	2621
4.05	4.077	4.073	3.986	4.026	4.014	2634
4.05	4.077	4.073	3.986	4.025	4.013	2646
4.05	4.076	4.073	3.986	4.022	4.011	2657
4.049	4.076	4.073	3.984	4.022	4.01	2658
4.047	4.076	4.071	3.984	4.02	4.01	2685
4.046	4.076	4.07	3.982	4.017	4.008	2696
4.046	4.074	4.071	3.982	4.017	4.008	2709
4.044	4.074	4.07	3.981	4.017	4.005	2720
4.041	4.073	4.07	3.981	4.016	4.005	2731
4.041	4.074	4.068	3.981	4.014	4.004	2742
4.04	4.073	4.068	3.98	4.013	4.002	2752
4.038	4.073	4.068	3.978	4.011	4.001	2762
4.038	4.073	4.067	3.98	4.01	4.001	2763
4.035	4.071	4.067	3.978	4.01	4.001	2775
4.034	4.073	4.067	3.977	4.008	3.999	2787
4.034	4.071	4.067	3.977	4.008	3.999	2798
4.032	4.068	4.065	3.977	4.005	3.997	2811
4.031	4.068	4.064	3.975	4.005	3.997	2823
4.028	4.068	4.064	3.975	4.004	3.997	2835
4.026	4.067	4.062	3.975	4.002	3.994	2848
4.026	4.067	4.062	3.973	4.001	3.994	2861
4.025	4.067	4.061	3.972	4.001	3.993	2872
4.022	4.065	4.061	3.973	4.001	3.993	2899
4.022	4.065	4.059	3.97	3.999	3.992	2910
4.02	4.065	4.059	3.97	3.999	3.99	2932
4.019	4.064	4.059	3.97	3.997	3.989	2942

4.016	4.064	4.058	3.969	3.997	3.987	2943
4.014	4.064	4.058	3.969	3.997	3.987	2953
4.014	4.064	4.056	3.969	3.994	3.986	2966
4.013	4.062	4.056	3.967	3.994	3.986	2978
4.01	4.062	4.056	3.967	3.993	3.986	2988
4.008	4.061	4.055	3.967	3.993	3.986	2998
4.008	4.061	4.053	3.967	3.992	3.984	3009
4.005	4.059	4.052	3.966	3.99	3.984	3021
4.004	4.058	4.052	3.966	3.989	3.982	3033
4.004	4.058	4.049	3.963	3.987	3.982	3045
4.001	4.058	4.049	3.964	3.987	3.981	3057
4.001	4.058	4.049	3.963	3.986	3.981	3068
3.997	4.056	4.046	3.961	3.986	3.981	3081
3.997	4.055	4.046	3.961	3.986	3.98	3090
3.996	4.055	4.044	3.959	3.986	3.978	3100
3.994	4.055	4.043	3.957	3.984	3.98	3114
3.994	4.053	4.041	3.956	3.984	3.978	3125
3.993	4.052	4.041	3.957	3.982	3.977	3136
3.993	4.052	4.041	3.957	3.982	3.977	3155
3.992	4.05	4.04	3.955	3.981	3.977	3165
3.992	4.049	4.038	3.951	3.981	3.975	3177
3.99	4.049	4.035	3.951	3.981	3.975	3190
3.99	4.047	4.034	3.951	3.98	3.975	3202
3.989	4.046	4.032	3.95	3.978	3.973	3214
3.987	4.046	4.032	3.95	3.98	3.972	3236
3.987	4.043	4.031	3.95	3.978	3.973	3248
3.986	4.041	4.028	3.95	3.977	3.97	3260
3.984	4.04	4.028	3.948	3.977	3.97	3273
3.982	4.038	4.026	3.95	3.977	3.97	3285
3.982	4.037	4.025	3.948	3.975	3.969	3294
3.982	4.037	4.022	3.947	3.975	3.969	3308
3.981	4.035	4.022	3.948	3.975	3.969	3319
3.98	4.034	4.02	3.947	3.973	3.967	3329
3.98	4.032	4.017	3.948	3.972	3.967	3330
3.98	4.031	4.017	3.945	3.973	3.967	3342
3.98	4.029	4.017	3.945	3.97	3.967	3355
3.978	4.029	4.016	3.944	3.97	3.966	3368
3.978	4.026	4.014	3.942	3.97	3.967	3381
3.977	4.023	4.013	3.942	3.969	3.966	3383
3.975	4.023	4.011	3.942	3.969	3.964	3397

3.975	4.022	4.01	3.942	3.969	3.964	3409
3.975	4.019	4.01	3.94	3.967	3.964	3421
3.975	4.016	4.008	3.94	3.967	3.963	3434
3.973	4.016	4.008	3.94	3.967	3.963	3447
3.973	4.013	4.005	3.939	3.967	3.964	3460
3.972	4.011	4.005	3.94	3.964	3.963	3473
3.97	4.01	4.004	3.939	3.963	3.959	3486
3.97	4.008	4.002	3.939	3.963	3.959	3498
3.97	4.008	4.001	3.937	3.964	3.96	3509
3.97	4.007	4.001	3.937	3.962	3.959	3534
3.97	4.005	4.001	3.937	3.959	3.957	3546
3.969	4.005	3.999	3.936	3.96	3.954	3558
3.969	4.005	3.999	3.936	3.959	3.954	3581
3.969	4.005	3.997	3.936	3.957	3.953	3591
3.969	4.004	3.997	3.934	3.956	3.953	3597
3.967	4.002	3.997	3.934	3.953	3.951	3612
3.967	4.002	3.994	3.934	3.953	3.948	3636
3.967	4.001	3.989	3.933	3.951	3.95	3647
3.966	4.001	3.987	3.933	3.951	3.948	3658
3.966	4.001	3.987	3.933	3.951	3.947	3671
3.966	4.001	3.986	3.933	3.951	3.948	3685
3.964	3.999	3.964	3.931	3.95	3.947	3697
3.964	3.997	3.981	3.93	3.95	3.948	3711
3.963	3.997	3.981	3.93	3.95	3.945	3723
3.963	3.996	3.981	3.93	3.95	3.945	3733
3.963	3.993	3.981	3.928	3.948	3.945	3746
3.963	3.993	3.981	3.928	3.95	3.945	3757
3.961	3.992	3.981	3.927	3.948	3.945	3769
3.961	3.993	3.98	3.927	3.947	3.945	3794
3.96	3.993	3.978	3.925	3.948	3.945	3803
3.96	3.993	3.975	3.925	3.947	3.944	3813
3.959	3.993	3.973	3.924	3.948	3.942	3829
3.959	3.99	3.972	3.924	3.945	3.942	3843
3.959	3.989	3.973	3.924	3.945	3.939	3845
3.956	3.989	3.97	3.923	3.944	3.94	3853
3.954	3.989	3.97	3.923	3.942	3.939	3865
3.956	3.987	3.97	3.921	3.942	3.939	3888
3.954	3.987	3.969	3.921	3.942	3.937	3901
3.954	3.987	3.969	3.92	3.942	3.937	3913
3.951	3.986	3.969	3.92	3.94	3.937	3934

3.951	3.983	3.969	3.92	3.94	3.936	3945
3.951	3.981	3.969	3.918	3.94	3.936	3956
3.951	3.981	3.969	3.918	3.939	3.936	3967
3.95	3.978	3.967	3.918	3.94	3.934	3979
3.95	3.978	3.967	3.917	3.939	3.934	3992
3.948	3.977	3.967	3.917	3.939	3.934	4004
3.95	3.973	3.967	3.917	3.937	3.933	4016
3.948	3.973	3.966	3.915	3.937	3.933	4025
3.948	3.972	3.967	3.915	3.937	3.933	4037
3.948	3.973	3.966	3.915	3.936	3.933	4051
3.947	3.97	3.964	3.914	3.936	3.931	4065
3.947	3.967	3.963	3.914	3.936	3.93	4087
3.947	3.967	3.961	3.912	3.934	3.93	4100
3.947	3.967	3.961	3.912	3.934	3.93	4112
3.947	3.966	3.961	3.912	3.934	3.928	4124
3.945	3.967	3.961	3.911	3.933	3.928	4137
3.945	3.966	3.96	3.911	3.933	3.927	4151
3.944	3.966	3.959	3.911	3.933	3.927	4167
3.944	3.964	3.959	3.909	3.933	3.925	4180
3.942	3.964	3.96	3.909	3.931	3.925	4191
3.942	3.964	3.959	3.909	3.93	3.924	4216
3.942	3.964	3.957	3.907	3.93	3.924	4242
3.942	3.963	3.956	3.906	3.93	3.924	4253
3.942	3.961	3.957	3.906	3.928	3.923	4265
3.94	3.961	3.957	3.906	3.928	3.923	4276
3.94	3.961	3.954	3.906	3.927	3.921	4278
3.939	3.96	3.956	3.904	3.927	3.921	4299
3.939	3.961	3.956	3.904	3.925	3.92	4313
3.939	3.959	3.954	3.903	3.925	3.92	4323
3.939	3.959	3.954	3.904	3.924	3.92	4348
3.937	3.957	3.953	3.903	3.924	3.918	4361
3.937	3.957	3.953	3.903	3.924	3.918	4372
3.937	3.957	3.951	3.901	3.923	3.918	4386
3.937	3.957	3.951	3.9	3.923	3.917	4398
3.937	3.957	3.951	3.9	3.921	3.917	4410
3.936	3.956	3.951	3.9	3.921	3.917	4423
3.936	3.956	3.95	3.9	3.92	3.915	4438
3.936	3.956	3.95	3.9	3.92	3.915	4451
3.934	3.956	3.95	3.9	3.92	3.915	4473
3.933	3.956	3.95	3.898	3.918	3.914	4488

3.934	3.954	3.948	3.897	3.918	3.914	4499
3.933	3.954	3.95	3.897	3.918	3.912	4511
3.931	3.953	3.948	3.897	3.917	3.912	4525
3.931	3.954	3.947	3.897	3.917	3.912	4537
3.93	3.953	3.948	3.895	3.917	3.911	4548
3.93	3.953	3.947	3.895	3.915	3.911	4574
3.93	3.953	3.948	3.894	3.915	3.911	4586
3.93	3.951	3.945	3.895	3.915	3.909	4596
3.928	3.951	3.945	3.894	3.914	3.909	4608
3.928	3.951	3.945	3.891	3.914	3.909	4620
3.928	3.951	3.945	3.891	3.912	3.907	4630
3.927	3.951	3.945	3.891	3.912	3.906	4642
3.925	3.95	3.945	3.89	3.912	3.906	4655
3.925	3.95	3.945	3.89	3.911	3.906	4665
3.925	3.95	3.944	3.888	3.911	3.906	4673
3.925	3.948	3.942	3.887	3.911	3.904	4674
3.924	3.95	3.942	3.887	3.909	3.904	4687
3.924	3.948	3.942	3.887	3.909	3.903	4701
3.923	3.948	3.942	3.885	3.909	3.904	4713
3.923	3.948	3.94	3.885	3.907	3.903	4725
3.921	3.948	3.94	3.885	3.906	3.903	4738
3.921	3.948	3.94	3.884	3.906	3.901	4758
3.921	3.947	3.939	3.885	3.906	3.9	4770
3.92	3.947	3.94	3.884	3.906	3.9	4786
3.92	3.947	3.939	3.882	3.904	3.9	4798
3.92	3.947	3.939	3.884	3.904	3.9	4804
3.92	3.945	3.939	3.882	3.903	3.898	4817
3.918	3.945	3.939	3.882	3.904	3.897	4829
3.918	3.945	3.937	3.882	3.903	3.898	4841
3.917	3.944	3.937	3.881	3.903	3.898	4852
3.917	3.944	3.937	3.879	3.901	3.897	4862
3.917	3.944	3.936	3.879	3.9	3.895	4881
3.915	3.942	3.936	3.879	3.9	3.895	4892
3.915	3.942	3.936	3.879	3.9	3.894	4904
3.914	3.942	3.934	3.879	3.9	3.895	4910
3.914	3.942	3.934	3.878	3.898	3.894	4922
3.912	3.942	3.934	3.878	3.897	3.894	4932
3.912	3.94	3.933	3.876	3.898	3.894	4944
3.912	3.939	3.933	3.878	3.898	3.891	4955
3.912	3.937	3.933	3.876	3.897	3.89	4969

3.911	3.939	3.933	3.875	3.895	3.89	4993
3.909	3.937	3.931	3.875	3.895	3.888	5004
3.909	3.937	3.93	3.873	3.894	3.887	5016
3.907	3.936	3.93	3.873	3.895	3.888	5026
3.907	3.936	3.93	3.873	3.894	3.887	5037
3.906	3.936	3.928	3.873	3.894	3.885	5049
3.906	3.936	3.928	3.873	3.894	3.885	5061
3.906	3.934	3.927	3.871	3.891	3.885	5073
3.906	3.934	3.927	3.87	3.89	3.884	5082
3.904	3.933	3.925	3.871	3.89	3.885	5095
3.903	3.931	3.925	3.87	3.888	3.884	5097
3.903	3.931	3.924	3.868	3.887	3.882	5106
3.903	3.931	3.924	3.87	3.888	3.884	5118
3.901	3.931	3.924	3.868	3.887	3.882	5128
3.901	3.93	3.923	3.868	3.885	3.882	5138
3.901	3.93	3.923	3.868	3.885	3.882	5149
3.9	3.93	3.921	3.868	3.885	3.881	5160
3.9	3.928	3.92	3.867	3.884	3.879	5173
3.9	3.928	3.918	3.867	3.885	3.879	5185
3.898	3.928	3.918	3.865	3.884	3.879	5193
3.898	3.927	3.918	3.865	3.882	3.879	5210
3.897	3.925	3.917	3.865	3.884	3.879	5220
3.897	3.925	3.917	3.865	3.882	3.878	5233
3.895	3.925	3.917	3.864	3.882	3.878	5243
3.895	3.924	3.915	3.864	3.882	3.876	5255
3.894	3.924	3.915	3.862	3.881	3.878	5271
3.894	3.924	3.914	3.862	3.879	3.876	5292
3.894	3.923	3.914	3.862	3.879	3.875	5302
3.892	3.923	3.914	3.862	3.879	3.875	5317
3.892	3.923	3.912	3.861	3.879	3.873	5327
3.892	3.923	3.912	3.862	3.879	3.873	5338
3.891	3.921	3.912	3.862	3.878	3.873	5350
3.891	3.921	3.911	3.861	3.878	3.873	5360
3.891	3.92	3.911	3.861	3.876	3.873	5372
3.891	3.918	3.909	3.861	3.878	3.871	5385
3.891	3.918	3.909	3.861	3.876	3.87	5399
3.89	3.918	3.909	3.861	3.875	3.871	5412
3.89	3.918	3.907	3.859	3.875	3.87	5422
3.89	3.918	3.907	3.859	3.873	3.868	5436
3.89	3.917	3.907	3.859	3.873	3.87	5450

3.888	3.917	3.906	3.858	3.873	3.868	5460
3.888	3.914	3.906	3.858	3.873	3.868	5473
3.888	3.912	3.906	3.858	3.873	3.868	5485
3.887	3.912	3.906	3.857	3.871	3.868	5497
3.887	3.912	3.904	3.857	3.87	3.867	5509
3.885	3.911	3.904	3.857	3.871	3.867	5522
3.885	3.911	3.903	3.857	3.87	3.865	5533
3.885	3.911	3.904	3.855	3.868	3.865	5545
3.884	3.909	3.903	3.855	3.87	3.865	5557
3.882	3.909	3.903	3.855	3.868	3.865	5570
3.882	3.909	3.901	3.855	3.868	3.864	5583
3.882	3.907	3.9	3.855	3.868	3.864	5594
3.881	3.907	3.9	3.854	3.868	3.862	5606
3.882	3.907	3.9	3.854	3.867	3.862	5621
3.882	3.906	3.9	3.854	3.867	3.862	5637
3.882	3.906	3.9	3.854	3.865	3.862	5647
3.881	3.904	3.9	3.852	3.865	3.861	5663
3.881	3.904	3.9	3.852	3.865	3.862	5685
3.879	3.904	3.9	3.851	3.865	3.862	5697
3.879	3.903	3.898	3.851	3.864	3.861	5698
3.879	3.901	3.897	3.851	3.864	3.861	5711
3.879	3.9	3.898	3.851	3.862	3.861	5725
3.878	3.9	3.898	3.849	3.862	3.861	5737
3.878	3.9	3.897	3.851	3.862	3.861	5762
3.876	3.898	3.897	3.849	3.862	3.859	5763
3.876	3.897	3.897	3.849	3.861	3.859	5776
3.875	3.897	3.897	3.849	3.862	3.859	5788
3.875	3.897	3.895	3.848	3.862	3.858	5789
3.875	3.895	3.895	3.848	3.861	3.858	5801
3.873	3.895	3.894	3.848	3.861	3.858	5804
3.873	3.894	3.895	3.846	3.861	3.857	5815
3.873	3.894	3.894	3.846	3.861	3.857	5837
3.871	3.894	3.894	3.846	3.861	3.857	5850
3.873	3.894	3.894	3.846	3.859	3.857	5865
3.871	3.892	3.891	3.846	3.859	3.855	5876
3.871	3.892	3.891	3.845	3.859	3.855	5891
3.87	3.892	3.891	3.845	3.858	3.855	5892
3.87	3.891	3.891	3.845	3.858	3.855	5904
3.87	3.891	3.89	3.845	3.858	3.855	5916
3.868	3.891	3.89	3.845	3.857	3.854	5927

3.868	3.89	3.888	3.845	3.857	3.854	5939
3.868	3.89	3.887	3.845	3.857	3.854	5953
3.868	3.888	3.888	3.845	3.857	3.854	5963
3.867	3.888	3.887	3.843	3.855	3.852	5964
3.867	3.888	3.887	3.843	3.855	3.852	5976
3.867	3.887	3.887	3.842	3.855	3.851	5977
3.867	3.887	3.885	3.842	3.855	3.851	5990
3.867	3.887	3.885	3.843	3.855	3.851	6004
3.865	3.887	3.885	3.842	3.854	3.851	6016
3.865	3.885	3.884	3.842	3.854	3.849	6025
3.864	3.884	3.885	3.84	3.854	3.851	6033
3.864	3.885	3.884	3.842	3.854	3.849	6034
3.864	3.884	3.882	3.842	3.852	3.849	6044
3.864	3.884	3.884	3.84	3.852	3.849	6060
3.862	3.882	3.882	3.84	3.851	3.848	6075
3.861	3.884	3.882	3.84	3.851	3.848	6088
3.861	3.882	3.882	3.838	3.851	3.848	6100
3.861	3.882	3.882	3.84	3.851	3.846	6114
3.861	3.881	3.882	3.84	3.849	3.846	6125
3.859	3.881	3.881	3.84	3.851	3.846	6138
3.859	3.879	3.879	3.84	3.849	3.846	6152
3.859	3.879	3.879	3.838	3.849	3.846	6164
3.858	3.879	3.879	3.838	3.849	3.845	6172
3.858	3.878	3.879	3.838	3.848	3.845	6185
3.858	3.878	3.879	3.838	3.848	3.845	6196
3.858	3.878	3.878	3.837	3.848	3.845	6198
3.857	3.878	3.878	3.837	3.846	3.845	6209
3.857	3.876	3.876	3.837	3.846	3.845	6210
3.857	3.876	3.878	3.835	3.846	3.845	6222
3.855	3.875	3.876	3.835	3.846	3.845	6234
3.855	3.875	3.876	3.835	3.846	3.843	6244
3.855	3.875	3.876	3.834	3.845	3.843	6256
3.855	3.875	3.876	3.834	3.845	3.842	6267
3.855	3.873	3.876	3.834	3.845	3.842	6291
3.855	3.875	3.876	3.834	3.845	3.843	6306
3.854	3.875	3.875	3.834	3.845	3.842	6315
3.854	3.873	3.875	3.832	3.845	3.842	6328
3.852	3.871	3.873	3.832	3.845	3.84	6342
3.852	3.871	3.873	3.832	3.845	3.842	6350
3.851	3.871	3.873	3.831	3.843	3.842	6366

3.851	3.871	3.873	3.832	3.843	3.84	6378
3.851	3.87	3.873	3.832	3.842	3.84	6385
3.851	3.87	3.871	3.831	3.842	3.84	6401
3.851	3.868	3.87	3.831	3.843	3.838	6412
3.849	3.868	3.871	3.829	3.842	3.84	6423
3.849	3.868	3.87	3.829	3.842	3.838	6431
3.849	3.867	3.868	3.829	3.84	3.838	6442
3.848	3.867	3.87	3.829	3.842	3.838	6454
3.848	3.867	3.868	3.828	3.842	3.838	6468
3.848	3.865	3.868	3.829	3.84	3.837	6479
3.846	3.865	3.868	3.828	3.84	3.837	6489
3.846	3.865	3.868	3.828	3.84	3.837	6502
3.846	3.864	3.867	3.828	3.838	3.835	6513
3.845	3.864	3.867	3.826	3.84	3.835	6514
3.845	3.864	3.865	3.826	3.838	3.835	6526
3.845	3.862	3.865	3.826	3.838	3.834	6537
3.845	3.862	3.865	3.825	3.838	3.834	6549
3.845	3.862	3.865	3.826	3.838	3.834	6560
3.845	3.862	3.864	3.826	3.837	3.834	6568
3.845	3.861	3.864	3.825	3.837	3.834	6569
3.843	3.861	3.862	3.823	3.837	3.832	6582
3.843	3.861	3.862	3.825	3.835	3.832	6584
3.842	3.859	3.862	3.823	3.835	3.832	6595
3.843	3.859	3.862	3.823	3.835	3.831	6606
3.842	3.859	3.861	3.823	3.834	3.832	6620
3.842	3.859	3.862	3.823	3.834	3.832	6630
3.842	3.858	3.862	3.822	3.834	3.831	6643
3.842	3.858	3.861	3.822	3.834	3.831	6652
3.84	3.858	3.861	3.822	3.834	3.829	6666
3.84	3.858	3.861	3.822	3.832	3.829	6667
3.84	3.857	3.861	3.821	3.832	3.829	6679
3.838	3.857	3.861	3.821	3.832	3.829	6691
3.838	3.855	3.859	3.821	3.831	3.828	6702
3.838	3.855	3.859	3.821	3.832	3.829	6714
3.838	3.855	3.859	3.823	3.832	3.828	6728
3.838	3.854	3.858	3.825	3.831	3.828	6740
3.837	3.855	3.858	3.825	3.831	3.828	6752
3.837	3.855	3.858	3.825	3.829	3.826	6774
3.837	3.854	3.857	3.826	3.829	3.826	6785
3.837	3.852	3.857	3.826	3.829	3.826	6796

3.837	3.852	3.857	3.826	3.829	3.825	6811
3.835	3.852	3.857	3.821	3.828	3.826	6823
3.835	3.852	3.855	3.819	3.829	3.826	6834
3.835	3.851	3.855	3.819	3.828	3.825	6847
3.834	3.851	3.855	3.819	3.828	3.823	6859
3.835	3.851	3.855	3.819	3.828	3.825	6869
3.834	3.851	3.855	3.818	3.826	3.823	6870
3.832	3.849	3.854	3.818	3.826	3.823	6891
3.832	3.849	3.854	3.819	3.826	3.823	6902
3.832	3.849	3.854	3.818	3.825	3.823	6915
3.832	3.848	3.854	3.818	3.826	3.822	6926
3.831	3.848	3.852	3.816	3.826	3.822	6939
3.832	3.848	3.852	3.818	3.825	3.822	6963
3.832	3.848	3.851	3.816	3.823	3.822	6975
3.831	3.848	3.851	3.818	3.825	3.821	6987
3.831	3.846	3.851	3.816	3.823	3.821	6999
3.831	3.846	3.851	3.813	3.823	3.821	7022
3.831	3.846	3.849	3.813	3.823	3.821	7037
3.829	3.846	3.851	3.812	3.823	3.823	7047
3.829	3.845	3.849	3.812	3.822	3.825	7058
3.829	3.845	3.849	3.812	3.822	3.825	7070
3.829	3.845	3.849	3.81	3.822	3.825	7083
3.828	3.845	3.848	3.809	3.822	3.826	7093
3.828	3.843	3.848	3.809	3.821	3.826	7104
3.828	3.843	3.848	3.809	3.821	3.826	7116
3.828	3.843	3.846	3.807	3.821	3.821	7129
3.826	3.843	3.846	3.807	3.821	3.819	7142
3.826	3.843	3.846	3.807	3.823	3.819	7153
3.826	3.842	3.846	3.807	3.825	3.819	7166
3.826	3.842	3.846	3.807	3.825	3.819	7180
3.825	3.842	3.845	3.805	3.825	3.818	7191
3.825	3.842	3.845	3.807	3.826	3.818	7211
3.825	3.842	3.845	3.807	3.826	3.819	7223
3.825	3.842	3.845	3.805	3.826	3.818	7236
3.823	3.84	3.845	3.805	3.821	3.818	7248
3.823	3.84	3.845	3.805	3.819	3.816	7262
3.825	3.838	3.845	3.804	3.819	3.818	7273
3.823	3.84	3.845	3.804	3.819	3.816	7285
3.822	3.838	3.843	3.804	3.819	3.818	7297
3.822	3.838	3.843	3.804	3.818	3.816	7321

3.822	3.837	3.842	3.802	3.818	3.815	7333
3.822	3.838	3.842	3.802	3.819	3.816	7347
3.822	3.837	3.843	3.802	3.818	3.815	7361
3.822	3.837	3.842	3.802	3.818	3.815	7372
3.821	3.837	3.842	3.802	3.816	3.815	7384
3.821	3.837	3.84	3.802	3.818	3.815	7398
3.821	3.837	3.842	3.802	3.816	3.813	7407
3.821	3.835	3.842	3.801	3.818	3.815	7417
3.821	3.835	3.84	3.801	3.816	3.813	7429
3.821	3.835	3.84	3.801	3.815	3.813	7454
3.821	3.835	3.84	3.801	3.816	3.813	7466
3.821	3.834	3.838	3.801	3.815	3.812	7477
3.821	3.835	3.84	3.801	3.815	3.812	7478
3.819	3.834	3.838	3.801	3.815	3.812	7490
3.819	3.832	3.838	3.801	3.815	3.81	7503
3.819	3.832	3.838	3.801	3.813	3.81	7514
3.819	3.832	3.838	3.799	3.815	3.81	7516
3.819	3.832	3.837	3.799	3.813	3.81	7524
3.818	3.832	3.837	3.798	3.813	3.81	7541
3.818	3.831	3.837	3.799	3.813	3.81	7554
3.819	3.831	3.835	3.798	3.812	3.81	7555
3.816	3.831	3.835	3.798	3.812	3.809	7568
3.818	3.829	3.835	3.796	3.812	3.809	7581
3.816	3.829	3.834	3.795	3.81	3.809	7590
3.816	3.829	3.834	3.795	3.81	3.807	7601
3.816	3.829	3.834	3.795	3.81	3.807	7612
3.816	3.829	3.834	3.795	3.81	3.807	7624
3.815	3.828	3.834	3.795	3.81	3.807	7640
3.815	3.828	3.832	3.795	3.81	3.807	7652
3.812	3.828	3.832	3.793	3.81	3.805	7664
3.812	3.825	3.832	3.795	3.809	3.807	7677
3.812	3.826	3.831	3.795	3.809	3.807	7691
3.812	3.825	3.832	3.793	3.809	3.805	7703
3.812	3.825	3.832	3.793	3.807	3.805	7712
3.81	3.825	3.831	3.789	3.807	3.805	7736
3.81	3.823	3.831	3.788	3.807	3.804	7746
3.809	3.825	3.829	3.788	3.807	3.804	7760
3.81	3.823	3.829	3.788	3.807	3.804	7772
3.809	3.823	3.829	3.788	3.805	3.804	7782
3.809	3.822	3.829	3.786	3.807	3.802	7815

3.809	3.823	3.828	3.786	3.807	3.802	7826
3.809	3.823	3.829	3.786	3.805	3.801	7839
3.809	3.822	3.828	3.786	3.805	3.801	7855
3.807	3.822	3.828	3.785	3.805	3.801	7865
3.807	3.822	3.828	3.785	3.804	3.799	7877
3.807	3.822	3.826	3.785	3.804	3.799	7889
3.807	3.822	3.823	3.785	3.804	3.798	7903
3.805	3.822	3.822	3.785	3.804	3.799	7915
3.804	3.821	3.822	3.782	3.802	3.798	7926
3.802	3.818	3.822	3.782	3.802	3.798	7951
3.802	3.818	3.821	3.782	3.802	3.798	7961
3.802	3.816	3.819	3.782	3.802	3.798	7974
3.802	3.816	3.819	3.779	3.802	3.798	7986
3.801	3.818	3.818	3.779	3.802	3.795	7997
3.801	3.816	3.818	3.779	3.802	3.795	8009
3.799	3.815	3.819	3.777	3.801	3.795	8026
3.799	3.815	3.818	3.777	3.801	3.795	8039
3.799	3.812	3.818	3.774	3.801	3.793	8049
3.798	3.812	3.816	3.774	3.801	3.793	8062
3.798	3.813	3.818	3.771	3.801	3.793	8077
3.798	3.812	3.816	3.773	3.801	3.792	8086
3.798	3.813	3.818	3.771	3.801	3.792	8098
3.798	3.81	3.816	3.771	3.801	3.792	8111
3.798	3.812	3.815	3.771	3.801	3.792	8123
3.796	3.81	3.816	3.769	3.799	3.792	8149
3.798	3.81	3.815	3.769	3.799	3.789	8161
3.796	3.81	3.815	3.769	3.798	3.789	8176
3.796	3.81	3.815	3.766	3.799	3.786	8187
3.796	3.81	3.815	3.766	3.798	3.786	8201
3.796	3.812	3.813	3.765	3.798	3.786	8213
3.796	3.812	3.815	3.766	3.798	3.785	8223
3.795	3.813	3.813	3.765	3.798	3.785	8233
3.795	3.812	3.813	3.765	3.798	3.785	8235
3.795	3.813	3.813	3.765	3.795	3.783	8245
3.795	3.812	3.812	3.765	3.795	3.783	8259
3.795	3.807	3.812	3.763	3.795	3.783	8270
3.793	3.807	3.812	3.763	3.795	3.78	8282
3.793	3.807	3.81	3.763	3.793	3.779	8294
3.795	3.807	3.81	3.763	3.795	3.779	8304
3.793	3.807	3.81	3.763	3.795	3.777	8305

3.793	3.807	3.81	3.763	3.793	3.776	8314
3.793	3.805	3.81	3.762	3.793	3.776	8328
3.792	3.805	3.81	3.762	3.793	3.776	8341
3.792	3.804	3.81	3.762	3.793	3.776	8354
3.792	3.805	3.809	3.762	3.792	3.776	8377
3.792	3.804	3.809	3.762	3.788	3.773	8391
3.79	3.802	3.809	3.762	3.788	3.769	8404
3.79	3.804	3.807	3.76	3.788	3.769	8416
3.79	3.802	3.807	3.76	3.785	3.769	8427
3.79	3.804	3.807	3.762	3.785	3.768	8439
3.79	3.802	3.807	3.76	3.785	3.768	8451
3.789	3.802	3.807	3.759	3.783	3.769	8461
3.79	3.802	3.804	3.76	3.783	3.768	8476
3.788	3.799	3.804	3.76	3.782	3.768	8486
3.788	3.799	3.802	3.76	3.782	3.765	8498
3.786	3.799	3.802	3.759	3.782	3.763	8509
3.785	3.799	3.802	3.759	3.782	3.763	8521
3.785	3.796	3.802	3.759	3.78	3.763	8529
3.785	3.795	3.801	3.759	3.78	3.763	8539
3.785	3.795	3.801	3.757	3.779	3.763	8540
3.785	3.795	3.799	3.759	3.776	3.763	8548
3.783	3.795	3.799	3.759	3.774	3.762	8560
3.785	3.795	3.798	3.757	3.774	3.762	8572
3.783	3.795	3.799	3.757	3.774	3.762	8585
3.783	3.793	3.796	3.757	3.774	3.762	8596
3.78	3.792	3.796	3.757	3.774	3.762	8610
3.78	3.79	3.795	3.757	3.773	3.762	8623
3.779	3.79	3.795	3.756	3.771	3.76	8649
3.78	3.79	3.795	3.756	3.771	3.76	8659
3.779	3.789	3.792	3.757	3.769	3.762	8669
3.779	3.789	3.792	3.756	3.769	3.76	8682
3.776	3.788	3.792	3.756	3.769	3.759	8696
3.776	3.788	3.792	3.755	3.769	3.76	8708
3.776	3.788	3.792	3.755	3.769	3.76	8720
3.776	3.788	3.789	3.755	3.768	3.76	8730
3.776	3.786	3.789	3.755	3.766	3.759	8741
3.776	3.785	3.789	3.755	3.765	3.759	8752
3.773	3.785	3.789	3.755	3.765	3.759	8762
3.773	3.785	3.789	3.755	3.765	3.759	8771
3.773	3.785	3.789	3.755	3.765	3.757	8782

3.773	3.785	3.786	3.755	3.763	3.759	8795
3.773	3.783	3.786	3.755	3.763	3.759	8810
3.771	3.782	3.785	3.755	3.763	3.757	8821
3.773	3.782	3.785	3.753	3.763	3.757	8846
3.771	3.782	3.783	3.753	3.763	3.757	8859
3.769	3.78	3.783	3.753	3.763	3.757	8874
3.769	3.782	3.783	3.752	3.762	3.757	8884
3.769	3.78	3.783	3.752	3.762	3.756	8897
3.769	3.78	3.783	3.752	3.762	3.756	8910
3.769	3.78	3.779	3.752	3.762	3.757	8922
3.768	3.779	3.779	3.752	3.762	3.756	8934
3.766	3.779	3.779	3.752	3.762	3.756	8959
3.766	3.779	3.779	3.75	3.76	3.755	8972
3.765	3.779	3.779	3.752	3.76	3.755	8982
3.766	3.774	3.779	3.752	3.762	3.755	9005
3.765	3.776	3.779	3.75	3.76	3.755	9017
3.765	3.774	3.779	3.75	3.759	3.755	9029
3.765	3.774	3.776	3.75	3.76	3.755	9042
3.765	3.776	3.776	3.75	3.76	3.755	9054
3.763	3.774	3.776	3.749	3.76	3.755	9067
3.763	3.774	3.776	3.749	3.759	3.755	9082
3.762	3.774	3.774	3.749	3.759	3.755	9084
3.763	3.771	3.774	3.747	3.759	3.755	9097
3.762	3.771	3.774	3.749	3.759	3.753	9110
3.762	3.773	3.774	3.749	3.757	3.753	9111
3.763	3.771	3.774	3.747	3.759	3.753	9125
3.762	3.771	3.774	3.747	3.759	3.752	9149
3.762	3.771	3.774	3.749	3.757	3.752	9164
3.762	3.769	3.774	3.747	3.757	3.752	9179
3.76	3.769	3.773	3.747	3.757	3.752	9190
3.76	3.769	3.774	3.747	3.757	3.752	9205
3.76	3.771	3.773	3.747	3.757	3.752	9217
3.76	3.769	3.773	3.746	3.756	3.75	9218
3.76	3.769	3.773	3.747	3.756	3.752	9233
3.76	3.768	3.773	3.746	3.757	3.752	9246
3.759	3.768	3.773	3.744	3.756	3.75	9261
3.759	3.768	3.771	3.746	3.756	3.75	9284
3.759	3.768	3.773	3.743	3.755	3.75	9299
3.759	3.768	3.771	3.743	3.755	3.75	9311
3.759	3.768	3.771	3.743	3.755	3.749	9321

3.759	3.768	3.771	3.743	3.755	3.749	9334
3.757	3.766	3.769	3.741	3.755	3.749	9346
3.757	3.766	3.769	3.741	3.755	3.747	9358
3.757	3.766	3.769	3.743	3.755	3.749	9369
3.757	3.766	3.766	3.741	3.755	3.749	9385
3.756	3.766	3.766	3.74	3.755	3.747	9397
3.755	3.765	3.766	3.741	3.755	3.747	9412
3.755	3.765	3.766	3.74	3.755	3.749	9425
3.755	3.763	3.766	3.74	3.753	3.747	9438
3.753	3.763	3.766	3.74	3.753	3.747	9451
3.755	3.763	3.765	3.738	3.753	3.747	9464
3.753	3.762	3.766	3.738	3.752	3.746	9476
3.753	3.762	3.765	3.738	3.752	3.747	9491
3.753	3.762	3.765	3.738	3.752	3.746	9504
3.753	3.762	3.765	3.738	3.752	3.744	9516
3.753	3.76	3.765	3.738	3.752	3.746	9530
3.752	3.76	3.763	3.738	3.752	3.744	9542
3.752	3.76	3.763	3.736	3.75	3.743	9553
3.752	3.76	3.763	3.738	3.752	3.743	9564
3.752	3.76	3.763	3.736	3.752	3.743	9576
3.752	3.76	3.763	3.736	3.75	3.743	9590
3.752	3.762	3.763	3.736	3.75	3.741	9600
3.75	3.76	3.762	3.736	3.75	3.741	9629
3.75	3.76	3.762	3.736	3.75	3.743	9643
3.75	3.76	3.762	3.735	3.749	3.741	9656
3.75	3.76	3.762	3.736	3.749	3.74	9671
3.75	3.759	3.762	3.735	3.749	3.741	9684
3.75	3.759	3.762	3.735	3.747	3.74	9685
3.749	3.759	3.76	3.733	3.749	3.74	9697
3.749	3.759	3.76	3.735	3.749	3.74	9709
3.749	3.759	3.762	3.732	3.749	3.738	9723
3.75	3.759	3.76	3.73	3.747	3.738	9735
3.747	3.757	3.76	3.73	3.747	3.738	9746
3.747	3.757	3.76	3.73	3.747	3.738	9760
3.749	3.757	3.76	3.729	3.747	3.738	9773
3.747	3.757	3.76	3.729	3.747	3.738	9786
3.747	3.757	3.76	3.729	3.746	3.738	9796
3.747	3.756	3.76	3.729	3.747	3.736	9808
3.747	3.756	3.759	3.727	3.746	3.738	9821
3.747	3.756	3.759	3.729	3.744	3.736	9833

3.746	3.756	3.759	3.729	3.746	3.736	9852
3.747	3.755	3.759	3.727	3.744	3.736	9866
3.747	3.755	3.757	3.726	3.744	3.736	9880
3.746	3.755	3.759	3.727	3.746	3.736	9897
3.746	3.755	3.759	3.727	3.743	3.735	9910
3.746	3.755	3.757	3.727	3.744	3.736	9922
3.746	3.755	3.757	3.726	3.743	3.735	9946
3.746	3.755	3.757	3.726	3.743	3.735	9956
3.746	3.753	3.757	3.724	3.743	3.733	9957
3.746	3.753	3.757	3.724	3.743	3.735	9967
3.744	3.753	3.756	3.726	3.741	3.733	9975
3.746	3.753	3.756	3.723	3.741	3.733	9991
3.744	3.753	3.757	3.723	3.743	3.733	10004
3.744	3.753	3.756	3.723	3.741	3.733	10016
3.744	3.752	3.756	3.723	3.74	3.733	10031
3.743	3.752	3.755	3.721	3.741	3.733	10042
3.744	3.752	3.755	3.721	3.74	3.732	10043
3.743	3.752	3.753	3.721	3.74	3.732	10065
3.744	3.752	3.753	3.721	3.74	3.732	10079
3.743	3.752	3.753	3.721	3.738	3.732	10091
3.743	3.75	3.75	3.719	3.738	3.73	10103
3.743	3.75	3.75	3.72	3.738	3.73	10119
3.743	3.75	3.75	3.719	3.738	3.738	10130
3.741	3.75	3.75	3.719	3.738	3.73	10144
3.741	3.75	3.749	3.719	3.738	3.73	10154
3.741	3.749	3.749	3.716	3.738	3.732	10169
3.741	3.75	3.749	3.716	3.736	3.73	10179
3.741	3.75	3.747	3.714	3.738	3.73	10189
3.741	3.75	3.749	3.714	3.736	3.73	10199
3.74	3.749	3.749	3.714	3.736	3.729	10223
3.741	3.749	3.747	3.713	3.736	3.729	10233
3.74	3.749	3.747	3.714	3.736	3.729	10235
3.74	3.747	3.749	3.713	3.736	3.729	10255
3.738	3.749	3.747	3.711	3.735	3.727	10256
3.736	3.749	3.747	3.711	3.736	3.729	10265
3.738	3.749	3.744	3.71	3.735	3.729	10282
3.736	3.747	3.746	3.71	3.735	3.724	10294
3.736	3.747	3.744	3.71	3.733	3.724	10307
3.736	3.747	3.744	3.71	3.735	3.723	10320
3.736	3.747	3.746	3.708	3.733	3.723	10334

3.735	3.747	3.743	3.708	3.732	3.723	10345
3.736	3.747	3.744	3.71	3.73	3.723	10346
3.735	3.747	3.743	3.707	3.73	3.72	10365
3.735	3.746	3.743	3.705	3.732	3.72	10366
3.733	3.746	3.743	3.705	3.73	3.719	10376
3.735	3.746	3.743	3.703	3.73	3.719	10397
3.733	3.744	3.741	3.702	3.73	3.719	10408
3.733	3.746	3.741	3.702	3.729	3.719	10419
3.733	3.746	3.743	3.702	3.729	3.716	10429
3.733	3.746	3.741	3.699	3.729	3.716	10430
3.733	3.744	3.74	3.699	3.729	3.714	10442
3.733	3.744	3.741	3.697	3.727	3.714	10452
3.732	3.744	3.74	3.697	3.729	3.713	10462
3.732	3.744	3.74	3.696	3.729	3.71	10474
3.732	3.744	3.74	3.697	3.727	3.71	10499
3.732	3.743	3.738	3.696	3.726	3.708	10508
3.73	3.743	3.738	3.696	3.727	3.705	10510
3.73	3.744	3.738	3.694	3.727	3.705	10518
3.73	3.743	3.738	3.694	3.727	3.705	10532
3.73	3.743	3.738	3.693	3.726	3.703	10542
3.732	3.743	3.738	3.691	3.726	3.702	10552
3.73	3.744	3.738	3.691	3.724	3.699	10565
3.73	3.743	3.736	3.691	3.724	3.699	10575
3.73	3.741	3.738	3.688	3.726	3.697	10577
3.729	3.743	3.736	3.688	3.723	3.697	10587
3.729	3.743	3.736	3.687	3.723	3.696	10589
3.729	3.743	3.736	3.687	3.721	3.696	10595
3.729	3.741	3.736	3.686	3.721	3.694	10610
3.727	3.741	3.736	3.686	3.721	3.694	10611
3.729	3.74	3.735	3.686	3.72	3.694	10635
3.729	3.74	3.736	3.686	3.72	3.694	10658
3.727	3.74	3.735	3.683	3.719	3.693	10670
3.726	3.738	3.73	3.683	3.719	3.691	10682
3.727	3.736	3.73	3.683	3.719	3.691	10694
3.727	3.736	3.73	3.681	3.716	3.691	10715
3.727	3.736	3.73	3.681	3.716	3.691	10728
3.726	3.736	3.73	3.681	3.714	3.691	10739
3.726	3.736	3.729	3.678	3.713	3.691	10751
3.726	3.735	3.729	3.678	3.711	3.688	10762
3.726	3.736	3.729	3.678	3.71	3.688	10770

3.725	3.735	3.729	3.674	3.71	3.688	10780
3.726	3.735	3.727	3.675	3.708	3.688	10800
3.723	3.733	3.729	3.675	3.708	3.685	10808
3.723	3.73	3.729	3.674	3.71	3.685	10818
3.723	3.73	3.727	3.674	3.707	3.681	10828
3.723	3.732	3.726	3.674	3.708	3.681	10847
3.721	3.732	3.727	3.672	3.708	3.68	10860
3.721	3.7632	3.727	3.672	3.705	3.678	10868
3.721	3.732	3.727	3.671	3.705	3.678	10870
3.721	3.73	3.726	3.671	3.703	3.675	10879
3.721	3.73	3.726	3.671	3.703	3.674	10889
3.72	3.732	3.724	3.671	3.703	3.674	10900
3.719	3.73	3.724	3.669	3.699	3.672	10910
3.719	3.73	3.726	3.667	3.699	3.672	10921
3.717	3.73	3.723	3.667	3.696	3.671	10942
3.716	3.729	3.723	3.667	3.696	3.671	10952
3.714	3.727	3.721	3.667	3.694	3.671	10960
3.714	3.726	3.721	3.666	3.694	3.671	10972
3.714	3.724	3.721	3.666	3.693	3.669	10973
3.711	3.724	3.721	3.664	3.693	3.666	10983
3.711	3.726	3.72	3.663	3.691	3.666	10993
3.71	3.723	3.72	3.661	3.691	3.664	11004
3.71	3.723	3.72	3.661	3.688	3.663	11004
3.708	3.723	3.719	3.658	3.688	3.661	11014
3.708	3.723	3.72	3.658	3.687	3.661	11015
3.71	3.721	3.719	3.657	3.687	3.658	11026
3.707	3.721	3.719	3.657	3.686	3.658	11048
3.708	3.721	3.719	3.654	3.686	3.657	11058
3.708	3.721	3.716	3.652	3.686	3.657	11070
3.705	3.721	3.716	3.651	3.686	3.654	11084
3.705	3.72	3.714	3.648	3.683	3.652	11094
3.703	3.719	3.714	3.645	3.683	3.651	11107
3.703	3.719	3.714	3.644	3.683	3.648	11120
3.703	3.717	3.711	3.642	3.683	3.645	11145
3.7	3.714	3.71	3.639	3.68	3.644	11159
3.7	3.714	3.711	3.636	3.678	3.642	11168
3.697	3.714	3.71	3.633	3.678	3.639	11180
3.697	3.713	3.71	3.628	3.675	3.636	11193
3.696	3.711	3.708	3.624	3.675	3.633	11206
3.697	3.711	3.708	3.619	3.674	3.628	11207

3.696	3.711	3.708	3.615	3.675	3.624	11218
3.696	3.71	3.707	3.612	3.674	3.619	11228
3.694	3.71	3.708	3.609	3.674	3.615	11251
3.691	3.71	3.708	3.601	3.674	3.612	11263
3.688	3.708	3.707	3.598	3.674	3.609	11273
3.688	3.708	3.703	3.598	3.671	3.601	11284
3.687	3.705	3.703	3.597	3.671	3.598	11297
3.683	3.705	3.703	3.595	3.669	3.598	11308
3.683	3.703	3.699	3.594	3.667	3.595	11336
3.68	3.703	3.699	3.588	3.667	3.594	11345
3.68	3.703	3.697	3.582	3.666	3.588	11370
3.68	3.702	3.697	3.578	3.664	3.582	11382
3.678	3.702	3.696	3.575	3.663	3.578	11392
3.68	3.699	3.697	3.572	3.661	3.575	11402
3.678	3.699	3.696	3.57	3.661	3.572	11416
3.678	3.699	3.696	3.57	3.658	3.57	11428
3.678	3.699	3.694	3.57	3.658	3.562	11438
3.678	3.697	3.694	3.562	3.657	3.556	11459
3.678	3.697	3.693	3.556	3.657	3.555	11460
3.677	3.696	3.691	3.555	3.654	3.549	11474
3.677	3.697	3.691	3.549	3.652	3.542	11485
3.677	3.696	3.691	3.542	3.651	3.537	11496
3.677	3.696	3.688	3.537	3.648	3.531	11508
3.677	3.694	3.688	3.537	3.645	3.526	11522
3.677	3.694	3.687	3.537	3.644	3.52	11533
3.675	3.693	3.687	3.536	3.642	3.517	11560
3.675	3.693	3.686	3.536	3.639	3.512	11569
3.674	3.693	3.686	3.531	3.636	3.507	11583
3.675	3.693	3.686	3.529	3.633	3.496	11590
3.675	3.691	3.686	3.529	3.628	3.492	11603
3.674	3.691	3.683	3.526	3.624	3.49	11614
3.674	3.691	3.683	3.52	3.619	3.48	11638
3.674	3.688	3.683	3.52	3.615	3.479	11648
3.674	3.688	3.683	3.52	3.612	3.474	11658
3.674	3.686	3.681	3.518	3.609	3.463	11668
3.672	3.686	3.681	3.517	3.601	3.456	11678
3.674	3.681	3.681	3.512	3.598	3.448	11693
3.672	3.68	3.681	3.507	3.598	3.443	11705
3.672	3.68	3.68	3.496	3.595	3.432	11715
3.671	3.677	3.68	3.492	3.594	3.427	11725

3.671	3.677	3.68	3.49	3.588	3.424	11738
3.671	3.677	3.68	3.492	3.582	3.415	11748
3.671	3.675	3.68	3.49	3.578	3.414	11759
3.669	3.675	3.68	3.48	3.575	3.407	11773
3.667	3.674	3.678	3.479	3.572	3.39	11784
3.667	3.675	3.68	3.474	3.57	3.384	11797
3.667	3.675	3.678	3.463	3.562	3.378	11817
3.667	3.674	3.678	3.456	3.556	3.369	11828
3.664	3.674	3.678	3.448	3.555	3.368	11841
3.663	3.674	3.678	3.443	3.549	3.357	11854
3.661	3.674	3.675	3.432	3.542	3.349	11865
3.661	3.674	3.674	3.427	3.537	3.342	11875
3.658	3.674	3.674	3.424	3.531	3.337	11885
3.658	3.672	3.672	3.415	3.526	3.33	11897
3.657	3.672	3.672	3.414	3.52	3.31	11910
3.657	3.671	3.671	3.407	3.517	3.309	11922
3.654	3.672	3.669	3.39	3.512	3.305	11945
3.652	3.672	3.667	3.384	3.507	3.299	11957
3.651	3.664	3.667	3.378	3.496	3.299	11966
3.648	3.663	3.667	3.369	3.492	3.296	11978
3.645	3.661	3.667	3.368	3.49	3.289	11987
3.644	3.661	3.666	3.357	3.48	3.272	12000
3.642	3.658	3.666	3.349	3.48	3.261	12012
3.639	3.658	3.664	3.342	3.479	3.242	12022
3.636	3.657	3.663	3.33	3.474	3.225	12036
3.633	3.657	3.661	3.31	3.463	3.209	12047
3.628	3.654	3.661	3.309	3.456	3.188	12072
3.624	3.652	3.657	3.299	3.448	3.179	12084
3.619	3.651	3.654	3.299	3.443	3.156	12096
3.615	3.648	3.652	3.296	3.432	3.143	12109

Table 6. Data Table for the Charging Graph in Figure 2.

Voltage Values					Time Values
3.779	**3.771**	**3.618**	**3.771**	**3.175**	**10.831**
3.78	**3.771**	**3.621**	**3.773**	**3.198**	**16.618**
3.782	**3.773**	**3.624**	**3.773**	**3.219**	**22.382**
3.782	**3.773**	**3.628**	**3.773**	**3.237**	**28.152**

3.782	**3.773**	**3.63**	**3.774**	**3.253**	**33.918**
3.785	**3.774**	**3.636**	**3.776**	**3.27**	**39.654**
3.785	**3.774**	**3.638**	**3.776**	**3.285**	**45.414**
3.785	**3.774**	**3.641**	**3.777**	**3.299**	**51.165**
3.785	**3.776**	**3.642**	**3.777**	**3.311**	**56.922**
3.785	**3.776**	**3.647**	**3.777**	**3.322**	**62.642**
3.786	**3.777**	**3.65**	**3.779**	**3.335**	**68.436**
3.788	**3.777**	**3.654**	**3.78**	**3.345**	**74.173**
3.786	**3.777**	**3.654**	**3.779**	**3.355**	**79.89**
3.788	**3.779**	**3.658**	**3.78**	**3.368**	**85.624**
3.788	**3.779**	**3.661**	**3.782**	**3.375**	**91.348**
3.789	**3.779**	**3.664**	**3.782**	**3.385**	**97.167**
3.789	**3.779**	**3.666**	**3.782**	**3.394**	**103.002**
3.789	**3.78**	**3.667**	**3.782**	**3.402**	**108.766**
3.789	**3.779**	**3.671**	**3.782**	**3.408**	**114.586**
3.79	**3.78**	**3.674**	**3.783**	**3.417**	**120.381**
3.79	**3.78**	**3.677**	**3.785**	**3.426**	**126.137**
3.79	**3.78**	**3.678**	**3.783**	**3.43**	**131.902**
3.792	**3.783**	**3.683**	**3.786**	**3.441**	**137.709**
3.792	**3.783**	**3.684**	**3.786**	**3.447**	**143.459**
3.793	**3.783**	**3.688**	**3.788**	**3.454**	**149.226**
3.793	**3.783**	**3.687**	**3.786**	**3.459**	**154.966**
3.793	**3.785**	**3.691**	**3.788**	**3.467**	**160.758**
3.795	**3.785**	**3.694**	**3.788**	**3.474**	**166.539**
3.795	**3.785**	**3.694**	**3.788**	**3.477**	**172.301**
3.795	**3.785**	**3.697**	**3.789**	**3.484**	**178.057**
3.795	**3.785**	**3.699**	**3.789**	**3.489**	**183.802**
3.796	**3.786**	**3.702**	**3.789**	**3.496**	**189.565**
3.796	**3.786**	**3.703**	**3.79**	**3.501**	**195.378**
3.796	**3.786**	**3.705**	**3.79**	**3.507**	**201.173**
3.796	**3.788**	**3.707**	**3.79**	**3.512**	**206.921**
3.796	**3.789**	**3.71**	**3.792**	**3.517**	**212.697**
3.798	**3.789**	**3.714**	**3.793**	**3.523**	**218.419**
3.798	**3.789**	**3.714**	**3.793**	**3.528**	**224.14**
3.799	**3.789**	**3.716**	**3.793**	**3.532**	**229.864**
3.798	**3.789**	**3.717**	**3.793**	**3.537**	**235.628**
3.798	**3.79**	**3.719**	**3.793**	**3.542**	**241.414**
3.799	**3.79**	**3.721**	**3.795**	**3.548**	**247.162**
3.799	**3.79**	**3.721**	**3.795**	**3.55**	**252.989**
3.799	**3.79**	**3.723**	**3.795**	**3.555**	**258.76**

3.801	**3.792**	**3.726**	**3.796**	**3.559**	**264.525**
3.802	**3.792**	**3.727**	**3.796**	**3.565**	**270.335**
3.799	**3.792**	**3.724**	**3.796**	**3.567**	**276.066**
3.801	**3.792**	**3.727**	**3.798**	**3.572**	**281.824**
3.802	**3.793**	**3.73**	**3.799**	**3.576**	**287.533**
3.802	**3.792**	**3.729**	**3.799**	**3.579**	**293.292**
3.802	**3.793**	**3.732**	**3.799**	**3.584**	**299.024**
3.802	**3.793**	**3.73**	**3.801**	**3.589**	**304.812**
3.802	**3.795**	**3.73**	**3.799**	**3.591**	**310.622**
3.802	**3.795**	**3.732**	**3.801**	**3.595**	**316.448**
3.804	**3.796**	**3.73**	**3.801**	**3.598**	**322.199**
3.804	**3.796**	**3.733**	**3.801**	**3.603**	**327.927**
3.804	**3.795**	**3.733**	**3.802**	**3.606**	**333.681**
3.805	**3.796**	**3.733**	**3.802**	**3.609**	**339.451**
3.805	**3.796**	**3.733**	**3.802**	**3.614**	**345.224**
3.805	**3.798**	**3.735**	**3.804**	**3.617**	**350.937**
3.805	**3.796**	**3.735**	**3.804**	**3.618**	**356.727**
3.805	**3.798**	**3.736**	**3.805**	**3.622**	**362.447**
3.807	**3.799**	**3.738**	**3.807**	**3.627**	**368.175**
3.805	**3.798**	**3.736**	**3.805**	**3.628**	**373.947**
3.807	**3.799**	**3.735**	**3.805**	**3.631**	**379.703**
3.805	**3.799**	**3.736**	**3.805**	**3.634**	**385.46**
3.809	**3.799**	**3.738**	**3.807**	**3.639**	**391.189**
3.807	**3.801**	**3.738**	**3.807**	**3.642**	**396.955**
3.809	**3.802**	**3.74**	**3.809**	**3.65**	**404.261**
3.81	**3.802**	**3.74**	**3.81**	**3.664**	**424.967**
3.81	**3.804**	**3.741**	**3.812**	**3.671**	**433.79**
3.812	**3.805**	**3.741**	**3.813**	**3.681**	**446.258**
3.812	**3.805**	**3.743**	**3.815**	**3.687**	**454.056**
3.813	**3.807**	**3.743**	**3.815**	**3.693**	**464.494**
3.813	**3.807**	**3.744**	**3.816**	**3.699**	**474.37**
3.813	**3.809**	**3.746**	**3.818**	**3.707**	**485.266**
3.815	**3.809**	**3.746**	**3.818**	**3.711**	**493.65**
3.815	**3.809**	**3.746**	**3.819**	**3.717**	**505.127**
3.816	**3.812**	**3.749**	**3.821**	**3.724**	**515.083**
3.815	**3.812**	**3.749**	**3.821**	**3.727**	**526.361**
3.818	**3.812**	**3.75**	**3.821**	**3.729**	**536.243**
3.818	**3.812**	**3.75**	**3.822**	**3.733**	**554.352**
3.818	**3.813**	**3.753**	**3.823**	**3.733**	**564.206**
3.818	**3.815**	**3.755**	**3.825**	**3.736**	**574.143**

3.819	**3.815**	**3.756**	**3.825**	**3.738**	**584.019**
3.819	**3.815**	**3.756**	**3.826**	**3.738**	**595.41**
3.819	**3.815**	**3.757**	**3.826**	**3.738**	**605.331**
3.821	**3.816**	**3.76**	**3.828**	**3.741**	**626.033**
3.821	**3.816**	**3.762**	**3.826**	**3.741**	**636.95**
3.821	**3.816**	**3.76**	**3.828**	**3.743**	**638.598**
3.821	**3.818**	**3.763**	**3.829**	**3.746**	**650.523**
3.822	**3.818**	**3.766**	**3.829**	**3.747**	**663.989**
3.822	**3.818**	**3.768**	**3.832**	**3.749**	**685.559**
3.823	**3.819**	**3.774**	**3.832**	**3.752**	**697.45**
3.823	**3.821**	**3.774**	**3.832**	**3.753**	**709.394**
3.825	**3.821**	**3.776**	**3.834**	**3.755**	**721.813**
3.825	**3.821**	**3.777**	**3.835**	**3.757**	**733.729**
3.825	**3.822**	**3.779**	**3.835**	**3.759**	**749.24**
3.825	**3.822**	**3.783**	**3.837**	**3.76**	**762.229**
3.826	**3.822**	**3.785**	**3.837**	**3.763**	**772.144**
3.826	**3.823**	**3.785**	**3.838**	**3.765**	**782.076**
3.826	**3.822**	**3.786**	**3.838**	**3.766**	**793.977**
3.828	**3.823**	**3.789**	**3.838**	**3.769**	**814.135**
3.829	**3.823**	**3.792**	**3.842**	**3.773**	**827.083**
3.829	**3.823**	**3.792**	**3.842**	**3.774**	**828.198**
3.829	**3.825**	**3.793**	**3.843**	**3.776**	**840.156**
3.829	**3.825**	**3.795**	**3.843**	**3.777**	**851.095**
3.831	**3.825**	**3.795**	**3.843**	**3.779**	**863.604**
3.832	**3.826**	**3.798**	**3.845**	**3.782**	**876**
3.832	**3.826**	**3.801**	**3.846**	**3.786**	**898.511**
3.834	**3.828**	**3.804**	**3.848**	**3.79**	**922.752**
3.834	**3.828**	**3.802**	**3.849**	**3.79**	**934.147**
3.835	**3.829**	**3.807**	**3.849**	**3.793**	**947.123**
3.837	**3.829**	**3.807**	**3.851**	**3.796**	**960.08**
3.837	**3.831**	**3.809**	**3.852**	**3.798**	**974.627**
3.837	**3.832**	**3.813**	**3.852**	**3.801**	**989.614**
3.838	**3.831**	**3.813**	**3.854**	**3.802**	**998.994**
3.838	**3.832**	**3.813**	**3.855**	**3.804**	**1011.435**
3.838	**3.832**	**3.816**	**3.855**	**3.807**	**1023.334**
3.84	**3.834**	**3.819**	**3.858**	**3.809**	**1043.989**
3.84	**3.834**	**3.819**	**3.858**	**3.812**	**1058.535**
3.84	**3.834**	**3.819**	**3.858**	**3.81**	**1070.946**
3.842	**3.835**	**3.822**	**3.861**	**3.813**	**1081.9**
3.842	**3.837**	**3.822**	**3.861**	**3.815**	**1094.858**

3.843	**3.835**	**3.822**	**3.862**	**3.818**	**1107.295**
3.845	**3.837**	**3.825**	**3.864**	**3.821**	**1121.797**
3.845	**3.837**	**3.826**	**3.865**	**3.821**	**1133.758**
3.846	**3.84**	**3.826**	**3.867**	**3.822**	**1150.307**
3.846	**3.838**	**3.828**	**3.867**	**3.823**	**1161.162**
3.846	**3.838**	**3.828**	**3.867**	**3.823**	**1162.844**
3.848	**3.84**	**3.831**	**3.868**	**3.826**	**1174.28**
3.848	**3.842**	**3.832**	**3.87**	**3.828**	**1187.754**
3.849	**3.842**	**3.829**	**3.87**	**3.828**	**1201.189**
3.849	**3.843**	**3.832**	**3.871**	**3.831**	**1215.707**
3.851	**3.843**	**3.832**	**3.873**	**3.831**	**1225.529**
3.852	**3.845**	**3.835**	**3.875**	**3.834**	**1239.499**
3.854	**3.845**	**3.835**	**3.876**	**3.834**	**1250.428**
3.854	**3.845**	**3.834**	**3.876**	**3.834**	**1264.418**
3.854	**3.846**	**3.835**	**3.879**	**3.837**	**1278.395**
3.855	**3.846**	**3.837**	**3.881**	**3.837**	**1289.767**
3.857	**3.848**	**3.838**	**3.882**	**3.84**	**1304.428**
3.857	**3.849**	**3.838**	**3.884**	**3.84**	**1318.932**
3.859	**3.851**	**3.84**	**3.887**	**3.842**	**1345.771**
3.859	**3.851**	**3.84**	**3.888**	**3.842**	**1358.188**
3.861	**3.851**	**3.84**	**3.888**	**3.843**	**1370.152**
3.859	**3.852**	**3.84**	**3.888**	**3.843**	**1371.312**
3.861	**3.852**	**3.84**	**3.89**	**3.843**	**1381.701**
3.861	**3.854**	**3.84**	**3.891**	**3.843**	**1393.09**
3.864	**3.854**	**3.842**	**3.894**	**3.845**	**1402.934**
3.864	**3.855**	**3.843**	**3.895**	**3.846**	**1425.66**
3.865	**3.855**	**3.843**	**3.897**	**3.846**	**1437.625**
3.867	**3.857**	**3.842**	**3.898**	**3.848**	**1461.198**
3.868	**3.858**	**3.845**	**3.901**	**3.849**	**1473.134**
3.868	**3.859**	**3.845**	**3.903**	**3.849**	**1484.633**
3.87	**3.859**	**3.843**	**3.904**	**3.849**	**1500.045**
3.871	**3.861**	**3.845**	**3.906**	**3.849**	**1510.896**
3.873	**3.862**	**3.846**	**3.909**	**3.852**	**1524.7**
3.875	**3.864**	**3.848**	**3.912**	**3.852**	**1545.393**
3.875	**3.864**	**3.846**	**3.912**	**3.852**	**1560.741**
3.876	**3.865**	**3.846**	**3.915**	**3.855**	**1572.614**
3.878	**3.867**	**3.849**	**3.917**	**3.857**	**1584.891**
3.879	**3.868**	**3.849**	**3.92**	**3.855**	**1597.37**
3.879	**3.867**	**3.848**	**3.921**	**3.855**	**1607.211**
3.881	**3.868**	**3.849**	**3.923**	**3.857**	**1616.529**

3.881	**3.87**	**3.851**	**3.924**	**3.858**	**1628.893**
3.881	**3.87**	**3.849**	**3.925**	**3.858**	**1639.266**
3.882	**3.871**	**3.851**	**3.925**	**3.858**	**1640.913**
3.882	**3.871**	**3.851**	**3.928**	**3.859**	**1652.215**
3.885	**3.873**	**3.849**	**3.928**	**3.859**	**1663.579**
3.885	**3.873**	**3.852**	**3.93**	**3.861**	**1673.323**
3.887	**3.875**	**3.852**	**3.933**	**3.861**	**1686.294**
3.888	**3.876**	**3.855**	**3.934**	**3.862**	**1696.159**
3.888	**3.876**	**3.852**	**3.936**	**3.862**	**1708.06**
3.89	**3.879**	**3.855**	**3.939**	**3.864**	**1720.996**
3.892	**3.881**	**3.855**	**3.94**	**3.864**	**1733.948**
3.892	**3.879**	**3.855**	**3.944**	**3.865**	**1746.928**
3.894	**3.881**	**3.855**	**3.945**	**3.867**	**1758.326**
3.897	**3.884**	**3.857**	**3.947**	**3.868**	**1771.744**
3.897	**3.885**	**3.855**	**3.948**	**3.867**	**1785.746**
3.898	**3.887**	**3.858**	**3.951**	**3.87**	**1799.689**
3.9	**3.888**	**3.861**	**3.954**	**3.871**	**1812.512**
3.903	**3.887**	**3.858**	**3.954**	**3.871**	**1824.875**
3.903	**3.89**	**3.858**	**3.957**	**3.871**	**1846.557**
3.904	**3.891**	**3.861**	**3.959**	**3.875**	**1857.951**
3.907	**3.892**	**3.861**	**3.96**	**3.876**	**1870.917**
3.907	**3.894**	**3.862**	**3.961**	**3.878**	**1880.343**
3.909	**3.895**	**3.862**	**3.964**	**3.878**	**1892.218**
3.911	**3.895**	**3.862**	**3.964**	**3.881**	**1902.614**
3.914	**3.898**	**3.865**	**3.967**	**3.881**	**1915.562**
3.914	**3.898**	**3.864**	**3.969**	**3.881**	**1927.397**
3.915	**3.9**	**3.867**	**3.97**	**3.884**	**1939.774**
3.917	**3.901**	**3.867**	**3.972**	**3.884**	**1959.379**
3.92	**3.903**	**3.867**	**3.973**	**3.887**	**1972.774**
3.921	**3.904**	**3.868**	**3.977**	**3.887**	**1982.045**
3.923	**3.906**	**3.868**	**3.977**	**3.888**	**1991.901**
3.924	**3.907**	**3.868**	**3.98**	**3.89**	**2005.914**
3.925	**3.911**	**3.871**	**3.981**	**3.891**	**2018.267**
3.927	**3.911**	**3.871**	**3.982**	**3.892**	**2031.205**
3.928	**3.912**	**3.871**	**3.984**	**3.894**	**2042.126**
3.928	**3.912**	**3.873**	**3.986**	**3.894**	**2052.081**
3.931	**3.915**	**3.875**	**3.987**	**3.897**	**2065.538**
3.933	**3.917**	**3.876**	**3.99**	**3.898**	**2077.479**
3.934	**3.918**	**3.876**	**3.99**	**3.898**	**2087.86**
3.934	**3.918**	**3.876**	**3.992**	**3.898**	**2089.536**

3.936	**3.918**	**3.876**	**3.992**	**3.9**	**2099.974**
3.936	**3.92**	**3.878**	**3.993**	**3.901**	**2109.35**
3.939	**3.921**	**3.881**	**3.996**	**3.904**	**2123.159**
3.94	**3.924**	**3.881**	**3.996**	**3.904**	**2134.51**
3.942	**3.924**	**3.882**	**3.997**	**3.906**	**2147.3**
3.942	**3.925**	**3.882**	**3.999**	**3.906**	**2159.8**
3.944	**3.927**	**3.882**	**3.999**	**3.907**	**2171.719**
3.945	**3.928**	**3.885**	**4.002**	**3.912**	**2184.236**
3.945	**3.93**	**3.885**	**4.004**	**3.911**	**2195.187**
3.947	**3.93**	**3.885**	**4.004**	**3.912**	**2206.106**
3.948	**3.931**	**3.887**	**4.004**	**3.915**	**2218.542**
3.95	**3.931**	**3.888**	**4.005**	**3.915**	**2220.164**
3.951	**3.934**	**3.888**	**4.007**	**3.92**	**2243.334**
3.953	**3.937**	**3.891**	**4.01**	**3.921**	**2256.222**
3.954	**3.937**	**3.891**	**4.01**	**3.923**	**2266.63**
3.954	**3.939**	**3.892**	**4.011**	**3.924**	**2276.493**
3.956	**3.939**	**3.892**	**4.013**	**3.924**	**2288.881**
3.959	**3.94**	**3.895**	**4.014**	**3.927**	**2301.85**
3.959	**3.94**	**3.894**	**4.014**	**3.927**	**2314.288**
3.96	**3.942**	**3.895**	**4.016**	**3.93**	**2327.722**
3.961	**3.945**	**3.901**	**4.019**	**3.934**	**2351.387**
3.961	**3.945**	**3.9**	**4.019**	**3.933**	**2353.03**
3.964	**3.947**	**3.901**	**4.022**	**3.934**	**2361.75**
3.964	**3.947**	**3.901**	**4.022**	**3.937**	**2373.712**
3.966	**3.948**	**3.903**	**4.023**	**3.939**	**2388.252**
3.967	**3.95**	**3.906**	**4.026**	**3.942**	**2401.214**
3.969	**3.951**	**3.904**	**4.028**	**3.942**	**2413.663**
3.969	**3.951**	**3.907**	**4.029**	**3.944**	**2427.124**
3.97	**3.951**	**3.907**	**4.031**	**3.945**	**2428.332**
3.972	**3.954**	**3.909**	**4.032**	**3.947**	**2444.404**
3.972	**3.954**	**3.911**	**4.035**	**3.948**	**2454.808**
3.973	**3.956**	**3.912**	**4.035**	**3.95**	**2455.952**
3.975	**3.956**	**3.912**	**4.037**	**3.95**	**2465.856**
3.975	**3.957**	**3.914**	**4.038**	**3.953**	**2477.836**
3.977	**3.959**	**3.914**	**4.043**	**3.954**	**2493.79**
3.978	**3.96**	**3.917**	**4.044**	**3.957**	**2503.624**
3.98	**3.961**	**3.92**	**4.047**	**3.959**	**2518.149**
3.981	**3.963**	**3.921**	**4.052**	**3.96**	**2531.128**
3.982	**3.964**	**3.923**	**4.056**	**3.963**	**2548.162**
3.986	**3.967**	**3.927**	**4.065**	**3.967**	**2575.331**

3.987	3.969	3.928	4.068	3.969	2585.18
3.987	3.97	3.93	4.073	3.97	2596.073
3.987	3.97	3.93	4.077	3.97	2610.067
3.99	3.972	3.931	4.08	3.975	2618.399
3.99	3.975	3.934	4.089	3.977	2634.352
3.992	3.977	3.936	4.092	3.978	2645.258
3.993	3.978	3.937	4.101	3.982	2667.551
3.994	3.98	3.94	4.104	3.984	2678.933
3.993	3.98	3.94	4.107	3.984	2689.809
3.996	3.981	3.944	4.113	3.987	2702.278
3.994	3.982	3.945	4.118	3.989	2716.758
3.997	3.984	3.944	4.121	3.99	2728.677
3.997	3.986	3.948	4.124	3.993	2741.652
3.999	3.986	3.947	4.127	3.993	2756.131
3.999	3.987	3.95	4.13	3.996	2769.541
4.001	3.99	3.951	4.133	3.999	2783.016
4.002	3.99	3.954	4.134	3.999	2784.144
4.002	3.99	3.954	4.134	4.001	2794.504
4.002	3.992	3.956	4.136	4.001	2807.384
4.004	3.992	3.956	4.136	4.002	2817.731
4.004	3.994	3.959	4.139	4.004	2830.021
4.005	3.994	3.959	4.14	4.007	2840.271
4.007	3.996	3.96	4.143	4.007	2859.224
4.007	3.996	3.961	4.145	4.008	2860.357
4.007	3.996	3.963	4.145	4.008	2870.719
4.01	3.997	3.967	4.151	4.013	2894.441
4.01	3.997	3.966	4.152	4.013	2904.174
4.013	3.999	3.969	4.158	4.014	2929.976
4.014	4.001	3.97	4.161	4.017	2942.395
4.014	4.002	3.972	4.163	4.019	2954.222
4.017	4.002	3.973	4.166	4.02	2969.062
4.019	4.005	3.977	4.172	4.023	2982.422
4.022	4.004	3.978	4.175	4.026	3005.562
4.022	4.005	3.98	4.178	4.028	3013.896
4.025	4.007	3.981	4.179	4.029	3030.416
4.026	4.008	3.984	4.185	4.034	3043.787
4.029	4.011	3.987	4.188	4.037	3055.211
4.031	4.01	3.989	4.191	4.038	3068.18
4.032	4.011	3.989	4.193	4.04	3079.082
4.034	4.011	3.989	4.196	4.041	3088.944

4.035	**4.013**	**3.99**	**4.199**	**4.044**	**3100.353**
4.037	**4.014**	**3.99**	**4.2**	**4.046**	**3110.195**
4.04	**4.014**	**3.994**	**4.205**	**4.05**	**3125.678**
4.043	**4.016**	**3.996**	**4.209**	**4.053**	**3136.092**
4.047	**4.019**	**3.997**	**4.214**	**4.059**	**3153.092**
4.047	**4.019**	**3.999**	**4.215**	**4.061**	**3154.234**
4.05	**4.019**	**3.999**	**4.218**	**4.064**	**3168.453**
4.053	**4.022**	**4.001**	**4.223**	**4.068**	**3181.4**
4.058	**4.023**	**4.004**	**4.226**	**4.073**	**3195.465**
4.061	**4.025**	**4.004**	**4.23**	**4.079**	**3206.883**
4.067	**4.028**	**4.007**	**4.236**	**4.086**	**3229.595**
4.07	**4.028**	**4.01**	**4.236**	**4.089**	**3230.754**
4.071	**4.029**	**4.007**	**4.239**	**4.092**	**3241.149**
4.079	**4.032**	**4.011**	**4.248**	**4.101**	**3265.409**
4.082	**4.034**	**4.011**	**4.25**	**4.106**	**3276.83**
4.085	**4.037**	**4.011**	**4.253**	**4.11**	**3286.673**