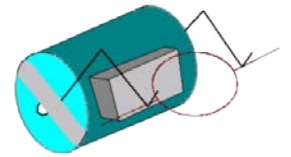Build this simple motor

BEAKMAN'S WORLD

Electronic Instrumentation

Project 1: Beakman's Motor

- Part A: Background

- Part B: Building the Basic Motor

- Part C: Designing an Improved Motor

- Part D: Building and Testing an Improved Motor

Beakman's Motor

- Projects are done in teams of 4
  - Work together
    - Divide up the work
    - Have at least one person start on the report on the first day, the report boss
  - Plan on rotating tasks for each project
    - The report boss is a different person for each project
  - This project requires the building of several coils
    - Let each member make at least one and test their own
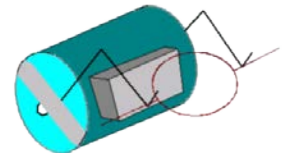
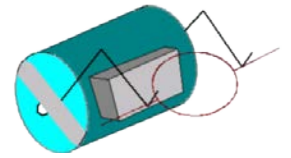# *Electromagnetic Revolution*

$$\nabla \cdot \vec{D} = \rho$$
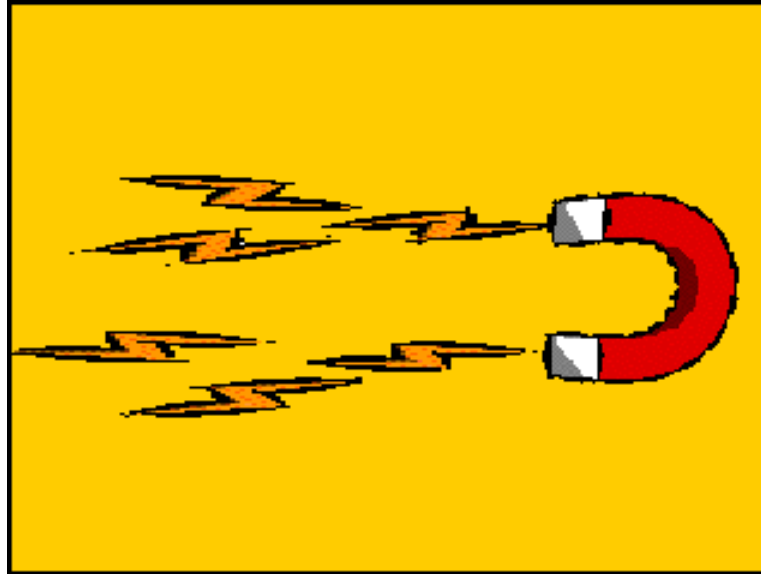
$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

- These four equations epitomize the electromagnetic revolution. Richard Feynman claimed that "ten thousand years from now, there can be little doubt that the most significant event of the 19th century will be judged as Maxwell's discovery of the laws of electrodynamics"
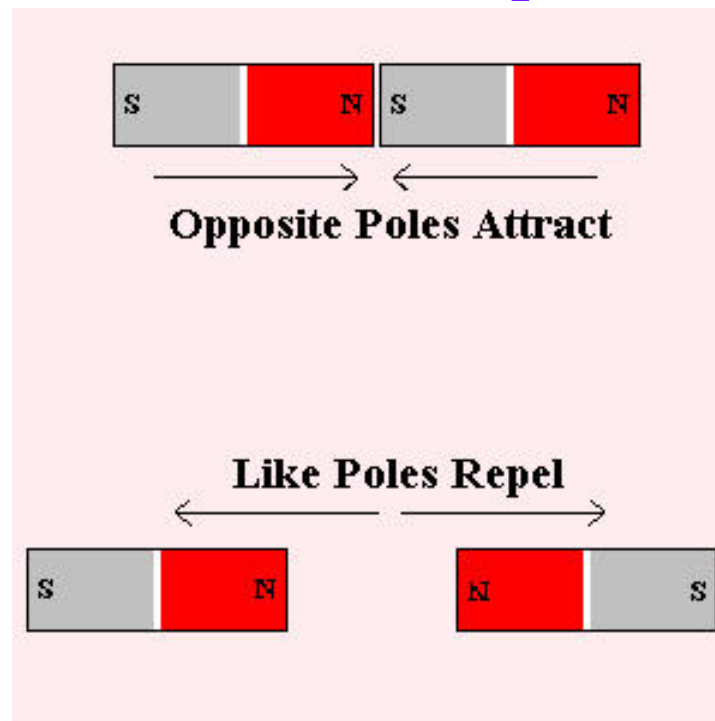
Magnetic Attraction

- It is possible to produce motion using magnetic attraction and/or repulsion

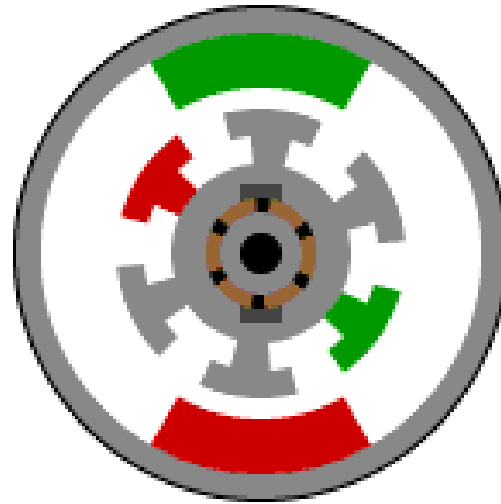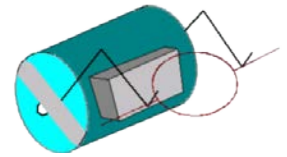- Either permanent magnets or electromagnets or both can be used
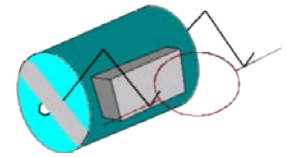
Magnetic Attraction and Repulsion



Opposite Poles Attract

Like Poles Repel

- ◆ One of the many facts we all recall from our earliest science education

DC Motors

- Opposite magnetic poles are shown in red and green.
- As the motor rotates, the commutator causes the three electromagnets to turn on one at a time.
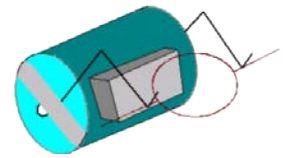- The magnetic attraction between the stationary magnet and the active electromagnet causes the motor to move.

Beakman's Motor
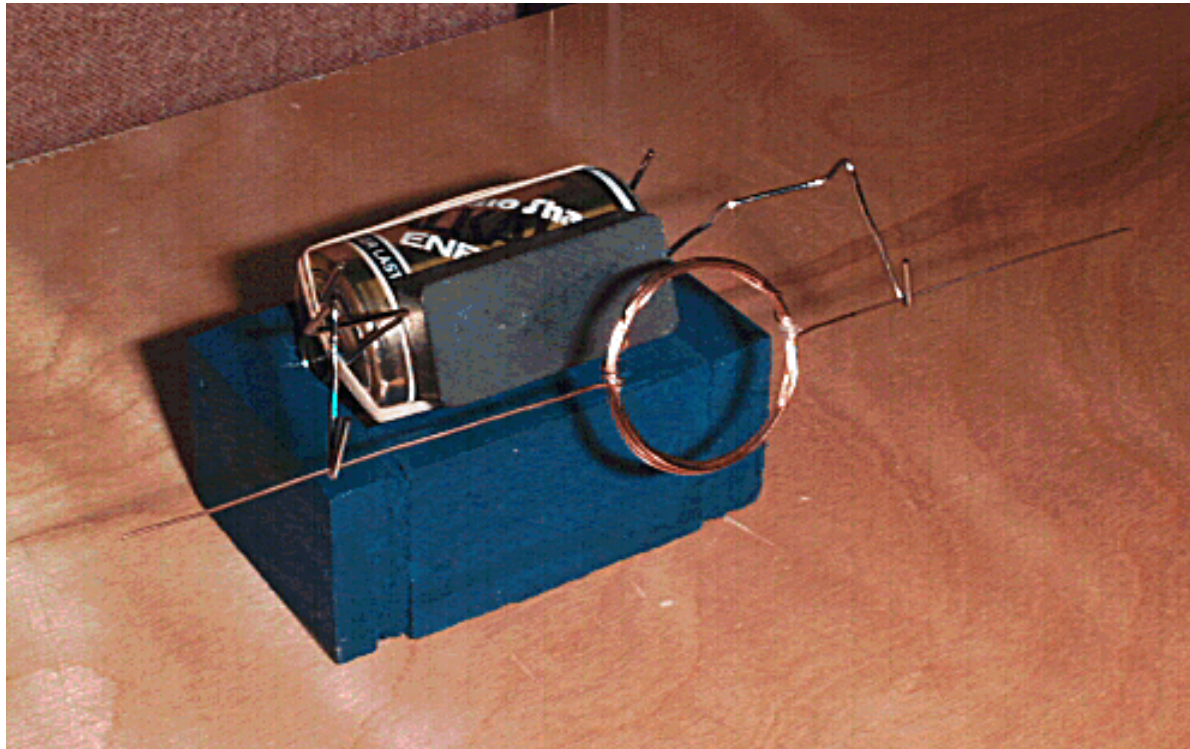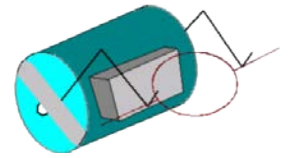
- ◆ A simple DC motor with brushes made with a battery, two paperclips, a rubber band and about 1 meter of enameled wire.
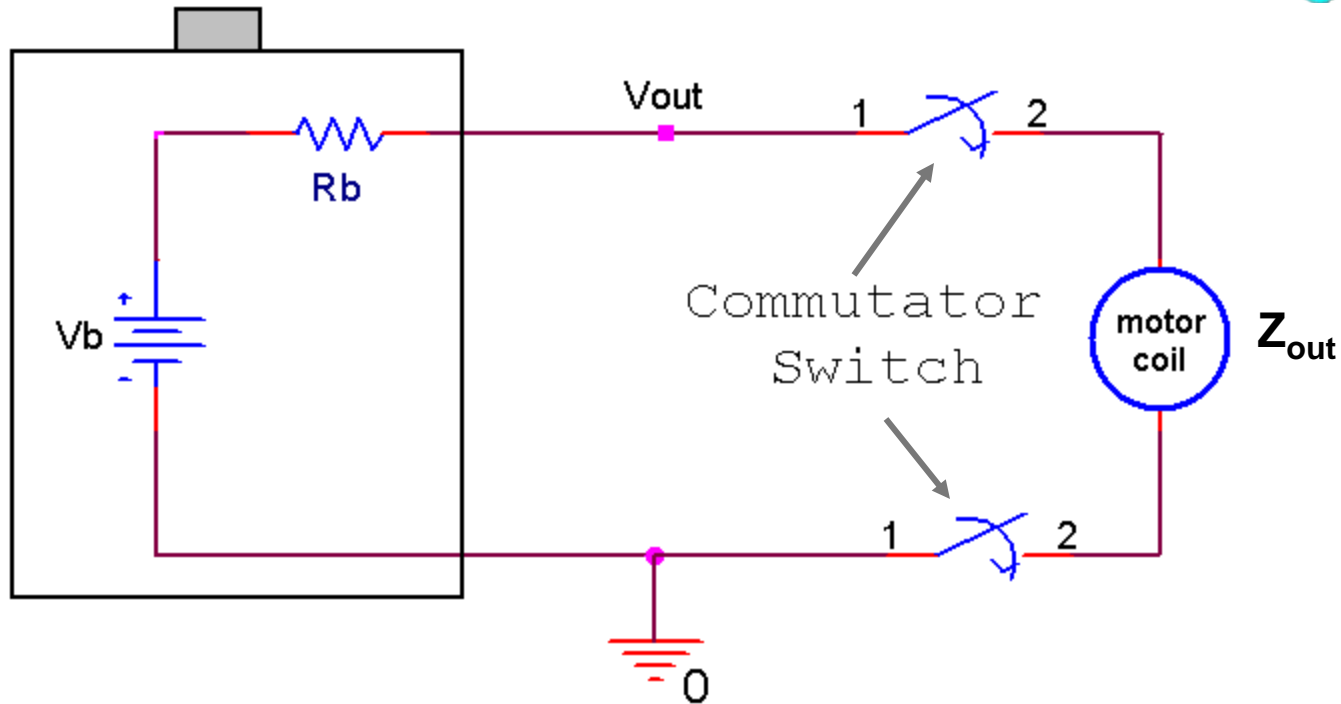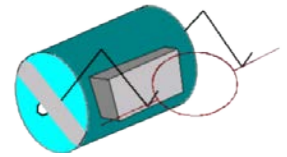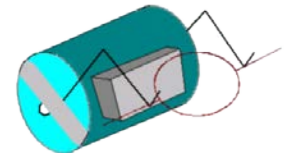
Beakman's World Movie
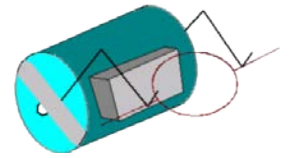
Materials

- One D-Cell Battery **(Supply your own – fresh batteries provide more power.)**

- One Wide Rubber Band

- Two Large Paper Clips

- One or Two Circular Ceramic Magnets

- Magnet Wire (the kind with enamel insulation)

- One Toilet Paper Tube (or PVC pipe)

- Fine Sandpaper and rubber mat for sanding surface
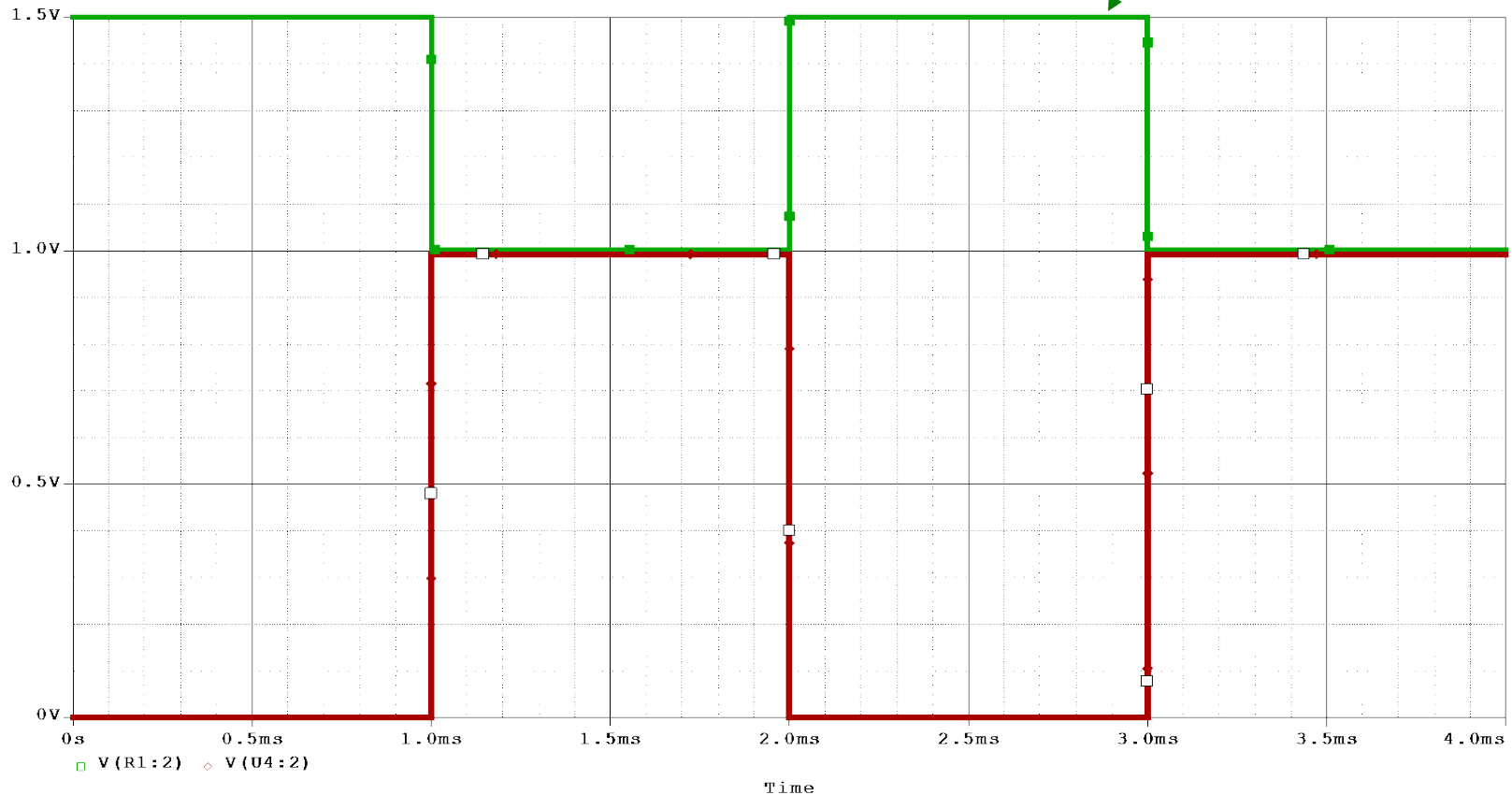
Measuring the Speed

As the coil rotates, it connects to the power supply about half the time. When this occurs, the voltage measured at the battery or power supply will drop (voltage divider action). Thus, a series of pulses will be observed, which can be used to determine the frequency of revolution.
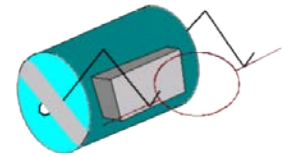
Measuring the Speed

◆ Voltage measured across the battery

Measuring the Speed

◆ Good data should show consistent pulses. Note that the duty cycle is still not good in this case.

◆ Poor data shows erratic contact is being made

Battery Resistance

Rbattery

Vbattery

R
100

Rmultimeter
10MEG

0

Rbattery

Vbattery

Rmultimeter
10MEG

0
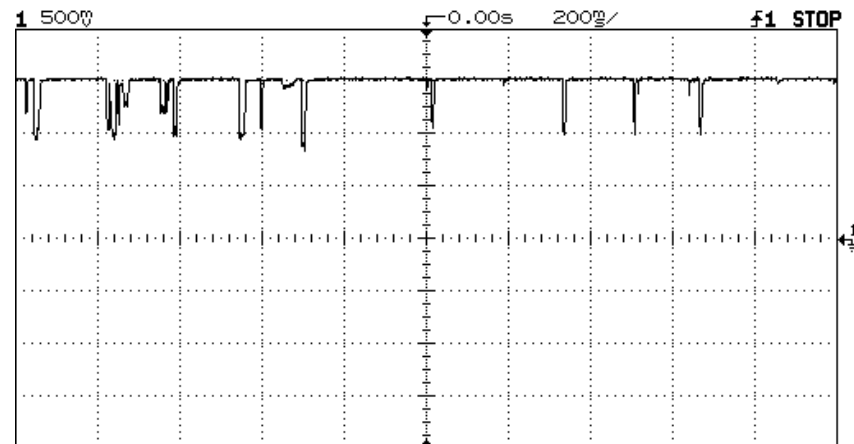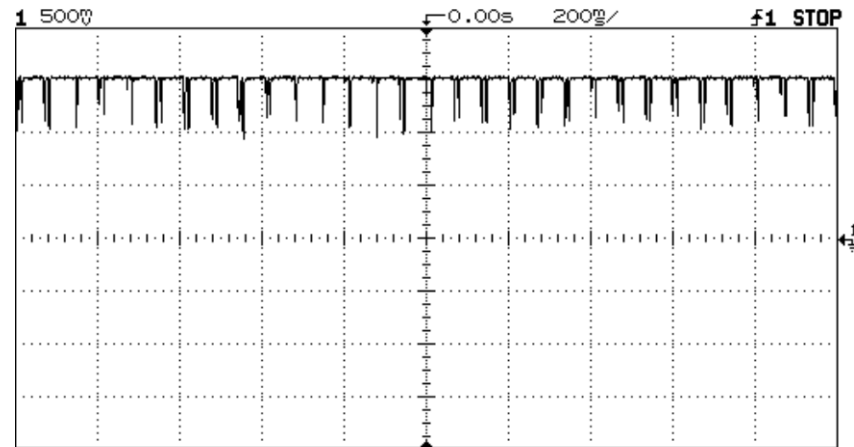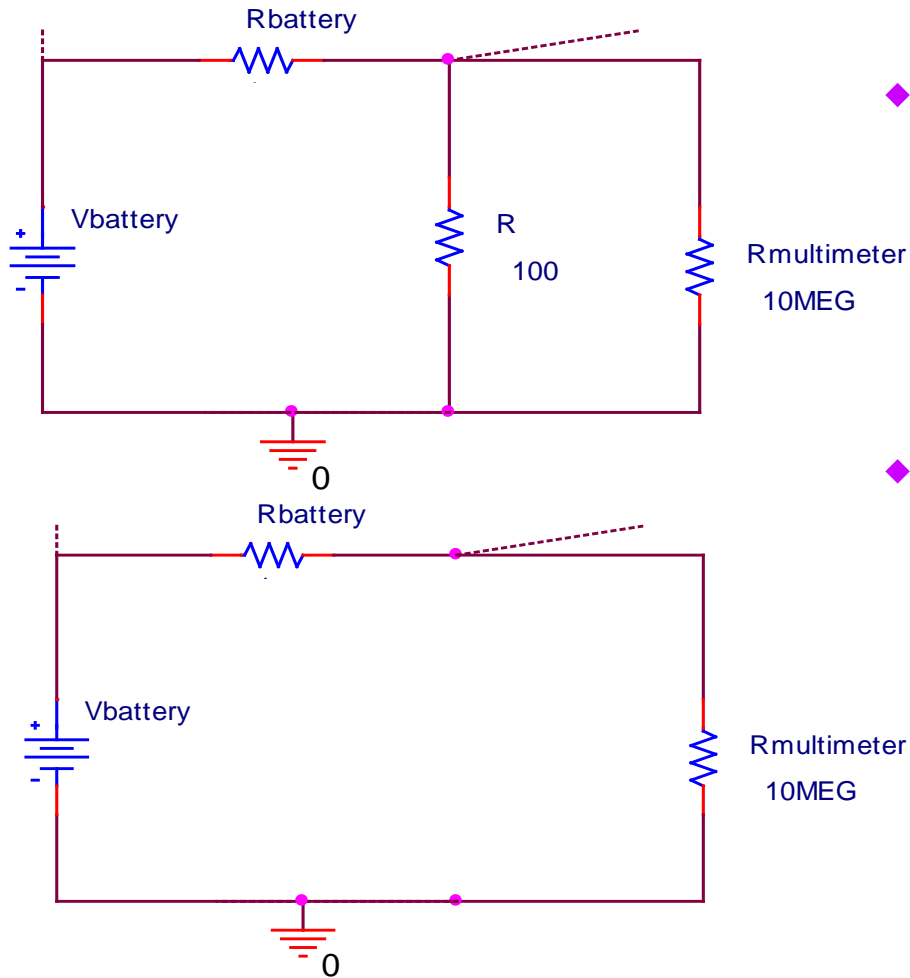
- ◆ Just like the function generator, batteries all have some kind of internal impedance.

- ◆ By connecting the battery to a known resistor and measuring the resulting voltage, it is possible to determine the internal resistance.
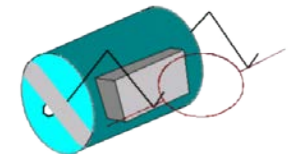
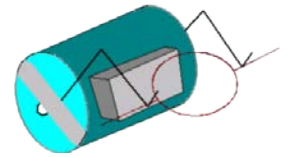| Type	R_{int} (Ω)	V_{oc} (V)	Capacity[a] continuous, to 1V/cell				Size (in)	Weight (gm)	Connec[b]	Comments
			(mAh)	@ (mA)	(mAh)	@ (mA)				
9V "1604"										
Le Clanche	35	9	300	1	160	10	0.65x1x1.9	35	S	
Heavy Duty	35	9	400	1	180	10	"	40	S	
Alkaline	2	9	500	1	470	10	"	55	S	280mAh@100mA
Lithium	18	9	1000	25	950	80	"	38	S	Kodak Li-MnO$_2$
1.5V Alkaline										
D	0.1	1.5	10000	10	8000	100	1.3Dx2.2L	125	B	4000mAh @ 1A
C	0.2	1.5	4500	10	3200	100	1.0Dx1.8L	64	B	
AA	0.4	1.5	1400	10	1000	100	0.55Dx1.9L	22	B	
AAA	0.6	1.5	600	10	400	100	0.4Dx1.7L	12	B	
Mercury										
625	–	1.35	250[c]	1	250[c]	10	0.62Dx0.24L	4	B	
675	10	1.35	190[c]	0.2	–	–	0.64Dx0.21L	2.6	B	
431	–	11.2	1000[c]	25	–	–	1.0Dx2.9L	115	S	
Silver										
76	10	1.55	180	1	–	–	0.46Dx0.21L	2.2	B	
Li-Oxyhalide										
D	–	3.9	14000[d]	175	10500[d]	350	1.3Dx2.3L	113	B,T	SOCl$_2$/BrCl
D	–	3.95	14000[d]	175	12000[d]	1000	"	110	B,T	SO$_2$Cl$_2$/Cl$_2$
D	–	3.5	9500[d]	175	8500[d]	1000	"	120	B,T	SOCl$_2$
Li solid	–	4.0	350[d]	1µA	175[d]	0.1	1.2Dx0.23L	16	T	high impedance
Ni-Cd										
D	0.009	1.3	4000[c]	800	3500[c]	4000	1.3Dx2.3L	130	B	Saft/Powersonic
9V	0.84	8.1	100[c]	10			0.65x1x1.9	35	S	

Note

http://hibp.ecse.rpi.edu/~connor/education/EIspecs/batteries.pdf

Task List

- Build the basic motor
  - Demonstrate that it will run for at least 30 seconds
  - Take data that verifies the rpm of the motor
  - Take data on the components of the system
- Improve the motor design, build and test it
  - Demonstrate that the motor works for at least 30 seconds without springs
  - Demonstrate that the motor works for at least 30 seconds with springs (hands and no hands).
  - Take data that verifies the rpm of the motor for all cases
 - Take data on the components of the new system
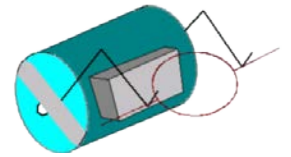
Building a Better Motor

- Coil diameter.
- Number of turns in coil.
- Shape and stability of paper clip cradle (but no loops).
- Gauge of wire
- Shape of coil
- Proximity to magnet
- Coil balance
- Coil weight
- Springs to hold coil in cradle

Springs
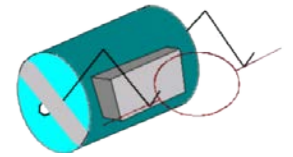
- Start by using a piece of wire to hold the coil into the cradle (hand-held springs).

- Build mechanical springs to do the same type of thing without human intervention.

- Springs cannot be part of the circuit. They cannot conduct electricity.

- Examples of springs:
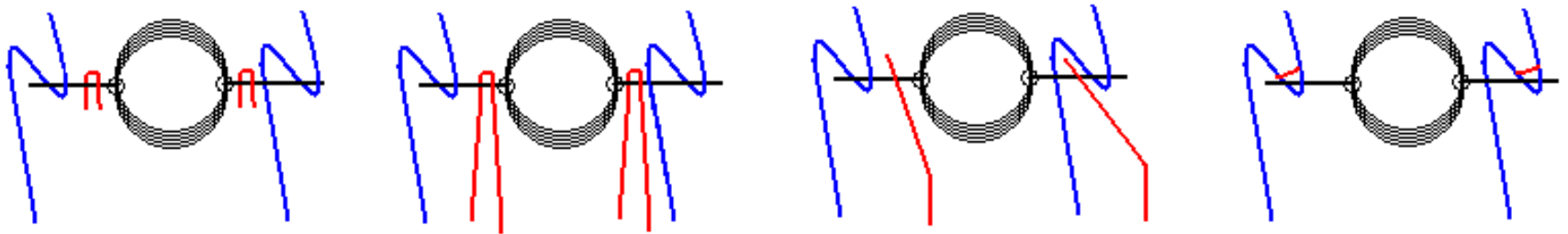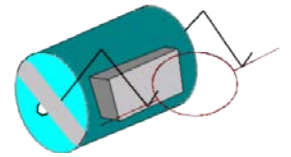
Project 1 Requirements

- Motors must be built using a 1.5 volt battery or 1.5 Volts DC from the power supply (JEC 4107 only.)

- You must use the magnet wire and magnets available in the studio.

- Supports, cradles, must be made from paper clips

- The cradles must have one open end, cannot have any complete loops.

- No more than 2 magnets & the magnets must be the ones supplied.

- You can use/find/make something to support the battery and/or the cradles

- Springs must either be made of non-conducting material or not connected to source.
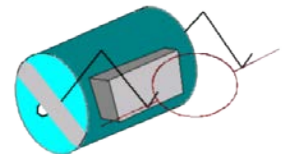
Project 1 Requirements

- You cannot use your hands to hold the mechanical spring or hold the motor in the cradle. That is, you cannot touch the motor during its test.

- You cannot use creative sanding to create a double duty cycle.

- Your motor must run for 30 seconds.

- Use the rubber mats for sanding. Students caught sanding tables lose 1000 points each time.
  - well maybe a little less than 1000, but just don't do it.

- Clean up. Be careful not to drop long thin wires on the floor, they ruin the vacuum cleaners. Groups that leave their areas in a mess will lose 1-1000 points each time.
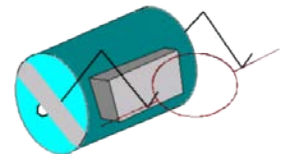
Extra Credit Opportunities

- Exceptionally creative approaches to implementation or in the final design
- If your motor is one of the fastest in the section, you will be eligible for a few additional points
- Engineering problems are often solved by experimenting with different types of configurations, finding which changes have the most positive effects, and systematically choosing a course of action based on those experiments. Present a systematic approach to finding a great design and you are eligible for extra credit.

Additional Topics of Interest
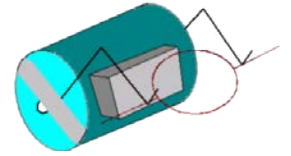
- Magnetism
  - Early Compass
  - Levitation
- Motors
  - DC Motors
  - Brushless DC Motors
  - Stepper Motors
- MEMS
- Battery Information
- Beakman's Motor Links
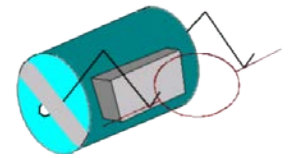
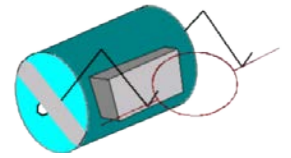## *Magnetism*

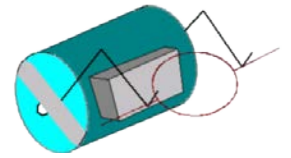- One of the first compasses, a fish shaped iron leaf was mentioned in the Wu Ching Tsung Yao written in 1040
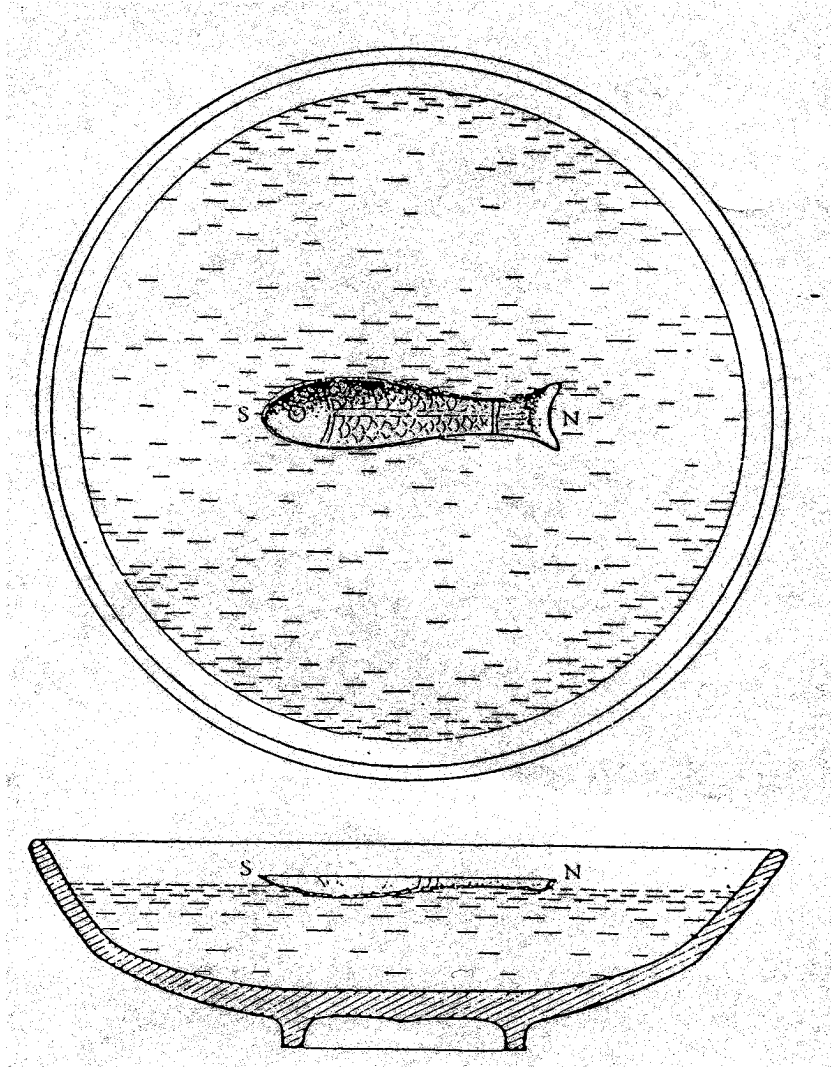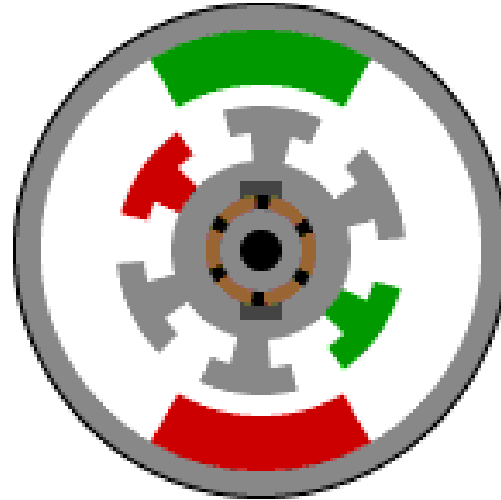
Trinity College, Dublin

Animal Magnetism

- A frog suspended in an intense magnetic field – all of us are paramagnetic
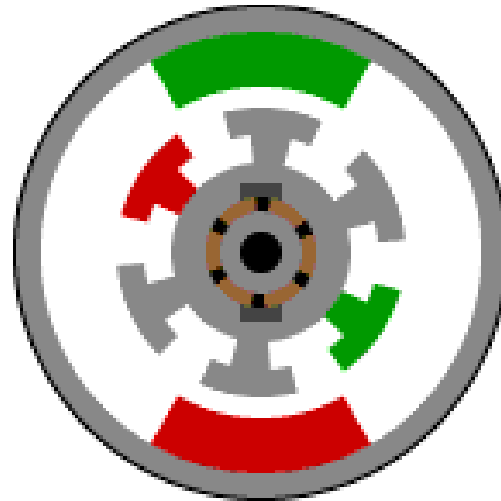- Much money is wasted on magnetic therapy

DC Motors

- The stator is the stationary outside part of a motor. The rotor is the inner part which rotates. In the motor animations, red represents a magnet or winding with a north polarization, while green represents a magnet or winding with a south polarization. Opposite, red and green, polarities attract.
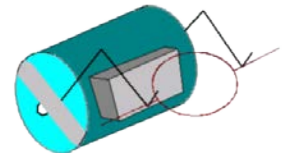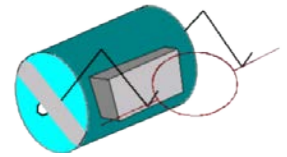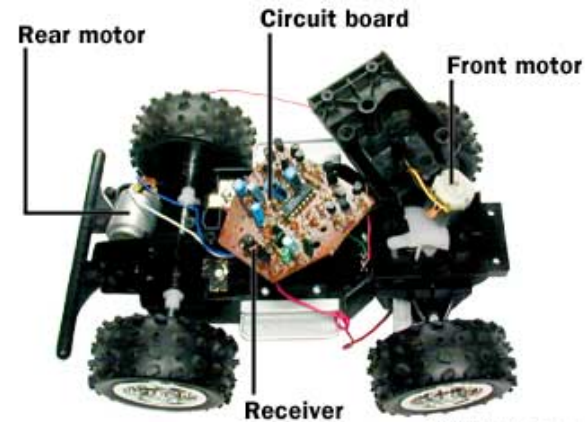
DC Motors

♦ Just as the rotor reaches alignment, the brushes move across the commutator contacts and energize the next winding. In the animation the commutator contacts are brown and the brushes are dark grey. A yellow spark shows when the brushes switch to the next winding.

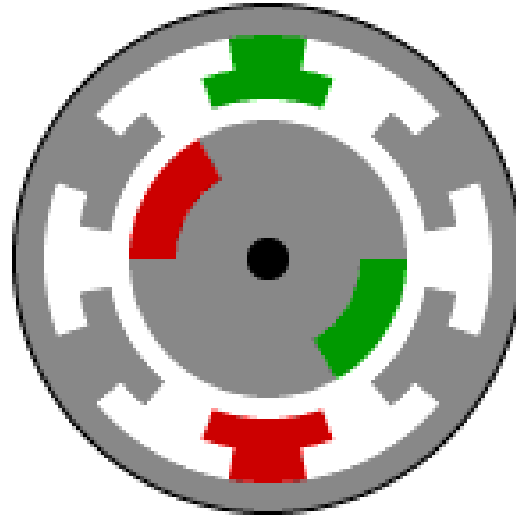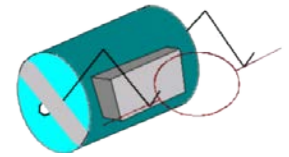# *DC Motor Applications*

- ◆ Automobiles
  - Windshield Wipers
  - Door locks
  - Window lifts
  - Antenna retractor
  - Seat adjust
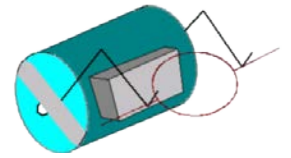 - Mirror adjust
  - Anti-lock Braking System

- Cordless hand drill
- Electric lawnmower
- Fans
- Toys
- Electric toothbrush
- Servo Motor

Brushless DC Motors

- A brushless dc motor has a rotor with permanent magnets and a stator with windings. It is essentially a dc motor turned inside out. The control electronics replace the function of the commutator and energize the proper winding.
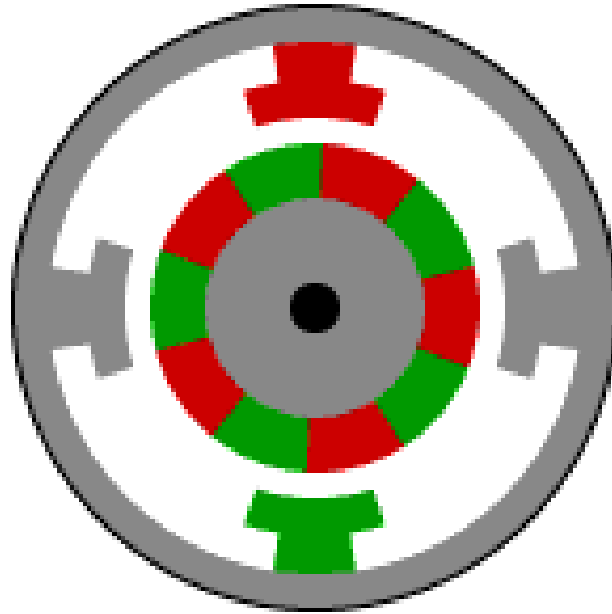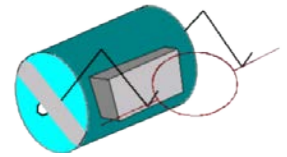
Brushless DC Motor Applications

- Medical: centrifuges, arthroscopic surgical tools, respirators, dental surgical tools, and organ transport pump systems

- Model airplanes, cars, boats, helicopters

- Microscopes

- Tape drives and winders

- Artificial heart


©2000 Texas Heart® Institute
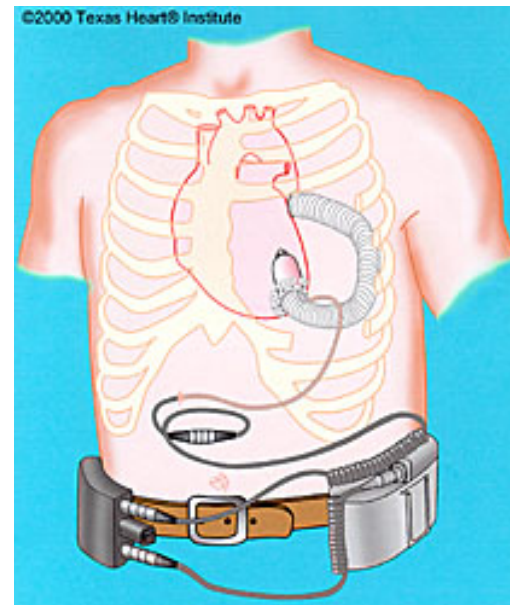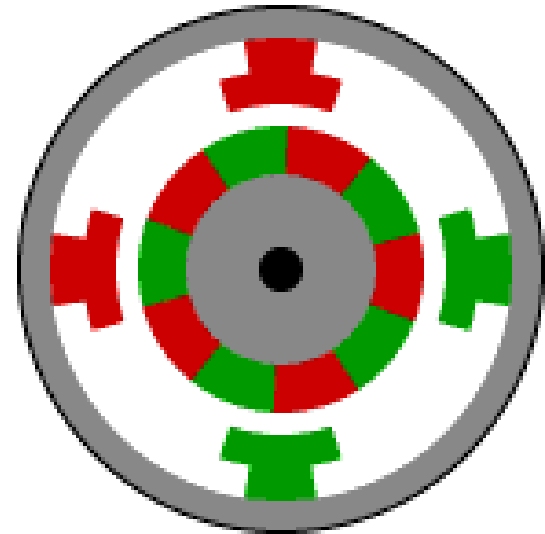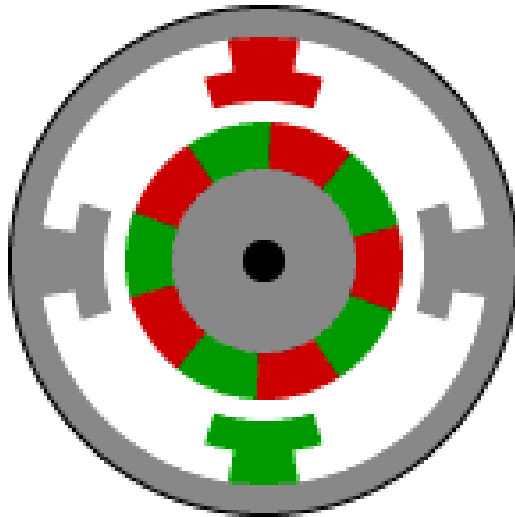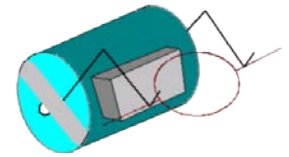
Full Stepper Motor

- ◆ This animation demonstrates the principle for a stepper motor using full step commutation. The rotor of a permanent magnet stepper motor consists of permanent magnets and the stator has two pairs of windings. Just as the rotor aligns with one of the stator poles, the second phase is energized. The two phases alternate on and off and also reverse polarity. There are four steps. One phase lags the other phase by one step. This is equivalent to one forth of an electrical cycle or 90°.
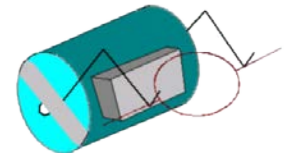
Half Stepper Motor
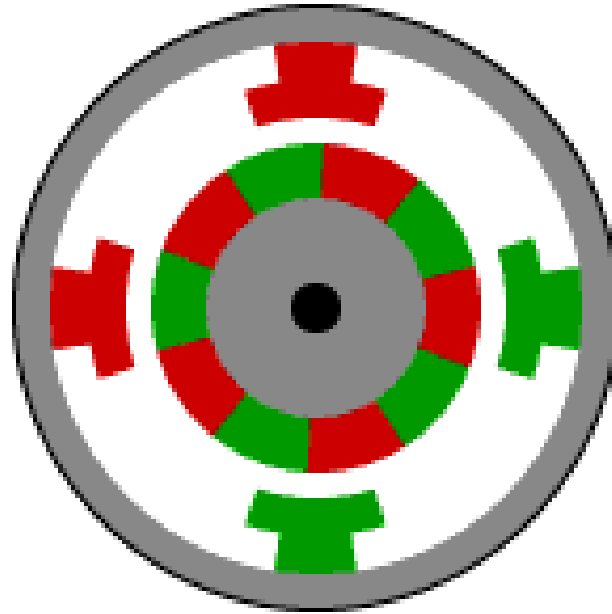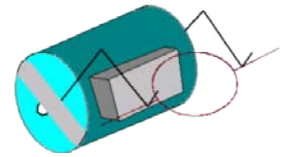
- This animation shows the stepping pattern for a half-step stepper motor. The commutation sequence for a half-step stepper motor has eight steps instead of four. The main difference is that the second phase is turned on before the first phase is turned off. Thus, sometimes both phases are energized at the same time. During the half-steps the rotor is held in between the two full-step positions. A half-step motor has twice the resolution of a full step motor. It is very popular for this reason.
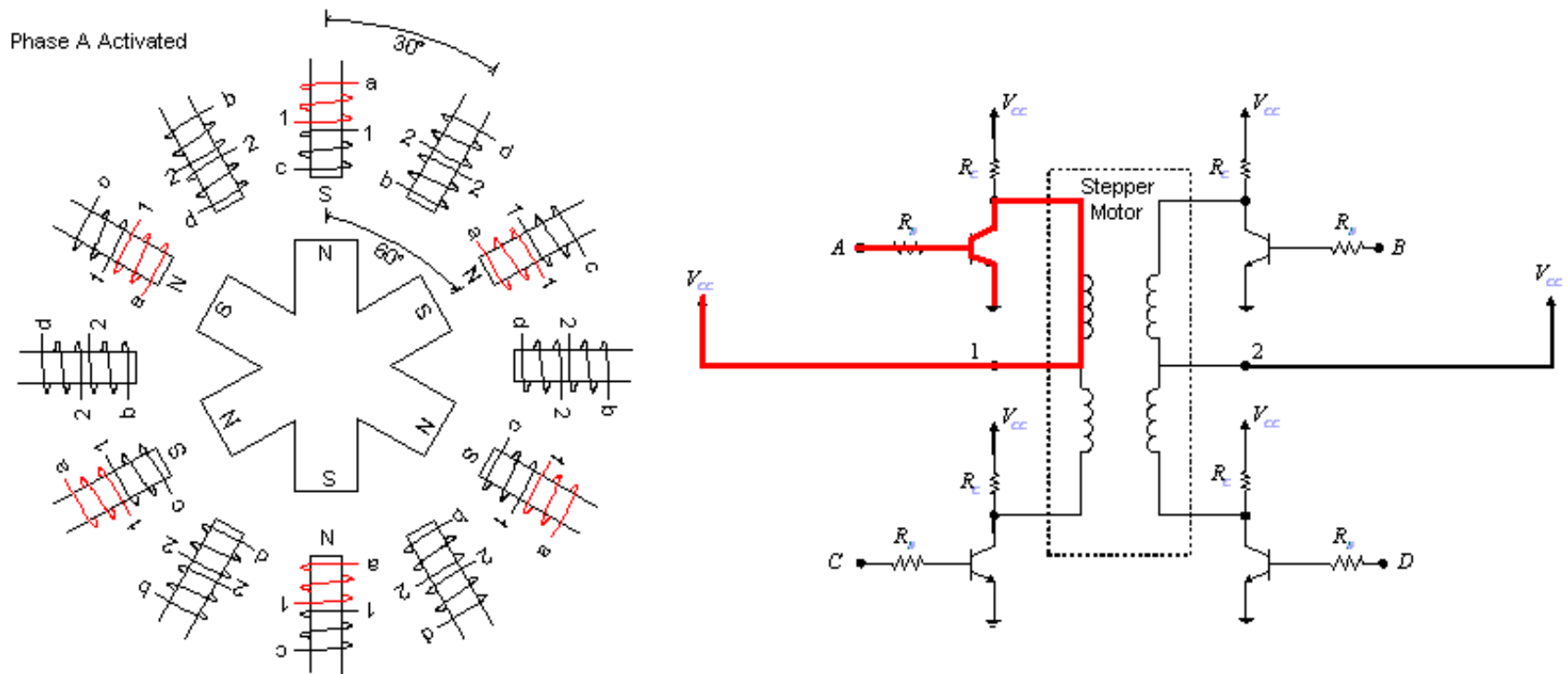
Stepper Motors

♦ This stepper motor is very simplified. The rotor of a real stepper motor usually has many poles. The animation has only ten poles, however a real stepper motor might have a hundred. These are formed using a single magnet mounted inline with the rotor axis and two pole pieces with many teeth. The teeth are staggered to produce many poles. The stator poles of a real stepper motor also has many teeth. The teeth are arranged so that the two phases are still 90° out of phase. This stepper motor uses permanent magnets. Some stepper motors do not have magnets and instead use the basic principles of a switched reluctance motor. The stator is similar but the rotor is composed of a iron laminates.
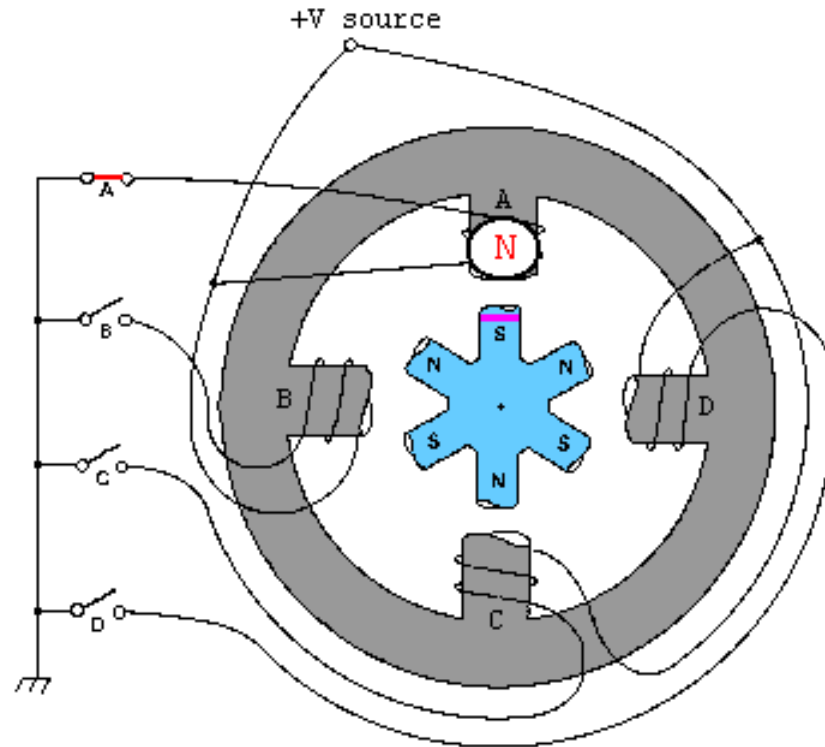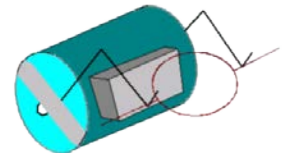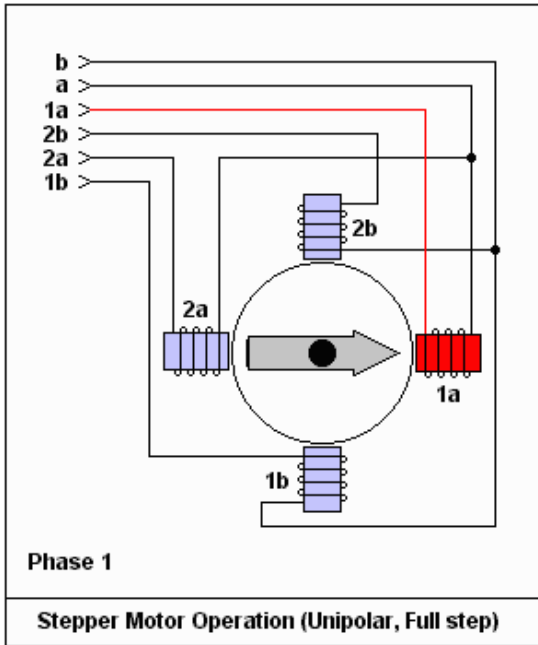
More on Stepper Motors
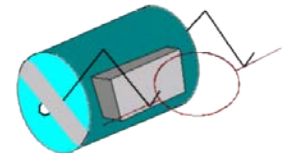
Phase A Activated

- Note how the phases are driven so that the rotor takes half steps

More on Stepper Motors

+ Animation shows how coils are energized for full steps

More on Stepper Motors

Index	1a	1b	2a	2b
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1
5	1	0	0	0
6	0	1	0	0
7	0	0	1	0
8	0	0	0	1

Clockwise Rotation

Stepper Motor Operation (Unipolar, Full step)

Phase 1

Index	1a	1b	2a	2b
1	1	0	0	0
2	1	1	0	0
3	0	1	0	0
4	0	1	1	0
5	0	0	1	0
6	0	0	1	1
7	0	0	0	1
8	1	0	0	1
9	1	0	0	0
10	1	1	0	0
11	0	1	0	0
12	0	1	1	0
13	0	0	1	0
14	0	0	1	1
15	0	0	0	1
16	1	0	0	1

Clockwise Rotation

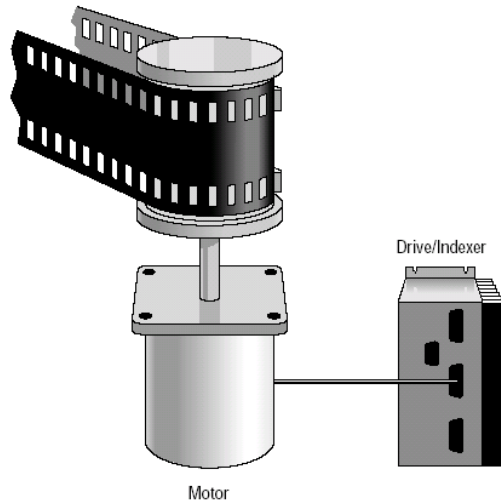**Stepper Motor Operation (Unipolar, Half step)**

Phase 1
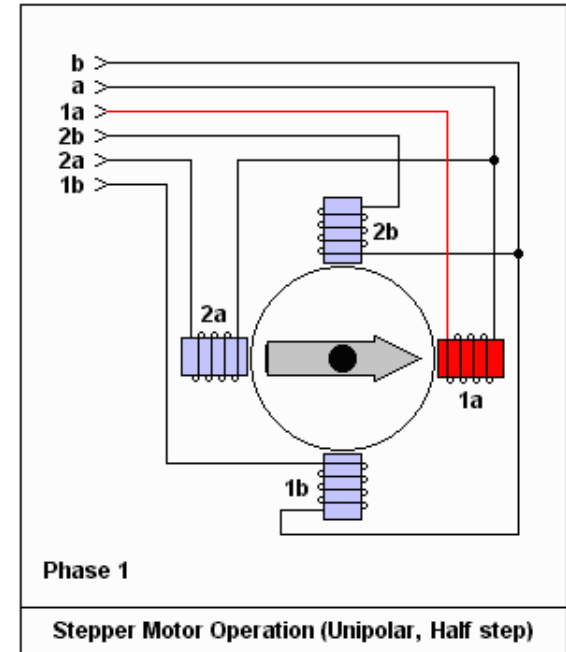
- Full step sequence showing how binary numbers can control the motor

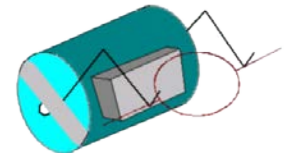- Half step sequence of binary control numbers

Stepper Motor Applications

- ◆ Film Drive
- ◆ Optical Scanner
- ◆ Printers
- ◆ ATM Machines

- ◆ I. V. Pump
- ◆ Blood Analyzer
- ◆ FAX Machines
- ◆ Thermostats

MEMS

- Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through the utilization of microfabrication technology. While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BICMOS processes), the micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices.
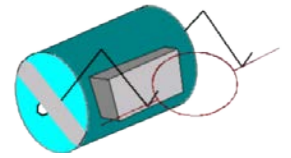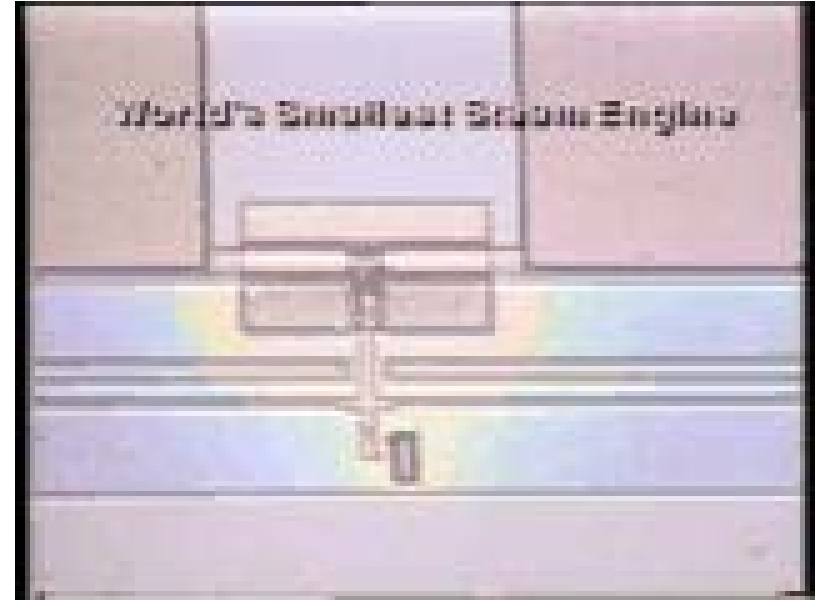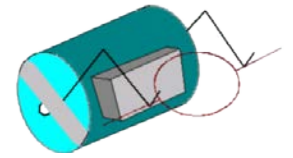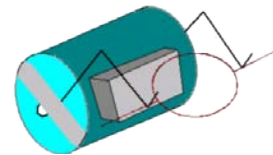
MEMS Stepper Motor
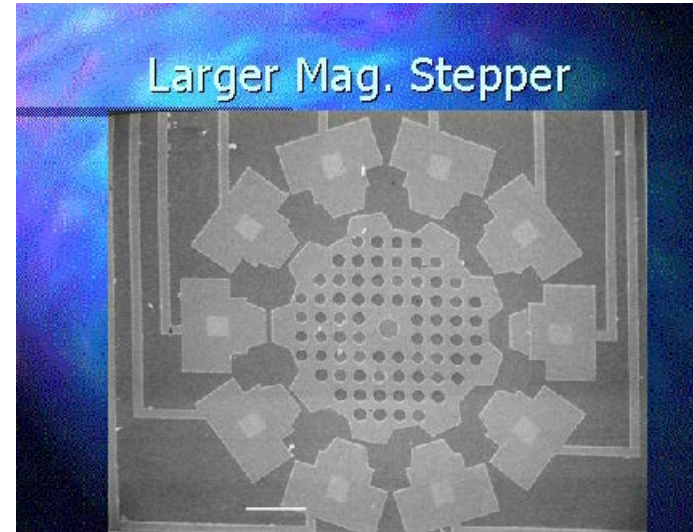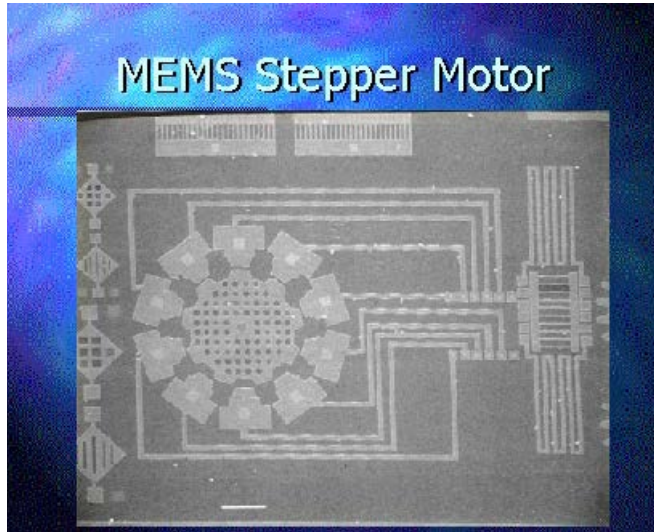
This motor is very much like the other stepper motors mentioned above, except that it is 2D and very small
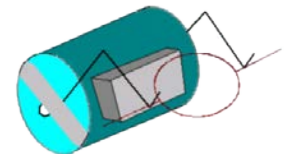
MEMS

World's Smallest Steam Engine

- ◆ Rotary motor
- ◆ Steam Engine (single piston)

RPI MEMS Faculty

- Prof. Yoav Peles
  http://www.rpi.edu/~pelesy/front_page.htm

- Prof. Borca-Tasçiuc
  http://www.rpi.edu/dept/mane/deptweb/faculty/member/borca.html

- CATS http://www.cats.rpi.edu/

- Prof. Kevin Craig
  http://www.rpi.edu/dept/mane/deptweb/faculty/member/craig.html

Battery Resistance Variation

Internal Resistance   (AA Batteries)
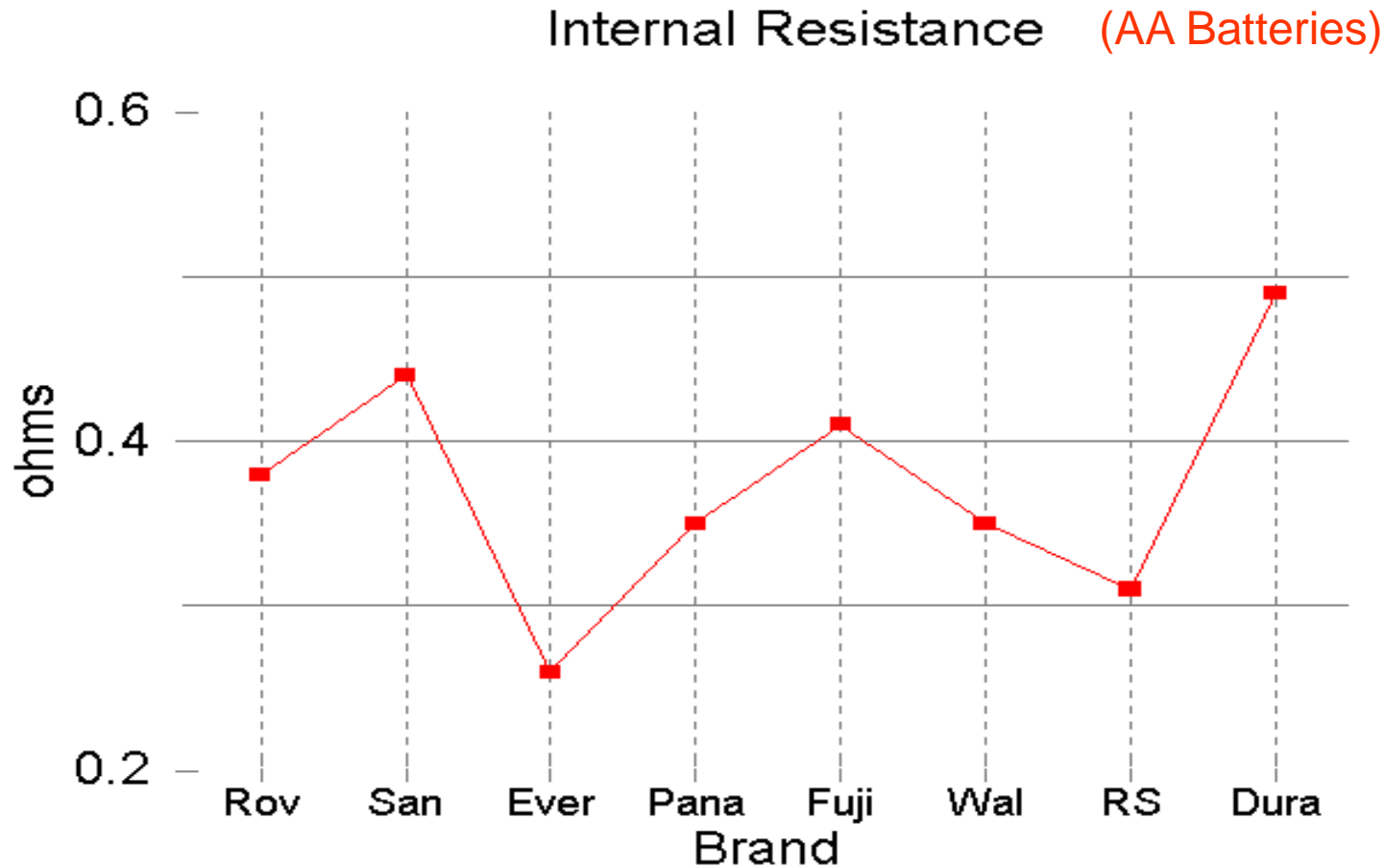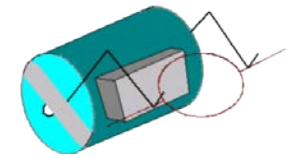
Discharging

Alkaline Batteries

Discharged thru 5 ohms

Legend:
- ROV 05
- Ener 05
- Fuji 05
- Pana 05
- Walg 05
- San 05
- RS 05
- Dura 05

Y-axis: EMF - volts (0.9, 1.1, 1.3, 1.5)
X-axis: Time - hours (0, 1, 2, 3, 4, 5, 6, 7)
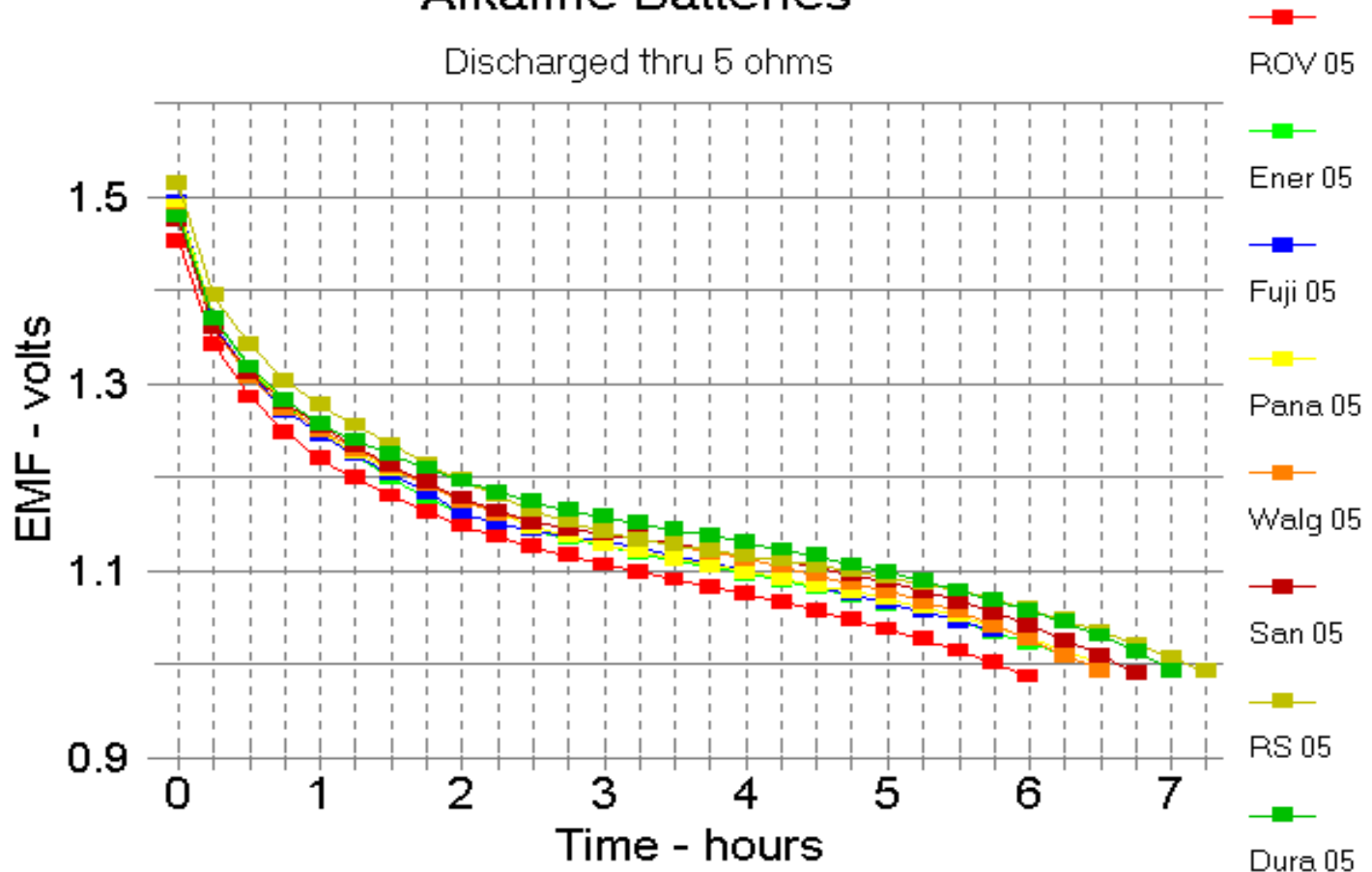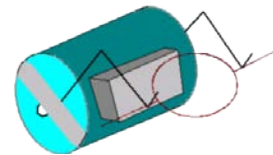
Additional Battery Information

- http://www.buchmann.ca

- http://www.batteryuniversity.com/index.htm

- http://home.att.net/~mikemelni1/battery.html
  (source of data on previous slides)

Building Beakman's Motor

- The two most important sites
  - http://fly.hiwaay.net/~palmer/motor.html
  - http://www.scitoys.com/scitoys/scitoys/electro/electro.html#motor

- Other Websites:
  - http://fly.hiwaay.net/~palmer/motor.html
  - http://www.scitoys.com/scitoys/scitoys/electro/electro.html#motor
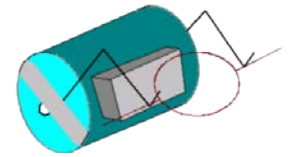 - http://www.micromo.com/library/docs/notes&tutorials/Development%20of%20Electromotive%20Force.pdf
  - http://hibp.ecse.rpi.edu/~connor/motor_comments.html
  - http://hibp.ecse.rpi.edu/~connor/education/motorS98.html

Build this
simple motor
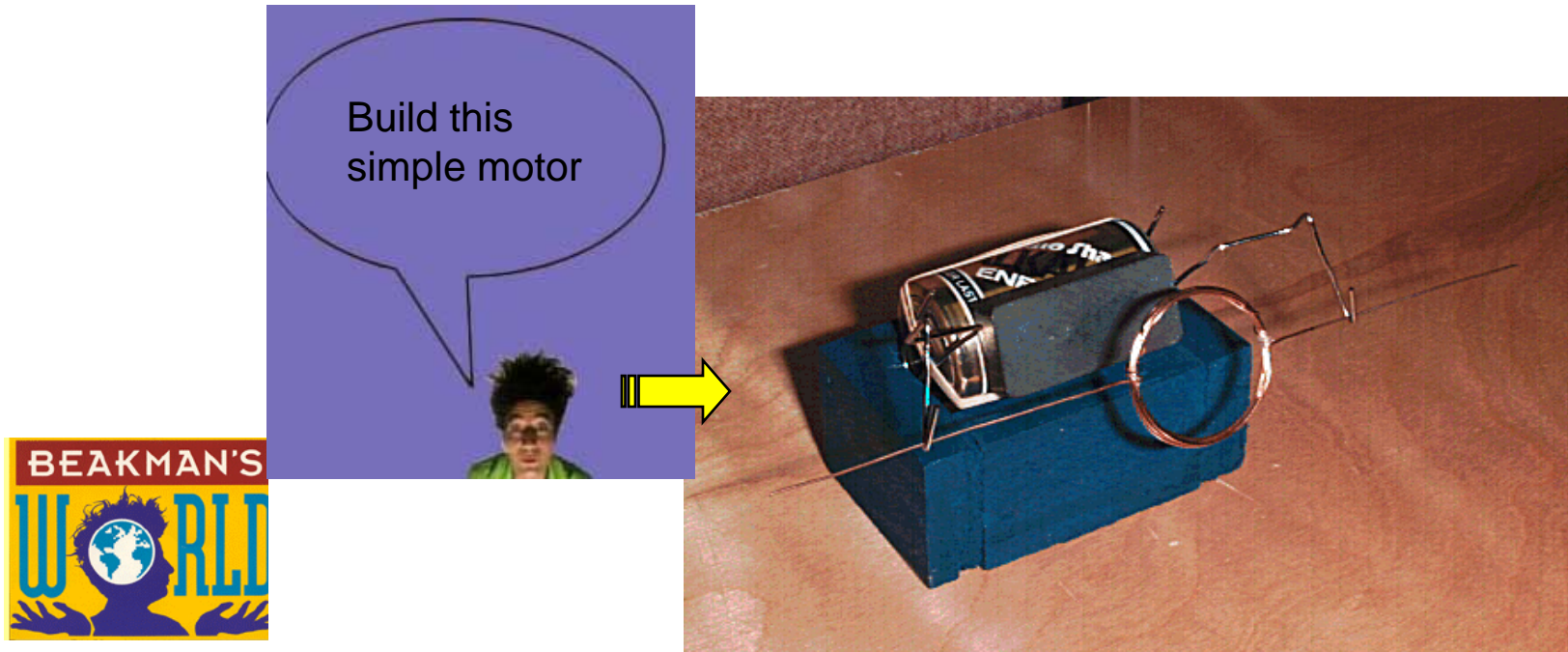
Electronic Instrumentation

Project 1 Rules

DO

- DO use large paper clips for the cradle
- DO use two of the 1" round magnets we provide
- DO use the power supply set to 1.5V
- DO use clay and some kind of support platform
- DO make your motor run for at least 30 s
- DO get a picture of your output and get it signed.
- DO use the sanding blocks.
- DO design "motor with mechanical springs" so that it runs entirely without human contact.
- DO post fast speeds up front.
- DO use the magnet wire provided.

DON'T
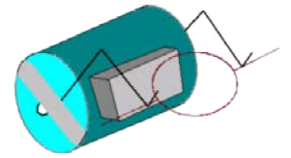
- DON'T make a cradle with a conducting loop
- DON'T use more than 2 round 1" magnets
- DON'T use the power supply set to more than 1.5V
- DON'T forget to take a picture for 4 motor cases and get them all signed.
- DON'T use springs that conduct electricity
- DON'T use creative sanding for one of your four required motor cases. You can do this for a "creativity" extra credit, if you want to try it.
- DON'T use your hands in any way for your final motor design.