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Workshop on Lego-Based Hands-on Micro and Nano Learning Modules

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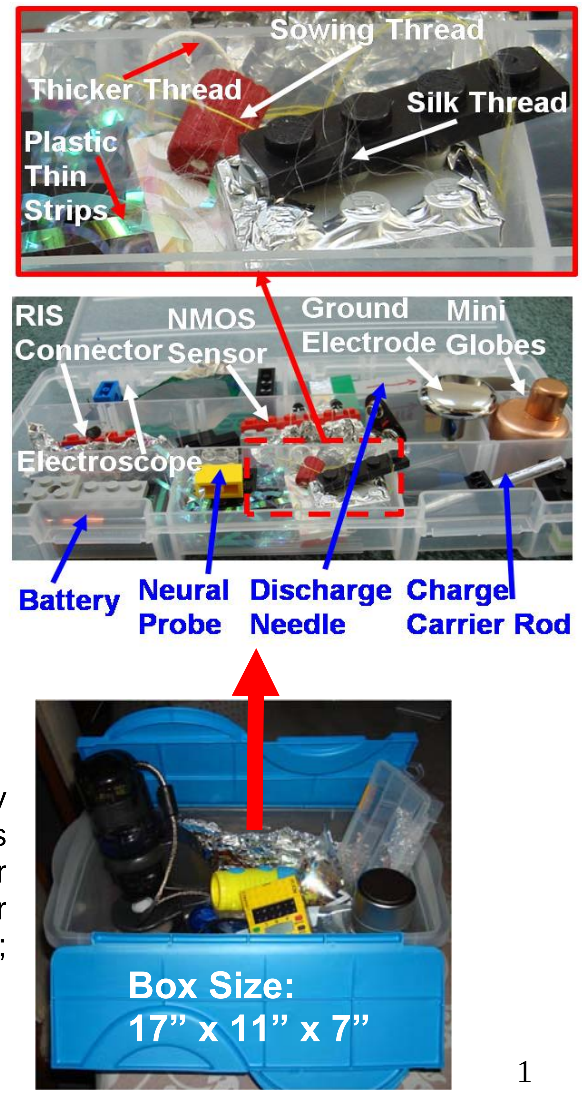
Abstract: "We mix dry learning topics with Legos, drive them around with robots, levitate them in the air with static charges and shock them with high voltage from Lego Van de Graaff generators." Suddenly they become fun and everyone wants to learn them.

The experiments in this workshop use 'top-down' approach to explain micro and nano concepts with the help of innovative hand-on learning modules. The approach is based on the notion that starting with bigger items (macro), studying micrometer-size objects (micro, microsystems), and then try to see and study nanometer-size objects (nano) is a better way to learn about nano and micro concepts. To make this learning process exciting and full of fun, (a) static charges, (b) programmable palm-size Lego robots, and (c) Lego Van de Graaf generators are used in the hand-on activities. All the items needed for each station are provided in a plastic box. The activities are divided into three experiments. A step by step description of all the activities in each experiment is provided in the manuals that are part of this document.

Who should attend? Science teachers, middle-high school students, college students, other interested in creative learning.



Box Contents

- **Plastic Organizer Box:** Static charge structures, 9 V battery, sensor, needle probe, discharge mini-globes, neural probe in Lego, modified RIS cable with sensor, pencil, NMOS/PMOS devices, neon bulb, etc.
- **Ziplock Bag # 1:** Confetti
- **Ziplock Bag # 2:** Microscope items
- **Ziplock Bag # 3:** Plastic spoon, polycarbonate sheet, cloth, electroscope, notebook, tape, scissors, etc.
- **Other Items in the Box:** Aluminum foil, RCX robot, USB tower, digital caliper, humidity meter, VDG generator, VDG globes, QX5 microscop, bubble maker, wood rods, etc.

Experimental Manuals

Manuals provided in this document:

1. Static Charges and Palm-Size Robots
2. Lego Van de Graaff generators and Microsystems
3. Nano Technology Exploration

Acknowledgement

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► FOLLOW STEPS I, II, ... VII

Information boxes, enclosed in dotted red lines and located on the right side of the page, are optional.

I. Experiment 1: Static Charges and Palm-Size Robots

Static Charge, usually created on objects such as dry skin, synthetic clothes and plastics through rubbing, is not easily movable. If an object loses negative charge (electrons) through the process of rubbing, it gains positive charge. The following materials gain charge (+ or -) through rubbing:

◄—— **More Negative** ———— **Zero** ———— **More Positive** ——►

Ebonite, Teflon, PVC, Polyester, Silver, Wood . . . . Paper, Cat's Fur, Nylon, Glass, Leather, Dry Skin

In general electric charge can be static or mobile. It is a basic property of particles found inside an atom. An atomic particle carrying the smallest amount of negative charge is called an **electron**. A particle carrying the smallest amount of positive charge is called a **proton**. The magnitude (amount) of charge carried by an electron is exactly equal to that carried by a proton but sign of their charge is opposite. ***An uncharged material (with zero net charge) has equal amounts of positive and negative charges.***

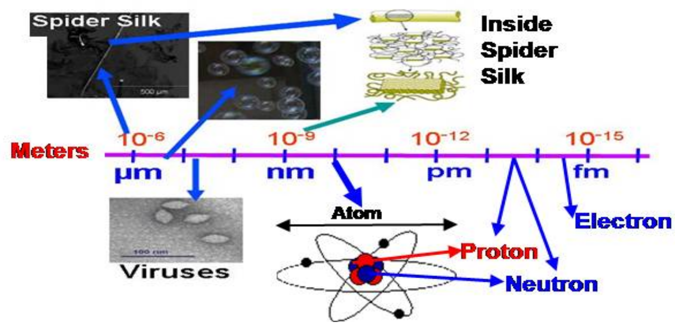
II. Objectives:

- Have fun with static charges
- To study a robot that can be controlled by static charges.
- Study mechanical and electronic sensors for positive and negative charges.

III. Materials Needed: *See Fig. 5*

- Robotics Invention System (RCX or NXT) with modified connector cable containing a static charge sensor.
- Plastic spoons, synthetic cloth, polycarbonate sheets, paper pieces, aluminum foil, motors, buzzers.
- Neon bulb, positive and negative charge sensors, pith balls, etc.

Atom is the smallest particle of any material (or element) that differentiates it from other materials (or elements); meaning that, if you divide an atom into smaller particles, the atom loses its identity. The number of protons in an atom tells us what material it belongs to. For example, the hydrogen atom always has one proton. If you add one more proton to the hydrogen atom it becomes helium atom! The total charge in an atom is zero but if you remove an electron from the atom, it becomes positive and addition of an electron makes it negative. Neutron, which has no charge, is also found in an atom.



IV. Introduction:

You walk across the rug, reach for the doorknob and .. ZAP!!! You get a static shock, the intensity of chock depends on the humidity. Normally the static charges are not dangerous. They can be annoying or useful:

- The static charges can be annoying if they damage the electronic devices such as computers and cell phones. Fortunately, today's devices are protected against this damage.
- The static charges can be fun to play with and can even be used to switch on electronic devices such as robots, buzzers, light bulbs (LEDs), and 'static charge piano'.

Humidity: The humidity level in the air is a measure of the amount of water vapor present in the air. Warm air, which has more thermal energy than cool air, can hold more water vapor. Thus, the humidity can be reduced by cooling the hot air. Smaller humidity levels lead to higher static charges if all other conditions are kept constant. The static charge leads to a voltage (in fact, any charge has electric field and voltage associated with it). Here are electrostatic voltages due to static charges under different humidity levels:

Means of Static Generation	Relative Humidity	
	10% to 20 %	65% to 90%
Walking across carpet	35 kV	1.5 kV
Walking on Vinyl Floor	12 kV	250 Volts
Worker moving at bench	6 kV	100 Volts
Opening a Vinyl envelope	7 kV	600 Volts
Picking up common Polyethylene bag	20 kV	1.2 kV
Sitting on chair padded with Polyurethane foam	18 kV	1.5 kV

V. Procedure:

Activity 1:

- Rub the cloth on a poly-carbonate plastic sheet, and bring the plastic sheet near a simple static charge sensor

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(called an **electroscope**, Figure 1)
Explanation: *When the electroscope is brought near the source of an object with static charge, some of the electrons in the hook (the top portion of the electroscope, Figure 1) are pulled up to the hook away from the leaves if the source is positive, or pushed towards the leaves if the source is negative. In either case, the leaves have the same type of charge and so they repel each other. The distance they open up is proportional to the charge of the source (if the sources are always held at the same distance from the hook).*

- Switch on an RCX robot with modified connector cable and static charge sensor (Fig. 2). The motor attached to RCX will move only if you bring the charged polycarbonate sheet near the control electrode of the sensor (you can also build a robot using one motor and then do this experiments). This sensor is called **NMOS sensor**.

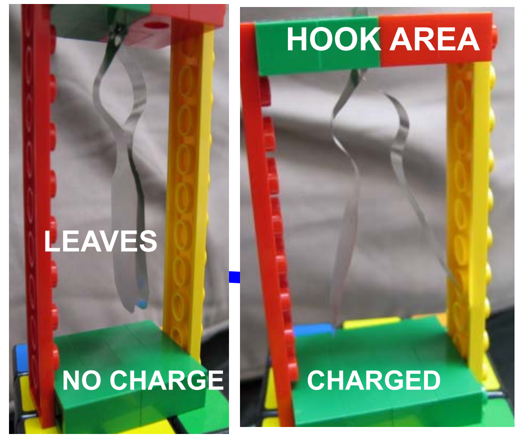


Fig. 1 An electroscope is an instrument for detecting the presence of static electricity. It consists of two thin metal leaves suspended from a metal hook.

Activity 2:

The electroscope used in the above activity does not detect the type of charge (positive or negative). To detect the type of charge, you can use electronic sensors called NMOS or PMOS switches (these switches are used by computers). The NMOS is switched on by a positive charge and the PMOS is switched on by a negative charge. The NMOS we use is BS 170 and the PMOS is BS 250 (available from Jameco Electronics for $ 0.20).

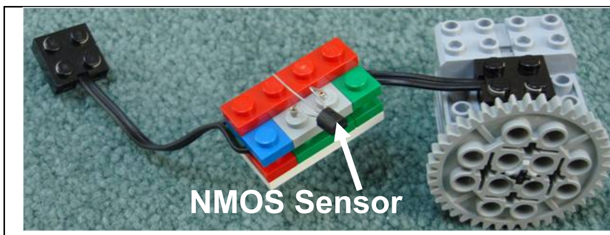


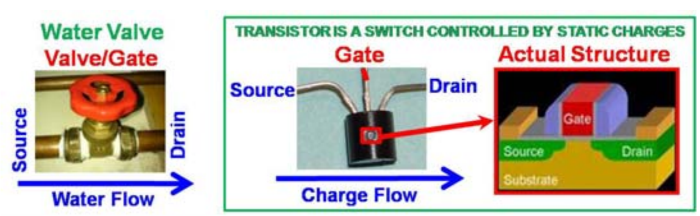
Fig. 2 Modified connected with NMOS sensor.

- As the robot was equipped with an NMOS sensor, the charge on the polycorbonate sheet must be positive.
- Now replace the NMOS with a PMOS sensor and the robot will be controlled by negative charges. Rub a plastic spoon on the green cloth to get the negative charge on the spoon.

Electronic Circuit consists of electronic components such as switches (NMOS, PMOS), battery, and other electronic devices.

- To understand the operation of NMOS and PMOS sensor switches and related electronic circuits, see sensor development procedure shown in Figure 3. This sensor board has NMOS and PMOS sensors connected in series with a light emitting diode (LED) and a battery in two separate circuits. Thus, this sensor can detect positive or negative charges.
- When you bring the charged polycarbonate sheet close to the sensor, you will find that the LED in the NMOS area of the sensor lights up (the new version of the sensor shown in Fig. 3A will be used in the session), meaning that the charge on the polycarbonate sheet is positive. Now try rubbing different materials on cloth

NMOS: Electrostatic switches, called MOS (Metal Oxide Semiconductor) devices, are used in computers. Typically, such switches have three terminals; a gate where the charge is applied and two electrodes (called Source and Drain) where devices (to be switched on) are connected. Using the basic MOS concept different types of computer switches are made. Some examples are n-channel MOS (NMOS), PMOS (p-channel), and CMOS (a complementary combination of NMOS and PMOS). In an NMOS, comparable to a water valve, the flow is controlled by a static charge applied at the Gate:



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(also use different types of cloths, plastic sheets, etc.) to find the type and strength of the charges you generate for different materials.

- Now slowly bring the charged sheet closer to the NMOS sensor until the LED lights up. Move the sheet back and the LED goes off. Try this a few times never getting too close to the sensor. Why does the LED go off if you move sheet back?

Explanation: *When the sheet is brought near the NMOS sensor, as shown in Figure 4, the near end of the gate wire of NMOS has negative charge and farther end, which is the actual gate inside the NMOS device, becomes positive by the process of charge induction. When the sheet is moved back, the induced positive and negative charges recombine and the NMOS is switched off.*

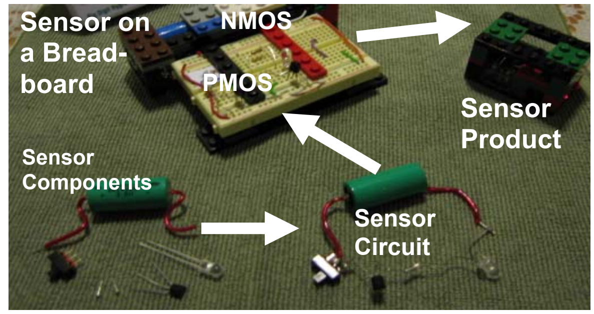

Fig. 3: Sensor development; from circuit to product.

- Now slowly bring the charged sheet very close to the NMOS sensor until the LED lights up. Move the sheet back and the LED does not go off. Why does the LED stay on if you move sheet back?
  - ***Explanation:*** *If you bring the sheet close enough to the sensor there is discharge (sparking) of positive charge directly to the gate. As a result the LED stays on even if you move the sheet back. You can reset the sensor by applying the negative charge at the gate.*

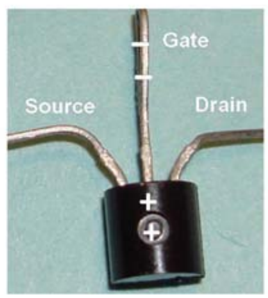

Fig. 4: The positive charge induces opposite charge at the closer end but similar charges at the further end.

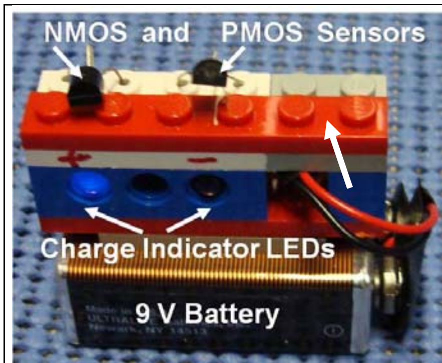

Fig. 3A New version of NMOS sensor product shown in Fig.2.

Important Note: In the above experiment if you bring the sheet too close to the NMOS sensor the NMOS will be totally damaged showing that an unprotected electronic device can be damaged by excessive static charges.

VI. Questions:

Does the charge on the polycarbonate sheet move if it is brought near another charged object? If you touch one end of the sheet, does all the charge disappear from the sheet? How are charge-making machines, called Van de Graaff (VDG) generators, made and how do they work?

VII. Further Exploration:

In the next experiment, we will explore more advanced concepts using Van de Graaff generators (See Fig. 5).

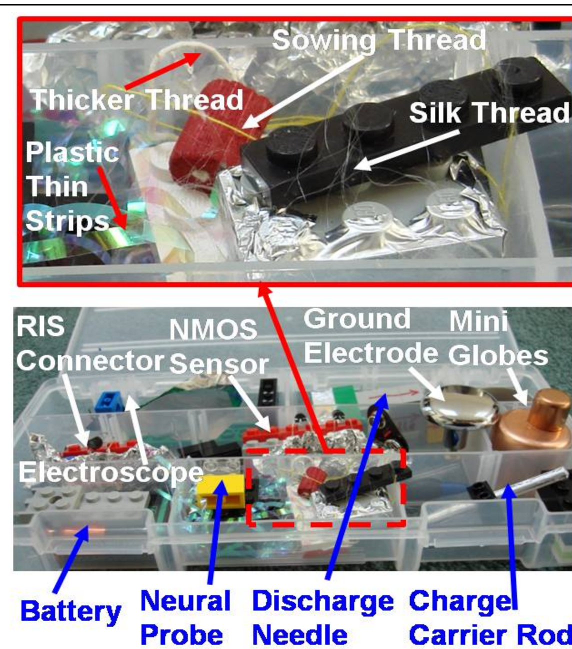

Fig. 5 Plastic organizer in the Blue Box.

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I. Experiment 2: Lego Van de Graaff Generators and Microsystems

A VDG generator uses a moving belt to generate very high voltages (in the range of 5 – 50 thousand volts for a toy VDG and up to 14 million volts for a commercial VDG) on a hollow metal globe (see Fig. 2). The globe voltage *V*, assuming a spherical globe of radius *a*, is given by $V = Ea$, where *E* is the electrostatic field at the surface of the globe. The maximum dome potential, V_m, is limited by the breakdown of the air, which occurs at $E = 30{,}000$ V/cm. Thus, $V_m = 30{,}000a$ volts, where *a* is the radius of the dome in centimeters. For a round globe with $a = 5$ cm, $V_m = 150{,}000$ V. However, the measured globe voltage of the round globe is approximately 50,000 V, which depends on VDG design parameters that typically include pulley materials and speed, belt material, charge collection efficiency and humidity.

II. Objectives:

- Learn about Van de Graaff generators.
- Perform some advanced experiments on static charges.
- Study microsystems.

III. Materials Needed:

See Fig. 1

- Van de Graaff generator, lastic spoons, synthetic cloth, polycarbonate sheets, confetti, aluminum foil, motors, buzzers.
- Neon bulb, positive and negative charge sensors.

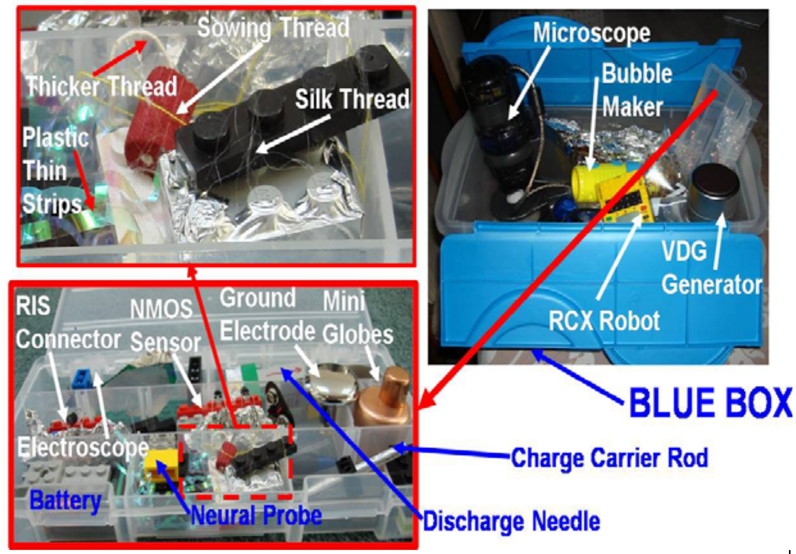

Fig. 1 Blue Box contents needed for the 3 experiments.

IV. Introduction:

In this experiment, as the Van de Graaff (VDG) generator can create charge continuously, we can repeat most of the activities from previous experiments in a more convenient way. Additionally, we can do some advanced level activities, which are exciting on one hand and provide a rich learning experience on the other.

V. Procedure:

Activity 1:

Turn on the RCX (yellow brick) and connect the Lego motor integrated into the VDG to the port A of the RCX. Press the green button on the RCX to run the VDG. As shown in Fig. 2, the running rubber belt brings positive charge on the globe because the brush 2 picks up the positive charge and transfers it to the globe. The lower brush 7 brings the negative charge to the ground wire. Using the VDG globe as the source of positive charge, repeat the activities of experiment # 1.

Activity 2:

- Connect the motor of a VDG generator (Fig. 2) to the port A of the RCX. Program the RCX to run the motor A at maximum speed. For the programming of the RCX use the program in the computer. If you have not done it before, help will be provided. Now bring the electroscope closer and closer to the top globe of the VDG generator

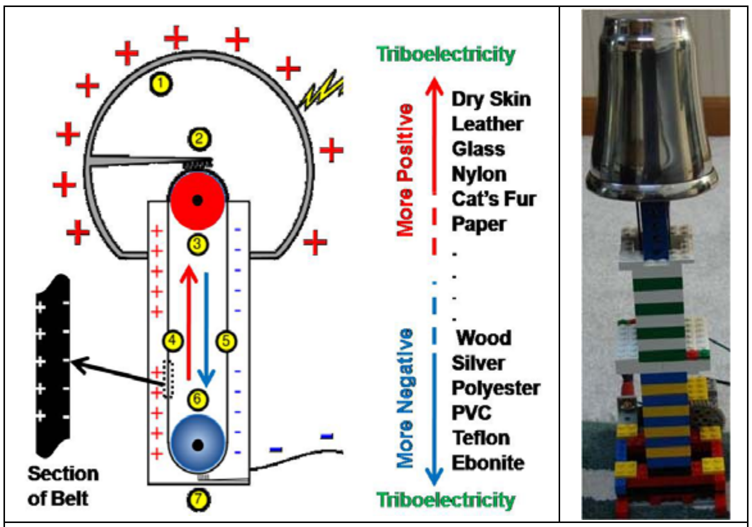

Fig. 2 The operation of a van de Graaff generator (left) and an 18 inches tall Lego VDG capable generating 60,000 volts if humidity is < 40 % (right).

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until its leaves go apart. Record the distance, between the electroscope and the globe, in the table below.

- Now program the RCX to run the motor A at a lower speed. Repeat the above procedure and record the distance in the table.
- Repeat the above procedure for another motor speed.

Activity 3:

- Program the RCX to run the motor A at maximum speed. Now bring the NMOS charge sensor closer and closer to the top globe of the VDG generator until one of its LEDs lights up. Measure the distance between the globe and the sensor. Record the distance in the table below. A ruler is provided for distance measurement.
- Now program the RCX to run the motor A at a lower speed. Repeat the above procedure and record the distance in the table.
- Repeat the above procedure for another motor speed.
- Try different globe sizes and make another table. You can make your own globe by wrapping Al foil on a plastic glass.

Motor Speed	Electroscope Distance (cm)			NMOS Sensor Distance (cm)		
	1st Try	2nd Try	3rd Try	1st Try	2nd Try	3rd Try

.

- Bring one lead of the neon bulb closer to VDG globe (Figure 3). The bulb blinks if is not touching the globe but is within 1-2 mm. The gas atoms split into positive and negative particles (plasmas), which produce light.

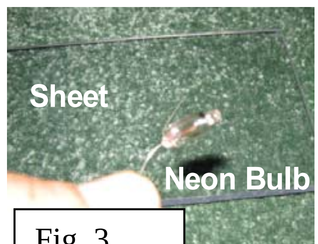

Fig. 3

Activity 3:

The static charges can be used to understand the basic operation principle of microsystems (or MEMS). In microsystems, mechanical parts such a beam can be moved by charges. Although, the MEMS components are typically in micrometers, in our experiments, we use a larger structure, which can be called Electro Mechanical Systems (EMS):

- Turn on the VDG.
- Move the structures shown in Fig. 4 closer to the globe and see what happens.

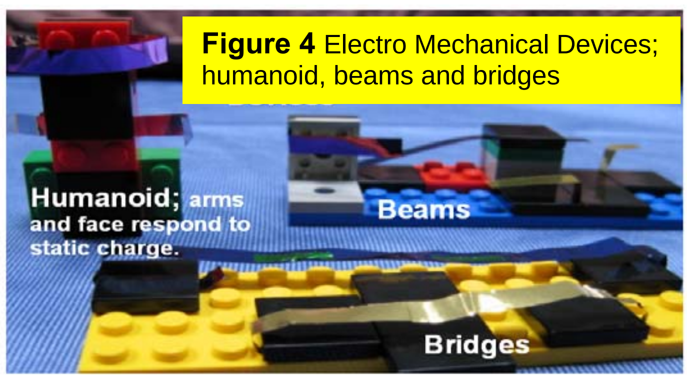

Figure 4 Electro Mechanical Devices; humanoid, beams and bridges

Explanation: The face and arms of the little humanoid move when you bring the globe close to it. Similarly, the bridges and beams move and vibrate if the globe is brought close to the structures. When the globe is brought near the free end of the beam, the induction of charges (separation of positive and negative charges within the beam) in the beam depends on whether the beam is a conductor (Figure 5) or insulator (Figure 6). In either case, there is a force of attraction between the

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positive and negative charges and the free end moves towards the sheet.

A similar principle is used in an electrostatic micrometer-size acceleration sensor (accelerometer) that is used to trigger the airbag in a car. Such a device is also used in the wireless controller of Nintendo's exciting new Wii video gaming system.

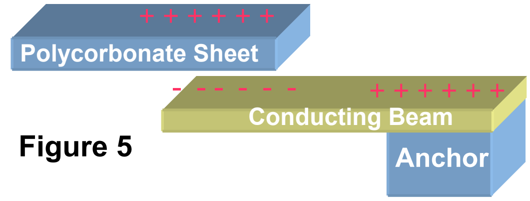

Figure 5

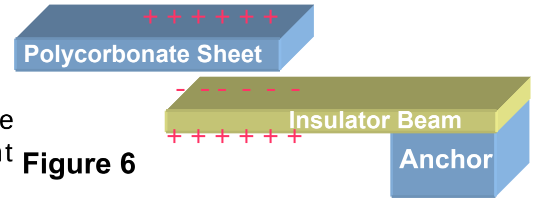

Figure 6

VI. Questions:

Can the neon bulb experiment be done using the polycarbonate sheet? Can it be repeated on different parts of the sheet without re-charging it?

VII. Further Exploration:

In the next experiment, we will explore nano concepts using Van de Graaff generators.

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I. Experiment 3: Nano Technology Exploration

II. Objectives:

- Learn about concept of dimensions.
- Study nano dimension.
- Use VDG to study nano dimensions.

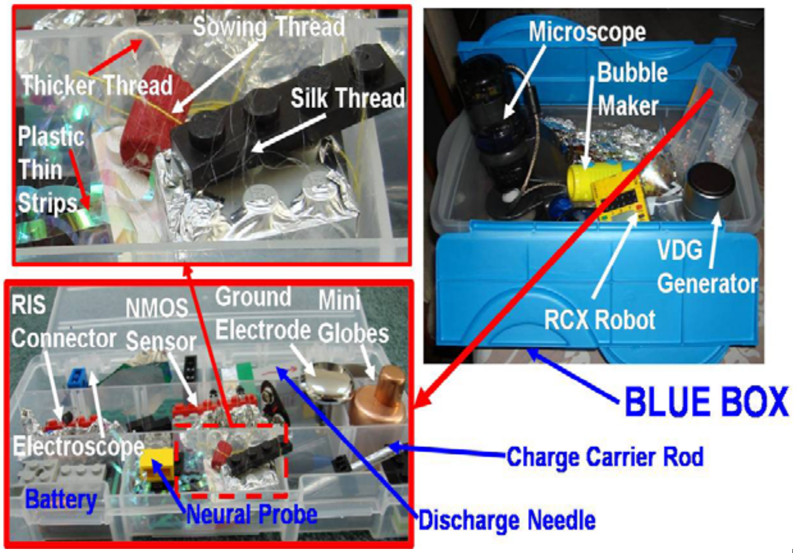


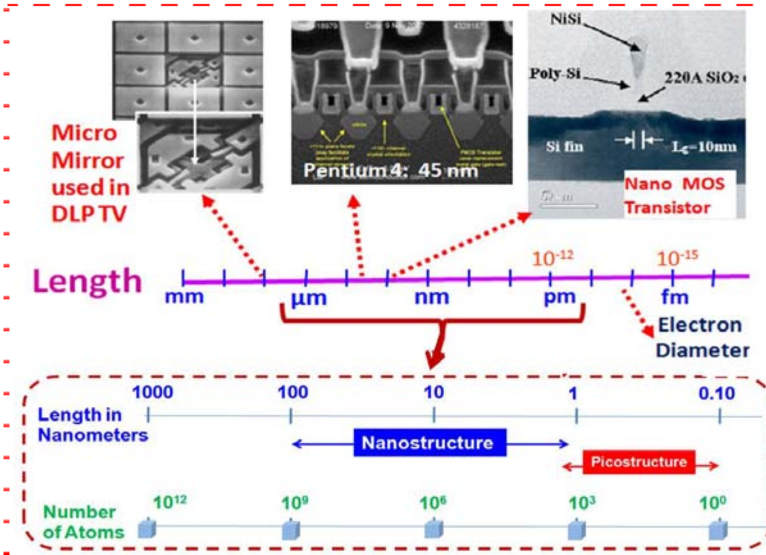
Fig. 1 Blue Box contents; it contains all the parts needed for 3 experiments.

III. Materials Needed:

See Fig. 1.

IV. Introduction:

It is interesting to look at common objects with decreasing sizes to define nano sizes. As the physical properties of materials (for example melting point) start changing as the physical dimensions are decreased below approximately 100 nanometers, structures smaller that 100 nm are defined as nanostructures and the technology need to make such small structures is called nanotechnology. For more details, see the information box (enclosed in red dashed border).



Definition of Micro and Nano: It is interesting to look at a broader definition of small structures with unusual properties. While the minimum conductive lengths in transistors in the latest Pentium microprocessors are at 45 nm level, these lengths in future processors are expected to be at 10 nm level. Can such lengths get smaller than 1 nm? Is it possible to define physical properties for particles at 1 nm or smaller? At such small length scales it is also important to consider the number of atoms. For the calculation of density of atoms in a particle of cubic shape, it is assumed that there is one atom in the cube if its dimension is 100 pm. As one needs a certain minimum number of atoms in a particle to calculate its physical properties, an important question is: At what smallest level, length or number of atoms, it becomes impossible to define the physical properties? It is found that if the particle size is less than approximately 1-2 nm or 1000 – 2000 pm, the physical properties cannot be defined. Based on number of atoms in a particle, the structures with dimensions around 1000 pm or less can be defined as picostructures and the technology needed to fabricate them as picotechnology (see above figure).

V. Procedure:

Activity 1: *Dimensions*

First look at the scale in the red information box before doing hands-on activities. Also look at the following website study the scale of length: http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/

What are the objects that you see on the above website that can be classified as nano? What objects can be defined as pico (see information box on the right)?

Activity 2: *Digital Caliper*

For the first hands-on experiment, a digital caliper is used. The learners are asked to (a) measure sizes of Lego pegs, gear tooth, paper, and plastic sheets, (b) record the data in a table, and (c) answer the following questions: *What is the smallest size you can measure using the digital caliper? What is the error in the measurements for different sizes of objects? Can you measure the difference in size of identical Lego blocks?*

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Activity 3:

For smaller objects the learners use Intel microscope. A number of objects are provided but the learners are encouraged to explore other objects, and explore the following questions: *What is the smallest size you can measure using the Intel microscope? What is the smallest size you can measure using the high magnification microscope? Can you see the spider silk?*

As shown in Fig. 2, different size samples can be studied using the Intel microscope. These samples will also be used later for the VDG experiments.

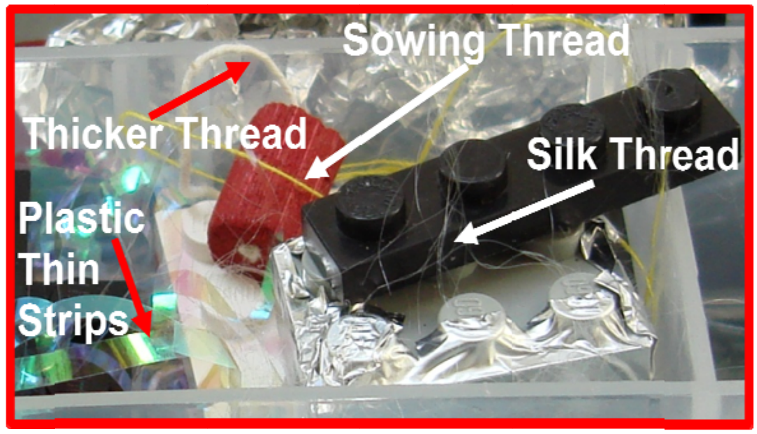
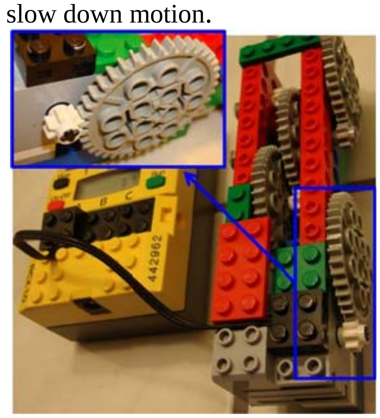


Fig. 2 Different samples that can be used for nano experiments using microscope and VDG.

Activity 4: Gear System, see Fig. 3.

For the next experiment, the learners build a Lego gear system to slow the movement of a gear by a large factor. For example, in the system shown in Fig. 6 the gear ratio for single stage is 5, and if 10 stages are used the slowest gear is moving at a speed that is approximately 10^7 times slower that the fastest gear. This means that if the tooth of the fastest gear moves through 1 mm the tooth of the slowest gear moves through 10^{-7} mm or 10^{-4} µm or 10^{-1} nm or 100 pm. The motor driving the fastest gear can be programmed by a Lego robot to run at different speeds. While the learner can measure the speed of fastest gear using a rotation sensor attached the gear and interfaced with the robot, a microscope can be used to track the movement of slower gears. This simple machine can help explore nano dimensions in length and time. The learner can explore a number of questions: *What is the smallest movement you can measure for the slowest gear using the Intel microscope? The slowest gear seems to be stopped while the fastest has a large kinetic energy. Where does the kinetic energy go as it gets to the slowest gear?*

Fig. 3 A gear combination to slow down motion.



Activity 4: Bubble Maker

The next experiment explores the nanometer size objects using a bubble maker machine. The soap bubbles are made of very thin soap film and can attract the attention of everyone including small children as seen in Fig. 4. The learners can also build a programmable Lego bubble maker to study the effect of fan and carrousel speeds on the size of bubbles. The learner produces soap bubbles and watches their changing color before they burst. They shine lights of different colors and see if certain colors are not seen or eliminated. Knowledge of physics can be used to show that the skin of a soap bubble is approximately 200 nm. Since each traversal of the film incurs a phase shift proportional to the thickness of the film and inversely proportional to the wavelength, the result of the interference depends on these two quantities. Thus, at a given thickness, interference is constructive for some wavelengths and destructive for others, so that white light impinging on the film is reflected with a hue that changes with thickness. The light is reflected from the top and bottom surfaces of skin of the bubble. Just before the bubble bursts in the air due to evaporation, it usually shows destructive interference for visible light of shorter wavelengths. Depending upon the angle of incidence, the skin thickness is in the range of 200 nm.

Questions: *Can our eyes see a film of 200 nm? How can you explain the reflections of light from the top and bottom surface of the film? Does the light reflected from the bottom surface travels a longer path? Are the bubbles attracted to static charges created on plastic sheet by the process of rubbing?*

Fig. 4 The eyes of this two-year old boy mirror a level of excitement that can only be indebted to the 200 nm thick skin of the bubbles.

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Activity 5: Bubbles and VDG

Another interesting way to study the nanometer size objects is to use programmable Van de Graaf generators. When the VDG is running, its globe has positive charge. If the bubbles are produced near the globe of a running VDG some very interesting observations can be made. For example, if a bubble comes within a few centimeters of VDG, a negative charge is induced on the near side of the bubble and positive charge is induced on the farther side of the bubble. Consequently, the bubble is attracted towards the globe, which carries a positive charge. Now one of the two things can happen. The bubble may move too fast towards the globe and can crash into the globe. However, if before it crashes, there is a sparking between the globe and the bubble, the bubble gets a net positive charge and it moves away from the globe. As the bubble skin flexes during this maneuver, there might be a change of its skin color.

In another experiment, carbon nanotube (CNT) sample, with patterns of CNTs that are 500 µm apart, is placed under an IntelQX5 microscope. Obviously the CNTs are too small (20 nm in diameter) to be seen under the 200 magnification of the microscope. However, if the globe of VDG is connected to a probe, which is brought near the CNT sample, some movement of patterns of CNTs (which are 100 µm x 100 µm) is expected to be observed. This very interesting experiment is expected to be completed in the next 2 months.

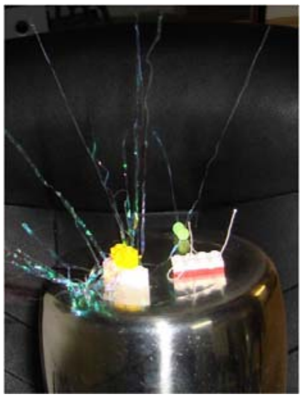

Fig.5 Plastic threads standing up on globe of VDG.

The plan is to first show to the learner a bigger replica of the CNT patterns (patterns of regular plastic or cotton threads mounted on a Lego plate for example, see Fig. 2) that is brought near the globe of VDG (Fig. 5). The learner can place different samples shown in Fig. 2 on the VDG globe and see how they are affected by the positive charge of the globe. While one of these samples is placed on the globe, bring two different objects, one at a time, near the globe and see what happens. The object that you bring close to the globe must be connected to the ground wire of the VDG. One of the objects is a needle embedded in Lego pieces and the other is a set of flat and smooth metal objects as shown in Fig. 6. In both cases, the thread standup will be affected. In case of flat electrode there will be spark (visible if done under low or no light) but for the needle there will be no spark. Explain why?

VI. Questions:

Can you think of another nano object, other than the skin of a soap bubble, that we can see with a naked eye? When you rub a cotton towel on your face after you take shower, you remove a very thin layer of your skin. What is the thickness of this layer?

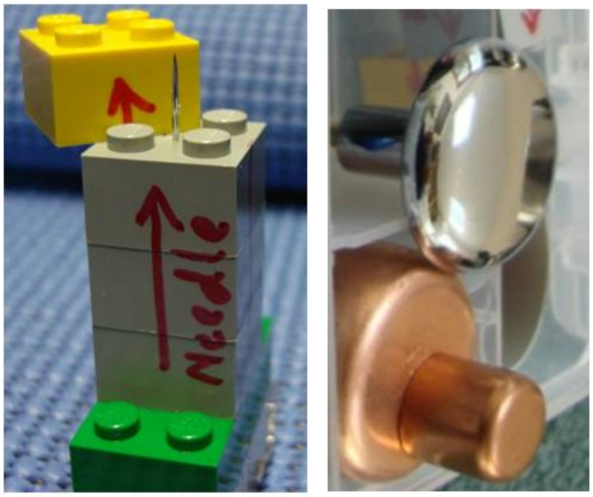

Fig. 6 Needle and flat metal ground electrodes.

VII. Further Exploration: Explore nano on the web:

Too small to see'; *http://www.toosmalltosee.org/*
'Nanoze'; http://www.nanooze.org
'Nanokids'; http://nanokids.rice.edu/
'Nanomaterials and Nanoworld'; *http://www.nclt.us/instructionalMaterials_activities.htm*
'NanoLeap'; http://snf.stanford.edu/Education/Nanoleap.RA.html
"Nanozone'; *www.nanozone.org*
'Powerof10'; http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/index.html
'Molecularium'; http://www.molecularium.rpi.edu
'NanoManipulator'; http://www.cs.unc.edu/Research/nano/ed/index.html
'Nanobio'; http://www.nbtc.cornell.edu/education/hs_internship.html, http://cnse.albany.edu/Nano_for_Kids.html