Engineering Design Lab

Winter Quarter 06-07

Magnetic Force Microscope "NANO" module

You will be submitting this handout as your lab report, so please fill out the following:

Your Section Number: _________

Your group members: ___________________________

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Recent years have witnessed a burgeoning excitement about nanotechnology and its impact on the world, including such topics as smaller, faster, cheaper, more robust computer chips, Micro Electro-Mechanical Systems (MEMS) devices, and developing structures through templating for bio-medical investigations including DNA sequencing and biomimetics. While you may have heard some of these buzzwords and experienced a little of the excitement of nanotechnology, we are guessing you are mostly unaware that the concepts learned in high school chemistry and physics classes are used in the development of nanotechnology! In addition, you most likely have seen applications or experienced benefits of nanotechnology without being aware of the nanotechnology relationship.

A good definition of nanotechnology is provided by the Merriam-Webster Dictionary:

> *Nanotechnology: the art of manipulating materials on an atomic or molecular scale especially to build microscopic devices*

While this describes the concept succinctly, it leads to many questions. One of the fundamental questions raised in nanoscience is: How do you know what is going on at such a small scale? Nanometer-sized object and features are well beyond the ability of optical microscopes (e.g the type you can look into with your eyes), so how do you know what is going on? The answer is that scientists use instruments to measure forces and interactions at these small scales, and then interpret the responses to build up a virtual image of what is going on.

One of these fundamental tools is the Scanning Probe Microscope, which uses a tiny, pointed tip to measure the forces between the tip and individual molecules. By scanning this tip across a surface, the nanoscale structure can be mapped, and an image is created.

In this module, you will build a model of a Scanning Probe Microscope using Lego bricks. You will not be able to measure atomic surface forces using legos (not a big surprise…), so we will use the more macroscopic force of magnetism. Your microscope will be a model of a Magnetic Force Microscope (MFM), a type of scanning proble microscope, which uses a magnetic tip to scan a magnetic surface.

You will use your Lego MFM to scan three unknown surfaces, and determine the magnetic pattern hidden beneath the surface. Your lab group will complete this handout, which includes your map of the magnetic surface and your best estimate at what the pattern is. There will be three unknown surfaces; an easy one which can be measured using the basic MFM design provided, a medium difficulty one which may or may not be measured using the provided design, and a hard one which will most likely require you to modify your MFM probe to determine the pattern.

Unfortunately, one of the drawbacks of microscopy at the nanoscale is that one can never see the real surface or pattern with their own eye. Just like real nanoscience, you will never see inside the unknown box for verification – you will have to build the best tool you can and trust that it can do a good job of imaging for you!

What is a Scanning Probe Microscope?

Scanning probe microscopy (SPM) is a method for mapping surface forces of materials on the atomic scale. By mapping these forces, much can be learned about the surfaces of materials, where many interesting and complex phenomena occur. For example, many chemical reactions involving solids are dependent on the nature of their surfaces. It is also useful for identifying properties in some novel materials; for example, using a magnetic force microscope to identify presence of magnetic properties in the material or to develop a 2D or 3D representation of magnetic islands.

In a Magnetic Force Microscope (MFM) a magnetic tip is used to probe the magnetic stray field above the sample surface. The magnetic tip is mounted on a small cantilever which translates the force into a deflection which can be measured. The Microscope can sense the deflection of the cantilever, which will result in a force image (static mode) or the resonance frequency change of the cantilever, which will result in a force gradient image. The sample is scanned under the tip which results in a mapping of the magnetic forces or force gradients above the surface.

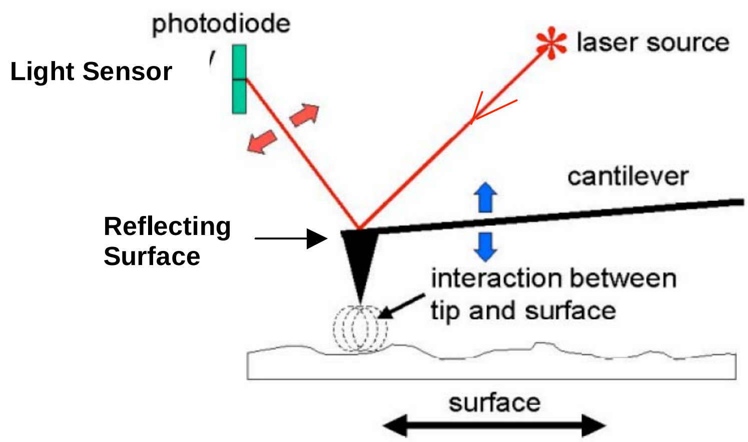
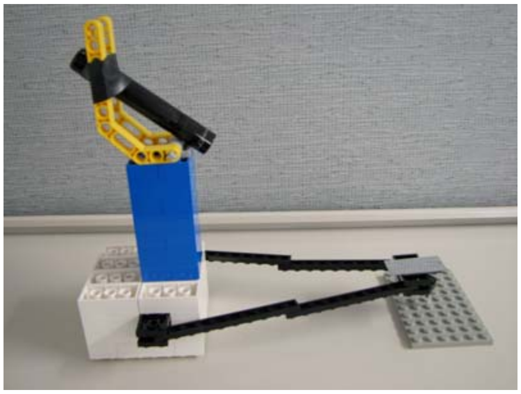


Figure 1 - The general principle behind force microscopy: Forces between the surface and the cantilever tip cause the tip to be deflected upward and downward. Deflection of the cantilever shifts the position of a laser beam that reflects off the top of the cantilever onto a photodiode array. The movement of the beam is tracked by the photodiodes and used to calculate the cantilever deflection. *Courtesy of Board of Trustees of Bradley University. (2004) Exploring the Nanoworld with LEGO®*

Pre-Lab Instructions: Magnetic Force Microscope Assembly (50 points):

The first step in magnetically mapping a surface is to construct a tool or instrument to image the surface for you. For this module, you will use Lego blocks and magnets to construct a probe tool. The following procedure outlines a good Lego MFM tool to probe the unknown surfaces.However, it is by no means an optimum tool. <u>In the pre-lab portion of this lab, your team will design and assemble magnetic Force Microscope, which you will use in the lab section to determine several unknown patterns.</u> The basic procedure provided would result in a Lego MFM tool that looks like this:



You are highly encouraged to modify the MFM design to improve its' qualities, which you may need to do for the most difficult sample of the three you will measure. Some parameters that you may want to improve are:

- resolution (how small a magnetic region can you isolate and image)
- tip interaction strength (how strong is the magnet at the tip? What is the magnet polarity?)
- cantilever travel length (longer cantilevers tend to bend more under the same force)
- variable tip height from the surface

<u>Additionally, you are not limited by the parts in your kit.</u> If you need additional Lego bricks you may stop by the EDL labs and sort through the extra parts. You can also use your own Lego bricks, or any other materials, which may be helpful to you. You may use any idea you come up with to build the best tool you can.

In order to design your tool to the correct dimensions, the unknown boxes to be probed are the roughly the same size as your EDL textbook. You can use your textbook as a sample to determine if the height and length of the cantilever are correct.

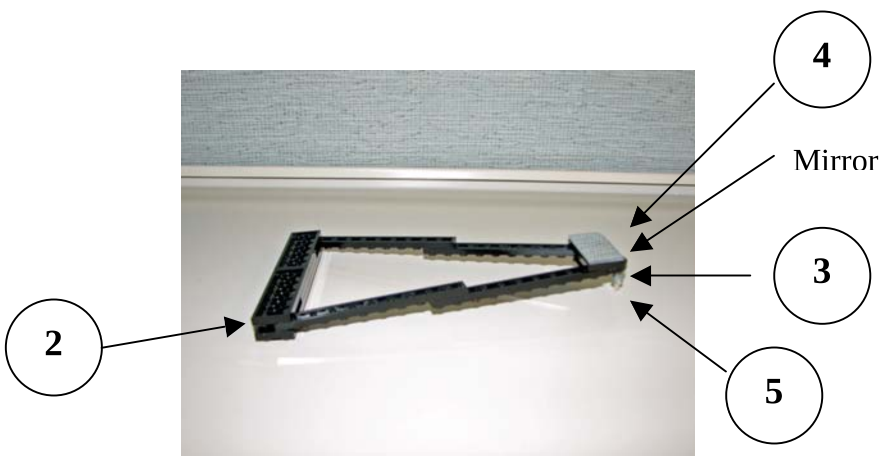
Basic MFM Assembly Procedure:

The MFM construction has three important parts; a cantilever with a tip, a supporting platform, and a light source mount. The cantilever is typically long and needs to be supported by a suitable structure (the platform). Below you will find step-by-step instructions to make a basic LEGO MFM.

1. Build the Cantilever

Parts List
2 X 6 Plates – 4 ea
1 X 10 Plates – 4 ea
2 X 4 Plates – 3 ea
LEGO magnetic brick – 1 ea
Triangular Probe Tip – 1 ea
Mirror – 1 ea
Connecting Pin – 1 ea (alternative method)
Guitar pick or substitute cut to make tip (alternative method)

1. Assemble cantilever as shown below using plates. This is a three layer assembly that must be of the same thickness as a standard brick.
2. Use 4 ea 2 X 6 plates and lock together in the center using a 2 X 4 plate. On either end use 4 ea 1 X 10 plates connected as shown.
3. Connect other end using 2 ea 2 X 4 plates.
4. Attach mirror to the top side using double sided tape.
5. Attach a magnetic brick to the underside. Other suitable shapes and materials for improving the sensitivity of the instrument can be substituted at the tip.

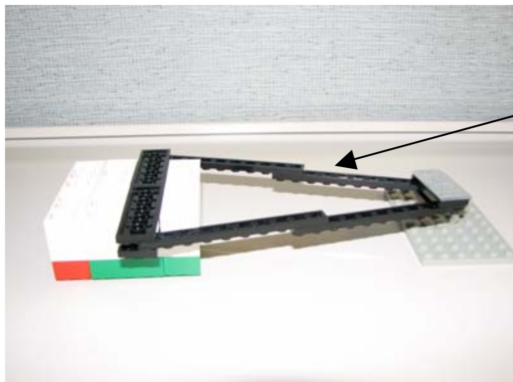


Cantilever assembled with mirror

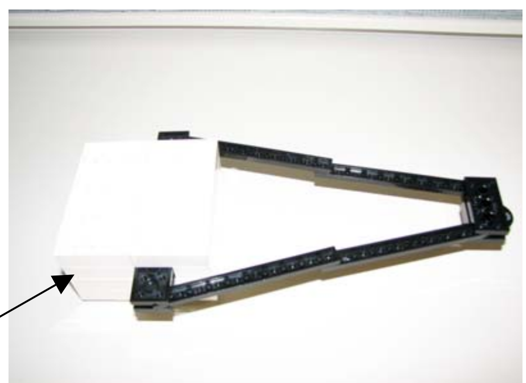
2. Build the Platform

Parts List
2 X 4 Bricks – 30 ea

Construct platform as shown in the following pictures. The platform needs to perform two duties. First, it must be heavy enough to prevent the cantilever from falling over. Second, it needs to provide some height so the cantilever is above the surface to be measured.



Cantilever from Step 1

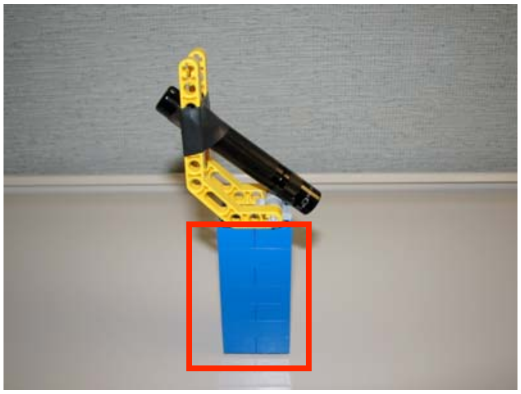


This is the important height you need to maintain

3. Build the Light Stand

Parts List
2 X 4 Bricks - Varies

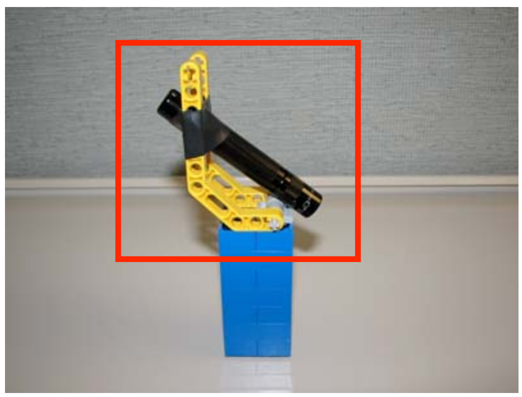
Construct a stand to place your light source on using 2 X 4 bricks. This stand may vary in height depending on your design, but for the basic MFM the height would be 7 levels (17 bricks) to accommodate the light. Please note that you will be issued the light source when you get to your lab session. If you want to practice, any laser pointer or mini flashlight will work also.



4. Light Source Mount

Parts List
2 X 3 Brick – 1 ea
Lever arm – 2 ea (alternate method)
Laser Pointer – 1 ea (provided in lab session – not in your parts kit)
4 Stud Axle – 1 ea (alternate method)
2 X 2 Plate with Axle Holder (alternate method)

- Take two lego lever arms (yellow in picture), and place them on top of the light stand, as shown. This part could be substituted by using a LEGO hinge or a 4 stud axle
- For reference: when you get to lab, you will be issued a laser pointer, which you will Tape or rubber band in the gap between the arms. The light source has to be positioned to shine light on top of the cantilever mirror. In the picture, the bulb of the penlight is near the light stand (blue bricks)

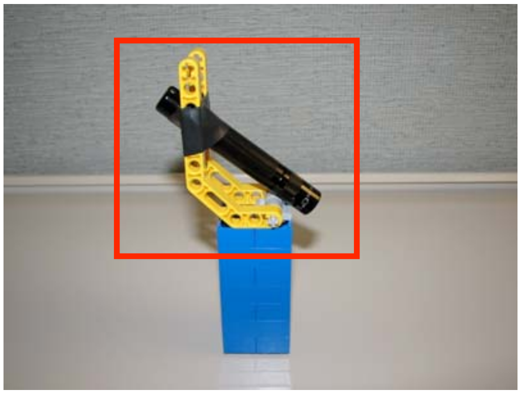


This is the end of the pre-lab. Provided you show up to lab with an MFM tool, you get the 50 points.

What to do when you get to Lab

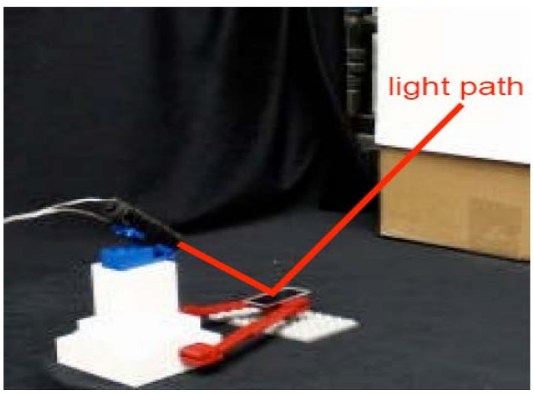
1. Install the light source:

The first thing to do is to obtain a laser pointer in the laboratory. Once you have the laser pointer, you will tape or rubber band it in the gap between the arms. The light source has to be positioned to shine light on top of the cantilever mirror. In the picture, the bulb of the penlight is near the light stand (blue bricks)



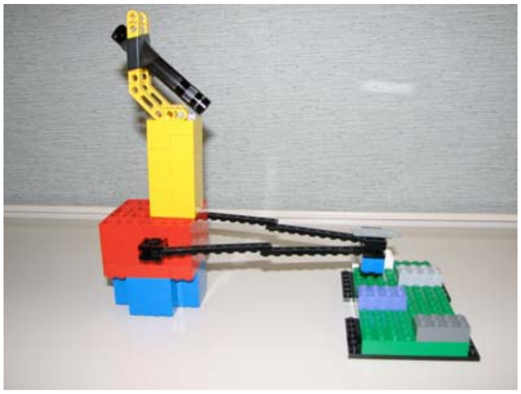
2. Align the light source

Adjust your light source so that it is striking the mirror and reflecting onto a wall or screen.



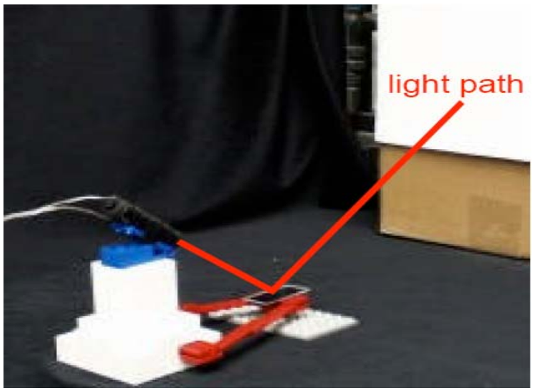
3. How to use the MFM tool

Moving your substrate beneath the probe tip will simulate the movement within an MFM. In this model, the magnetic LEGO brick will be in a non-contact mode with the substrate. As your MFM scans over a magnetic surface (bricks), there will be a strong interaction between your probe tip and the magnetic surface. Raise your cantilever platform by a height of at least three full bricks. Move your substrate underneath the magnetic probe tip and observe the movement of the cantilever and the reflected light on the wall or screen. This is simulating the operation of a Magnetic Force Microscope.



4. Calibration and measurement

Adjust your light source so that it is striking the mirror and reflecting onto a wall or screen. Moving your substrate beneath the probe tip will simulate the movement within an MFM. The movement of the Lego tip over the substrate surface will result in deflection of the cantilever. Light from the light source will reflect from the mirror on the cantilever and shine on a wall or screen. The farther the wall is from the AFM, the more the cantilever deflection will shift the beam on the wall. By putting markings on the wall with measured tape or by taping a ruler to the wall, you can measure the deflection of the cantilever.



You will be provided with a sheet of laminated grid paper for this lab session. You should put your MFM on the grid paper, and by moving the MFM tool over the grid paper as you scan the unknown boxes you can build a map of magnetic strength on the grid paper using the deflected light.

Congratulations, you are now performing scanning probe microscopy!

As you attempt to identify the patterns in the unknown boxes, there are some things to consider.

1. You will need to design a coordinate system for recoding the map on your lab sheet, so make sure you choose a good grid spacing. The grid provided may be adequate for the easy box, but it is unlikely to provide the resolution you need for the harder boxes.
2. For the easy box, simply measuring the presence of magnetic domains within the unknown sample will probably give you a decent map. However, as the boxes get more difficult, you may need to measure relative field strengths (e.g. HOW MUCH does the cantilever deflect?)
3. It is important to write down the ID number of the box you measure – they are all different!

THE EASY DIFFICULTY UNKNOWN BOX (20 points for correct identification)

Box ID Number: ______

Draw the pattern in the box here:

THE MEDIUM DIFFICULTY UNKNOWN BOX (15 points for correct identification)

Box ID Number: ______

Draw the pattern in the box here:

THE HARD DIFFICULTY UNKNOWN BOX (10 points for correct identification)

Box ID Number: ______

Draw the pattern in the box here:

DESCRIBE YOUR MODIFICATIONS TO THE BASIC DESIGN (15 POINTS):

Did you modify your MFM tool? ________

If so, describe the modifications and your rationale in making them:

Did the modifications work as you expected them to?

Would you modify the MFM differently than you did? Why?