2.007 Design and Manufacturing I
Spring 2009

2.007 –Design and Manufacturing I

Sensors and Batteries

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http://www.parallax.com/Portals/0/Images/Prod/2/280/28015-M.jpg
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Dan Frey
with much content provided by Yang Shao-Horn

7 April 2009

Low-dropout Regulator

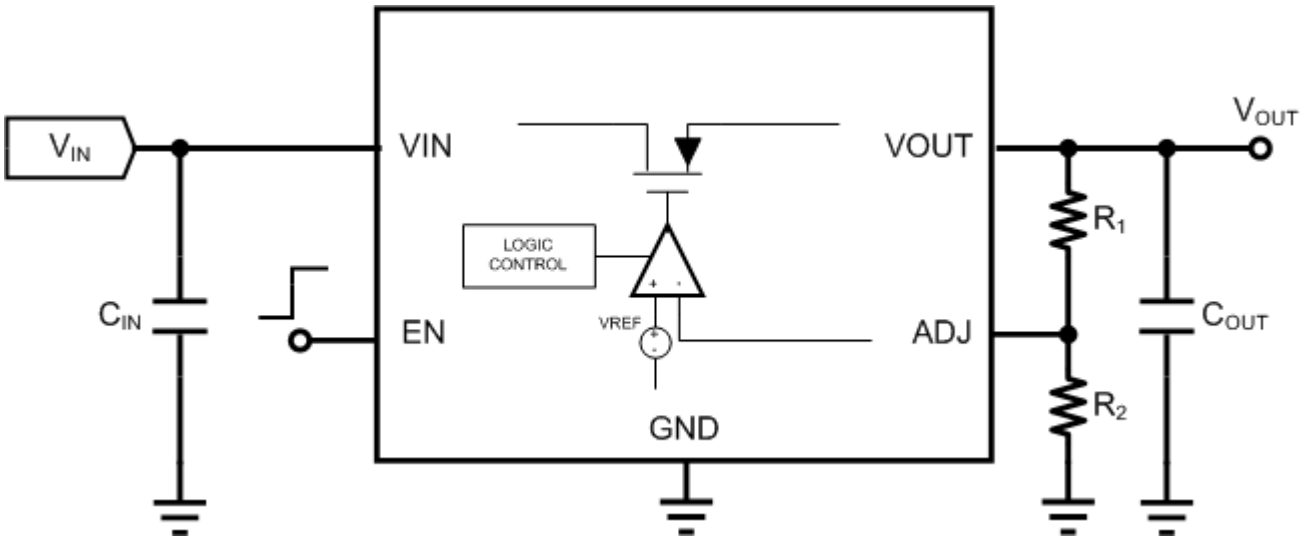

Image from Wikipedia, http://en.wikipedia.org

"…a DC linear voltage regulator which can operate with a very small input–output differential voltage. The main components are a power FET and a differential amplifier (error amplifier). … If the output voltage rises too high relative to the reference voltage, the drive to the power FET changes so as to maintain a constant output voltage."

http://en.wikipedia.org/wiki/Low_dropout_regulator

Sensors

- Contact (mechanical)
- Proximity (optical)
- Range (acoustic)
- Force (piezo)

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Force Measurement

- "piezoresistive"
  - (NOT piezoelectric)

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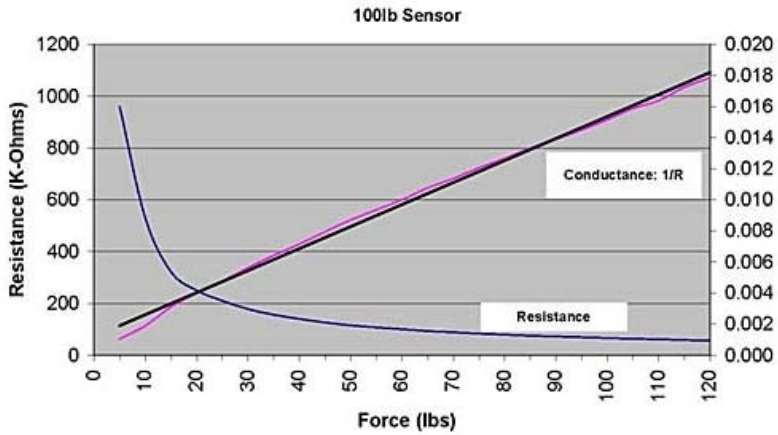
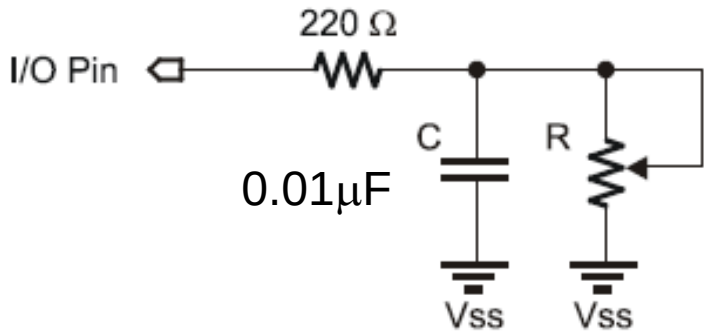
http://www.tekscan.com/pdfs/DatasheetA201.pdf



RCTIME

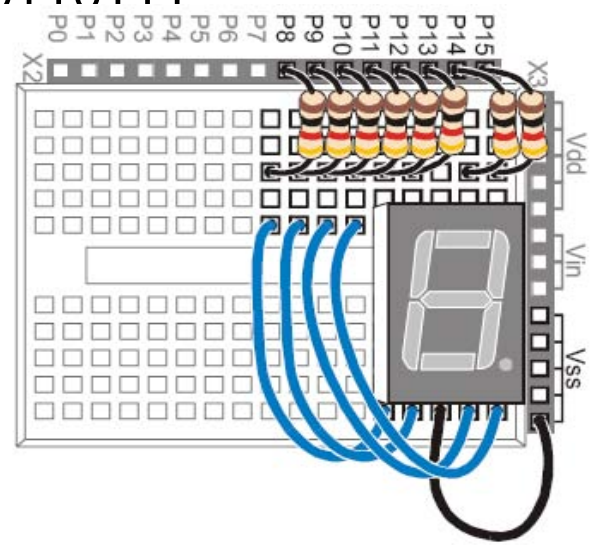



```
RC PIN 0
result VAR Word
DO
HIGH RC ' charge the cap
PAUSE 1 ' for 1 ms
RCTIME RC, 1, result ' measure RC discharge time
DEBUG DEC 30000/result, CR ' display value
PAUSE 5
LOOP
```

Displaying Digits

```
index Var NIB
DIRH = %11111111
DO
FOR index=0 TO 9
LOOKUP index, [ ~ %11100111, ~ %10000100, ~ %11010011,
                ~%11010110,~ %10110100, ~%01110110,
                ~%01110111, ~%11000100, ~%11110111,
                ~%11110110, ~%11110101, ~%00110111
                ~%01100011, ~%10010111, ~ %
                ~%01110001 ], OUTH
PAUSE 1000
NEXT
LOOP
```

NOTE: As we discussed in class, the DIRH command sets the "direction" of the pins (the "high" pins 8-15 for DIRH). This can be done just once before the DO loop.



Acoustic Ranging/Detection

- Ultrasonic pulse
- Distance-to-target is by measuring the time required for echo

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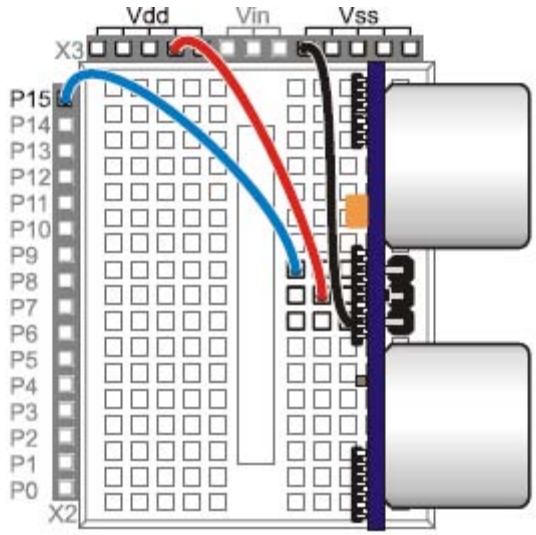
http://www.parallax.com/Portals/0/Images/Prod/2/280/28015-M.jpg
http://www.parallax.com/Portals/0/Downloads/docs/prod/acc/28015-PING-v1.5.pdf

Please see p. 3 in http://www.parallax.com/Portals/0/Downloads/docs/prod/acc/28015-PING-v1.5.pdf

Example Code

```
CmConstant CON 2260
InConstant CON 890
cmDistance VAR Word
inDistance VAR Word
time VAR Word
DO
PULSOUT 15, 5
PULSIN 15, 1, time
cmDistance = cmConstant ** time
inDistance = inConstant ** time
DEBUG HOME, DEC3 cmDistance, "
DEBUG CR, DEC3 inDistance, " in"
PAUSE 100
LOOP
```



NOTE: Here is a point we did not discuss in class: The ** operation is multiplication of a sort, not exponentiation. When you multiply, there is a good chance of overflow since this microcomputer stores nothing larger than a Word. The ** carries out the multiplication and returns the highest 16 bits, rather like a slide rule used to do.

Performance

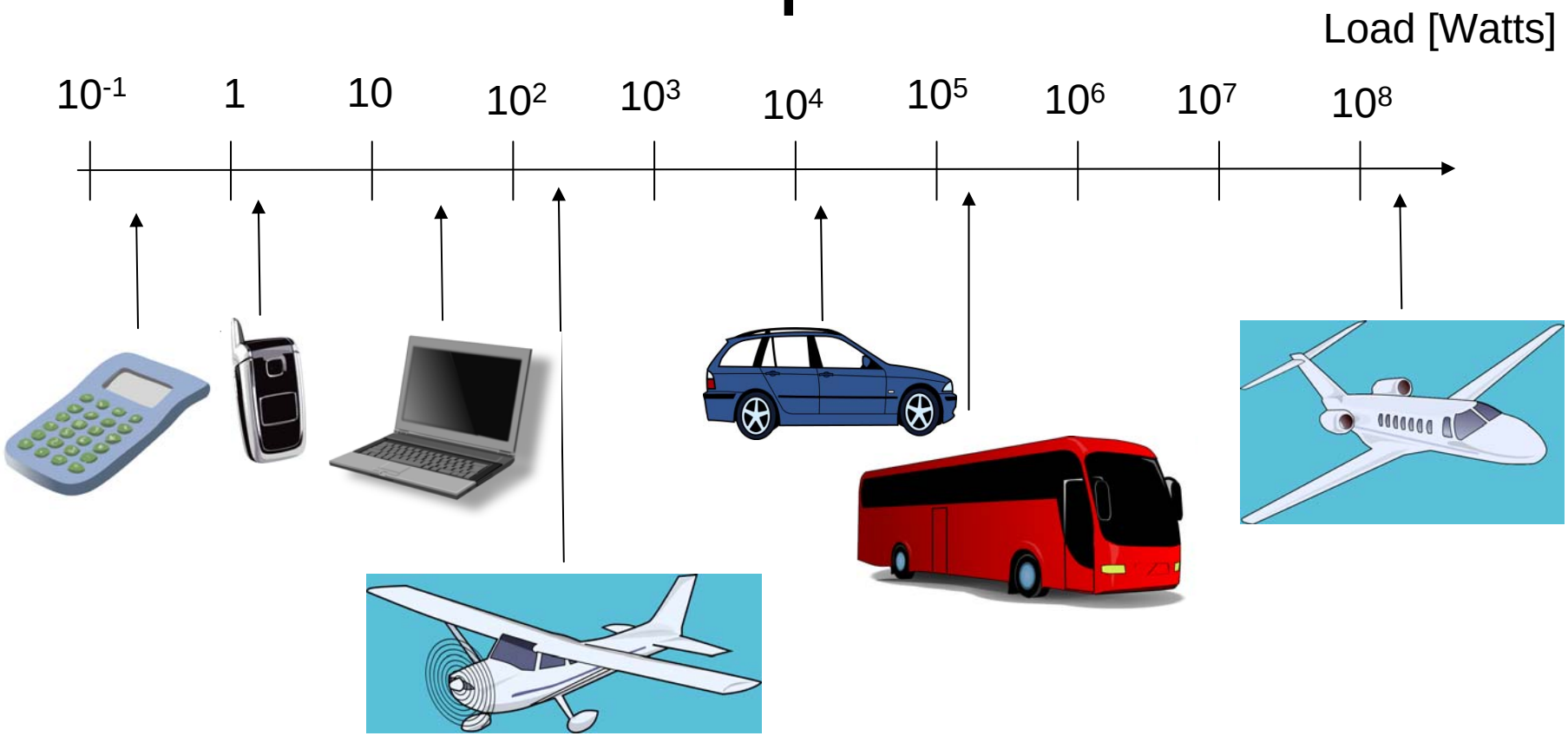
Please see pp. 4-5 in http://www.parallax.com/Portals/0/Downloads/docs/prod/acc/28015-PING-v1.5.pdf

Definition

- Bat·ter·y [Fr. *batterie*, beat]
  - *Milit.* two or more pieces of artillery used for combined action.
  - *Mech.* A set or series of similar machines, parts, or the like.
  - *Elec.* A device for generating or storing electricity consisting of one or more cells.

Excerpted from *New Webster's Dictionary of the English Language*

Power Requirements



Images from the Open Clip Art Library, http://openclipart.org,
and WP Clip Art, http://www.wpclipart.com

Information on the Package

1.5 Ah
4.8V
therefore 26 kJ
weighs 0.12 kg
so a 0.05 kg battery
with the same chemistry
should hold ~ 11 kJ

Image removed due to copyright restrictions. Please see http://www.rcjuampa.com.ar/images/NR4F1500.jpg

The Price of Portability

- The cost of energy from the wall outlet
- ~ $0.10 /kW*hr

- One D cell battery
- ~ $1.00
- 5W*hrs

Roughly a factor of 2000 markup

Considerations in Battery Selection

- Energy density
- Voltage
- Load / current profile
  - Constancy of voltage during discharge
  - Peak current capability
- Temperature profile
- Life
  - Shelf life
  - Service life
  - Cycles of charge / discharge
- Temperature range
- Price / availability

Types of Primary Batteries

Text removed due to copyright restrictions. Please see
http://www.duracell.com/procell/design/comparison.asp

Types of Rechargeable Batteries

Lead-Acid: Good low temperature behavior, good capability to produce high power, heavy

Uses: popular for automotive electrical systems, good high rate performance, generates hydrogen when discharged at very high rates.

Ni Cd: Inexpensive, good capability to produce high power, has some memory effect if lightly used and then recharged

Uses: Hobby cars, planes

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http://s.sears.com/is/image/Sears/02833023000-1
http://www.rcjuampa.com.ar/images/NR4F1500.jpg

Specific Energy of Primary and Secondary Batteries

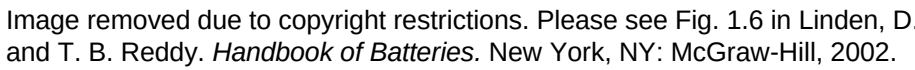


Image removed due to copyright restrictions. Please see Fig. 1.6 in Linden, D., and T. B. Reddy. *Handbook of Batteries.* New York, NY: McGraw-Hill, 2002.

Energy and Power Densities of Batteries

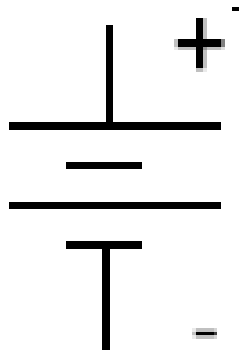
Images removed due to copyright restrictions. Please see
http://www.corrosion-doctors.org/Batteries/images/Fig6rago.gif
And
Fig. 1 in Tarascon, J.-M., and M. Armand. “Issues and Challenges Facing Rechargeable Lithium Batteries.” *Nature* 414 (November 2001): 359-367.

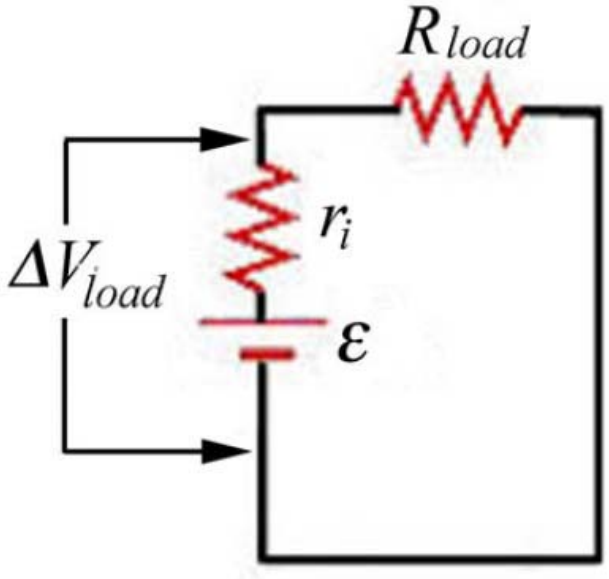
Typical Spec Sheets

Text removed due to copyright restrictions. Please see
http://www.duracell.com/oem/Pdf/Mn1604.pdf

Evaluating the Concept of "Internal Resistance"

- If a battery were well modeled by a voltage source and internal resistance, what behaviors should I observe?



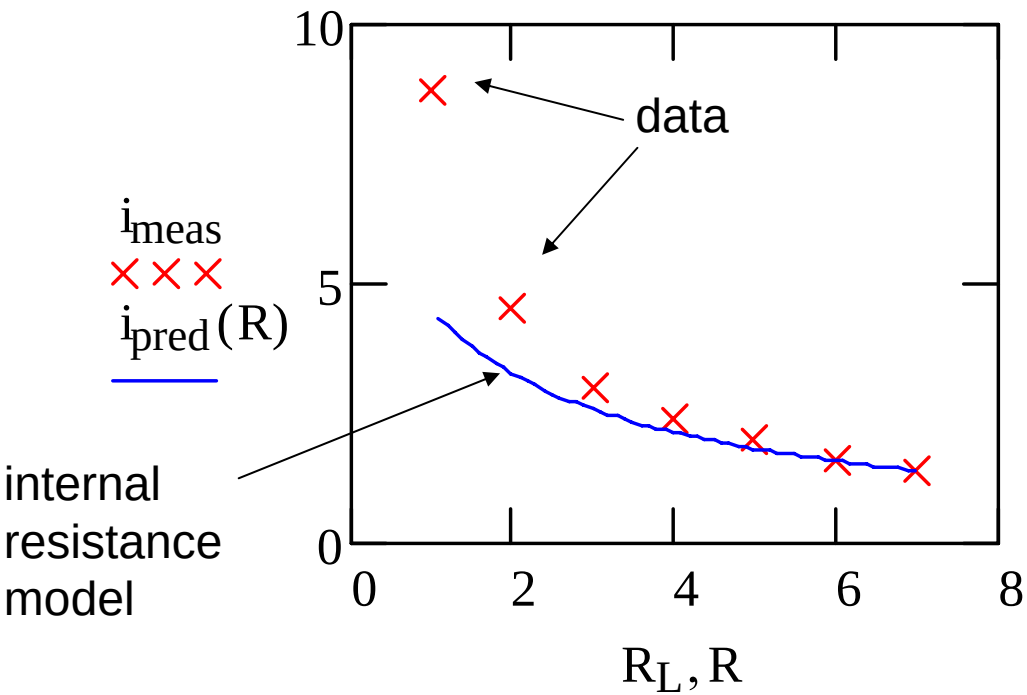


NOTE: I suppose we would observe that as current rises, the drop in terminal voltage will be linearly proportional to the current. E.g. if 1 amp causes a 0.8V drop, a 2 amp current will cause a 1.6V drop. But that's not what happens exactly.

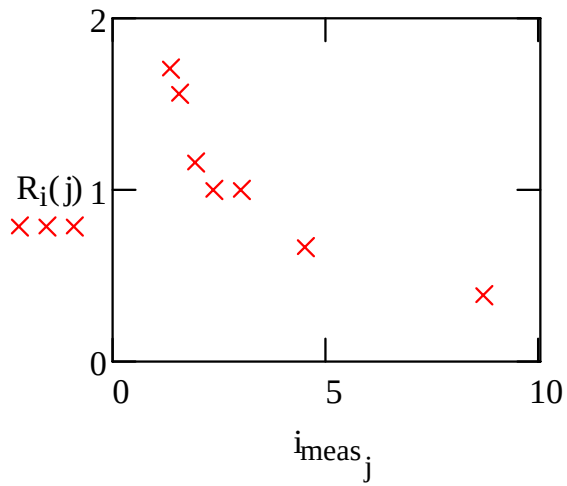
Current versus Externally Applied Load

- I used a NiCd battery pack
- I discharged it across a (physically) big variable resistance

The model can't fit the data well



Or else the model must include a resistance that is a function of current



Other Effects Poorly Modeled by Equivalent Circuit

- Increased temperature
  - Increases open circuit voltage
  - Lowers “internal resistance”
- Degree of discharge
  - More discharge decreases open circuit voltage
  - Raises “internal resistance”

A Better Way to Understand a Battery

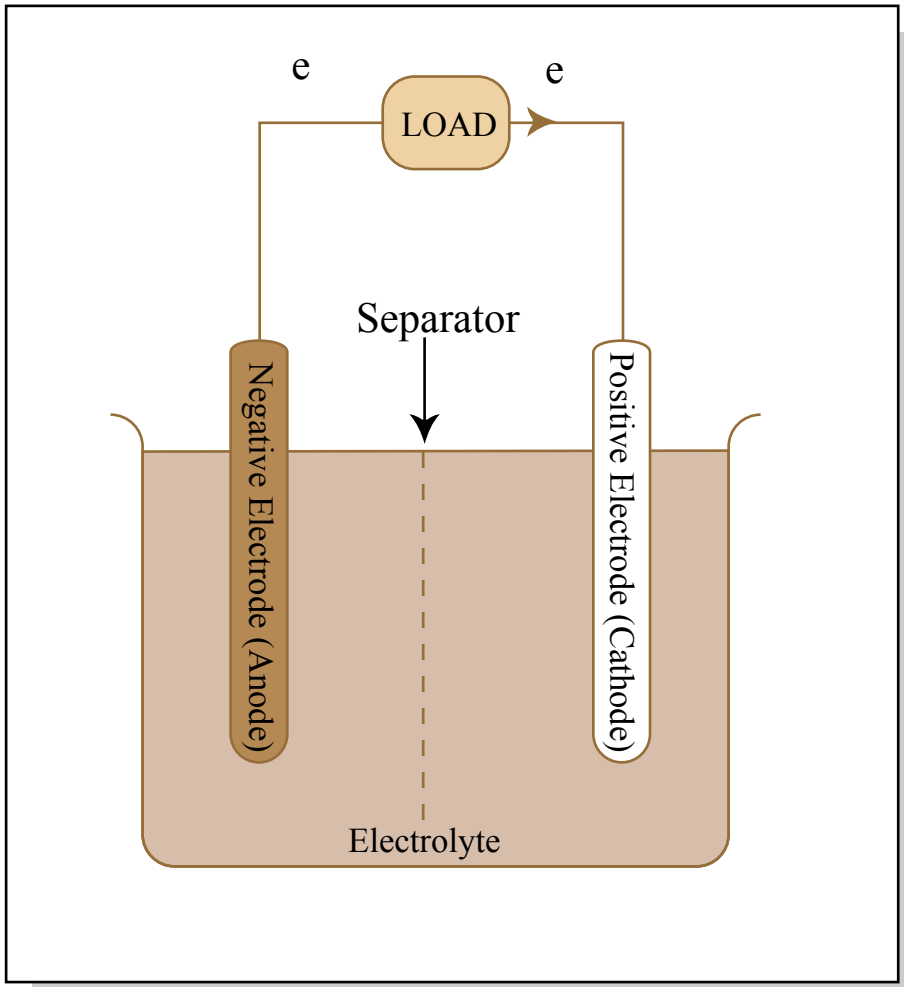


Figure by MIT OpenCourseWare.

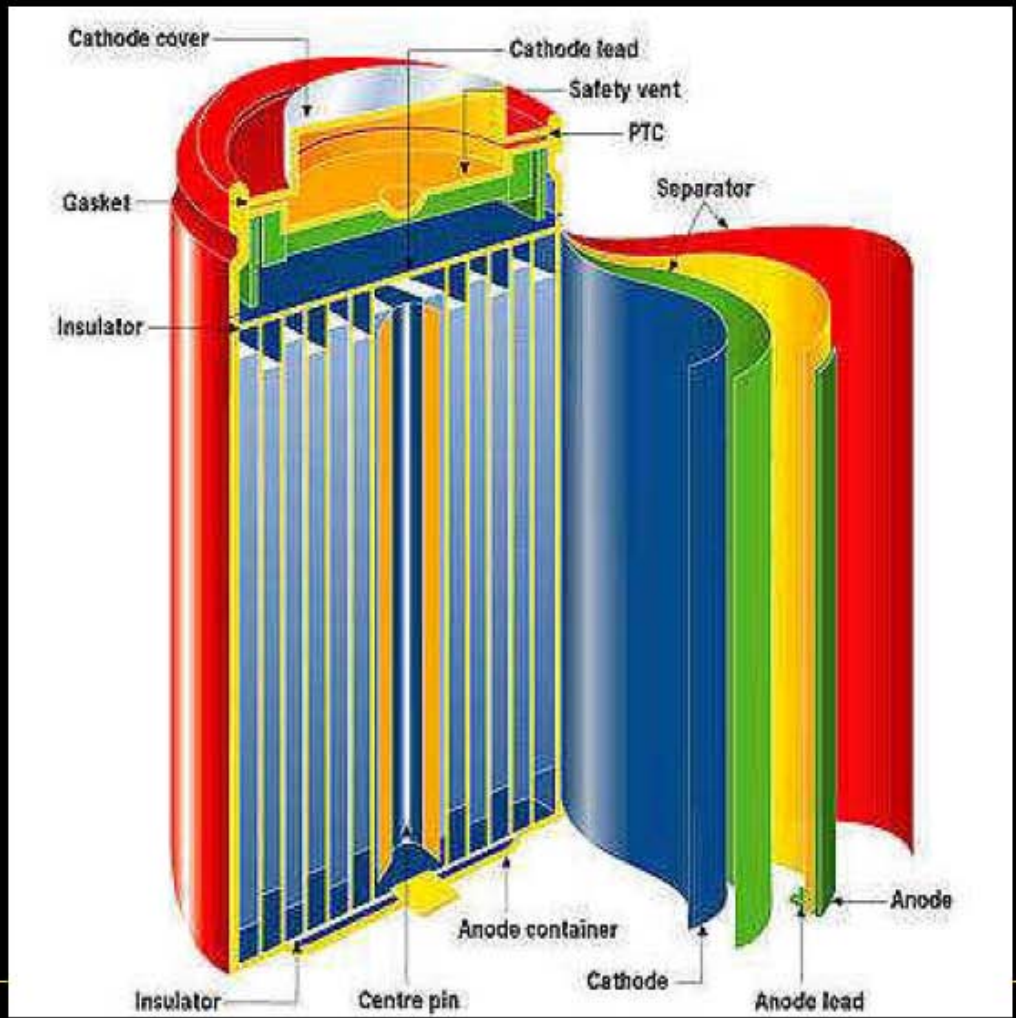
Factors that Actually Determine the Voltage vs Current Curve

- Resistance of the anode and cathode
- Reaction rate (a function of concentration and temperature)
- Rate of solid diffusion

Bobbin Construction

Image courtesy of Mcy_jerry at Wikipedia.

Jellyroll Construction



Causes of Inefficiency in Battery Operation

- Self discharge – side reactions that do not contribute to the production of current
- Passivation / dendritic deposition – influences on the surfaces of the electrodes that reduce voltage produced

Advantages / Disadvantages of Lead Acid Batteries

Advantages

- Low cost
- Available is many sizes (1Ah to >1000 Ah)
- Good performance at high rate
- Efficient ~ 70%
- High cell voltage
- Easily recycled

Disadvantages

- Low cycle life (50-500 cycles)
- Low energy density (30-40 Wh/kg)
- Poor long term storage in discharged state
- Hydrogen evolution (risk of explosion)

Image removed due to copyright restrictions. Please see http://s.sears.com/is/image/Sears/02833023000-1

Advantages / Disadvantages of Ni-Cd Batteries

Advantages

- Widely available
- Long cycle life (>1000 cycles if carefully maintained)
- Fast charge capability (C/3 to 4C with temperature monitoring)
- Low self-discharge (10% first day than 10%/month)
- Excellent long term storage

Disadvantages

- Low energy density (~40 Wh/kg)
- Memory effect
  - Overcome by deep discharge (to 1.1V)

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Sanyo KR-350 cells
(if 8cells, 3A max discharge, 350mAh in 3.8 oz.)

Advantages / Disadvantages of Ni-MH Batteries

Advantages

- Higher capacity than Ni-Cd
- Cd free
- Long cycle life
- Long shelf life

Disadvantages

- High rate performance not as good as Ni-Cd
- Poor charge retention
- Higher cost

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Advantages / Disadvantages of Rechargeable Lithium Batteries

Advantages

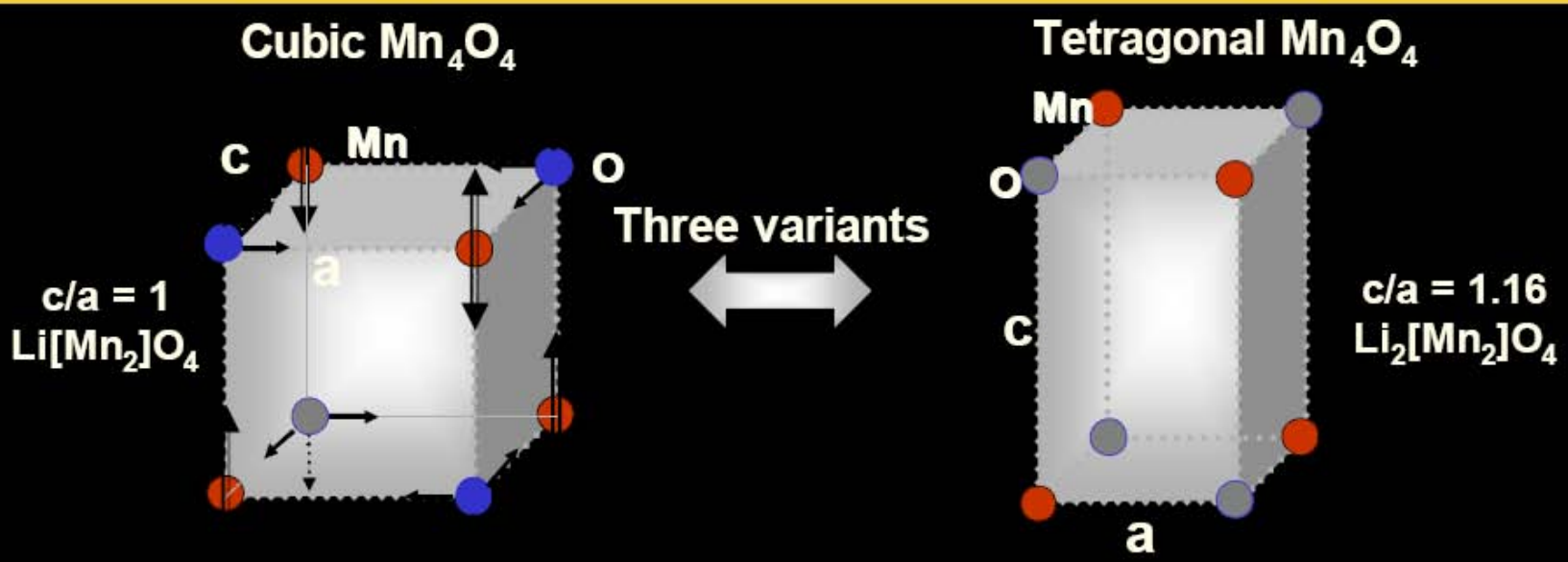
- High energy density
- High cell voltage
- Long charge retention

Disadvantages

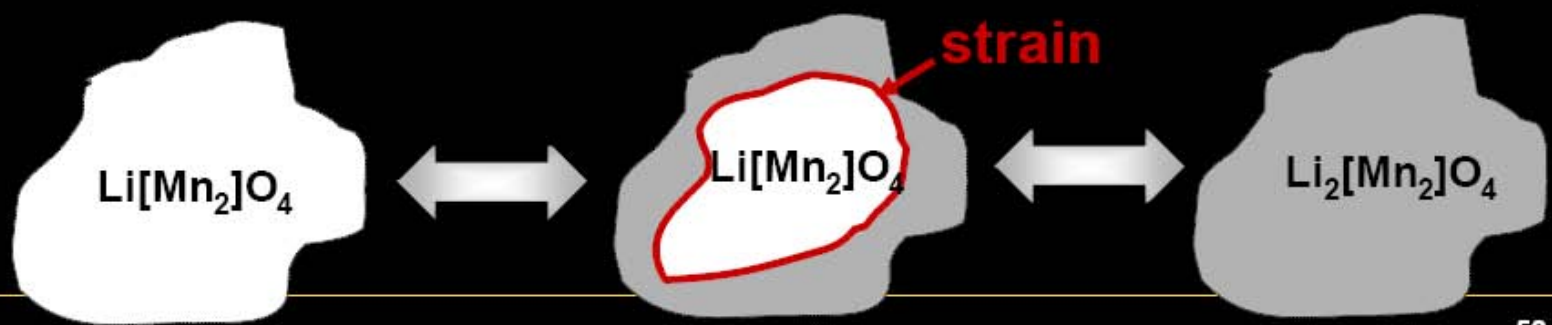
- High cost
- Low cycle life
- Capacity fading
- Potential safety / environmental issues

Please see http://www.hobby-lobby.com/enerland-lipoly-batteries.htm

The Cubic <=> Tetragonal Phase Transformation

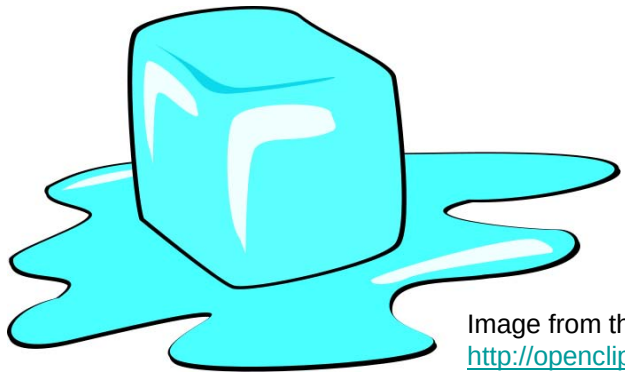


Microscopic view – Structural fatigue



Courtesy Yang Shao-Horn. Used with permission.

Energy and Phase Change



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LiPo batteries

730mAh

7.4V

19kJ

34gr

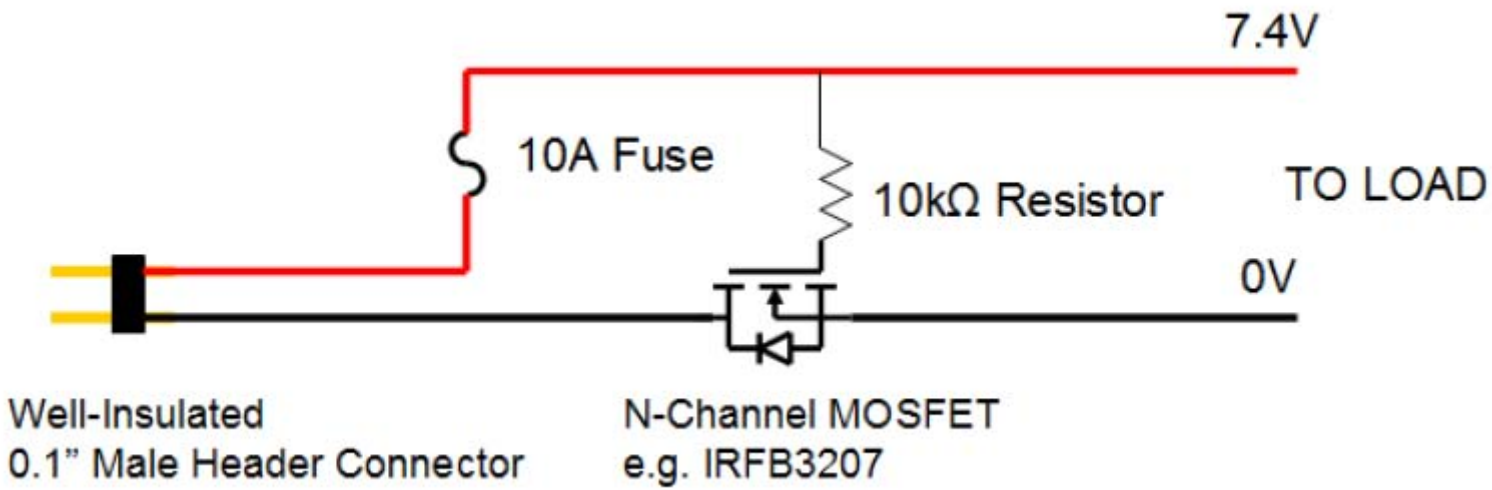
Ice Cube

34gr = a somewhat large cube ~3cm per side

80 cal or 330 J per gram to melt

10kJ

Circuit for 2.007 LiPo Batteries



Next Steps

- Wednesday 8 April
  - HW#3 due (one day extension)
  - Evening hours in the lab
- Thursday 9 April
  - No lecture
  - Lab times that day instead
  - Evening hours in the lab
- Tuesday 14 April
  - Lecture on belts, chains, and cams
- Thursday 16 April
  - Exam #2