Teacher's Preparatory Guide

Small Scale Stenciling: Mask Lab

Overview: This lab is analogous with some nanofabrication processes. This lab will help students understand some of the challenges encountered while making semiconductor chips and waveguides, both of which are found in electronic circuits. An additional lessons on wave guides can be found at:

http://www.nnin.org/nnin_wave_guide.html
http://www.nnin.org/nnin_k12_waveslinky_ucsb.html

Purpose: This lab is part 1 of a 2-part series of inquiry-driven labs designed to help students understand the process of patterning materials through selective exposure and development of films.

Time Required: One 45-minute student lab period, plus one pre-lab class

Level: Middle school or high school

Teacher Background: Computer chips are made layer by layer from the bottom to the top. Bottom up fabrication is one method of building nanostructures compared to top down which reduces the starting (bulk) material to obtain nanomaterials. Bottom up is akin to constructing an office building floor by floor with the caveat that all the plumbing, ventilation and electrical systems have to be installed as each floor is created. Thus each layer in the design requires not only careful planning, but multiple assembly processes as well to make sure that one layer is connected properly to the next.

One important step in the processing of computer chips is *photolithography*. It uses the interaction of light and chemicals to create patterns on silicon wafers. During this step, the "blueprint" for a layer is transferred onto the material and subsequent processing creates a pattern by adding or taking away material. The blueprints for each layer are printed on masks. Completed computer chips may need 12 or more different masks depending upon the complexity. The masks are created to block ultraviolet light in certain areas. The mask is placed over a photosensitive material (called *photoresist*) and ultraviolet light is shone through the mask. After developing the photoresist (similar to the process used in photography), the pattern from the mask is transferred to the photoresist. There are two types of photoresist, positive and negative, which form positive or negative images from the pattern on the mask as shown to the right.

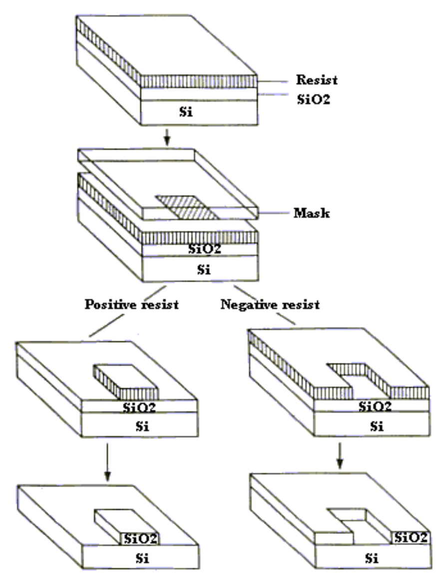

Image source:
http://www.ece.gatech.edu/research/labs

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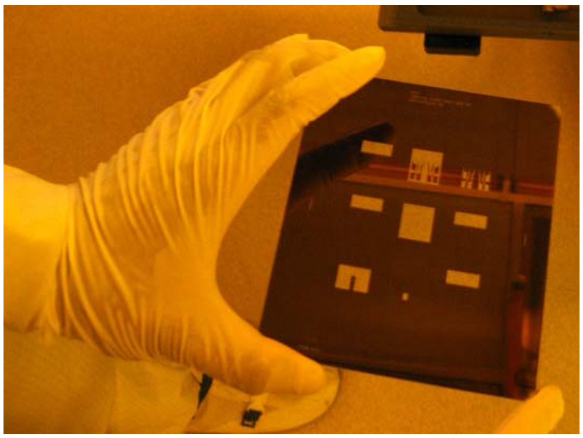
After the photoresist is developed, it can be used as a stencil. The diagram to the right shows the stencil used as protection from a chemical reaction, thus the exposed SiO_2 layer is dissolved, while the SiO_2 portions that are protected by the photoresist layer remains.
The photoresist can also be used as a barrier to new material deposition and ion implantation.

Advancements in technology require more complex and smaller computer chips. Devices on the **nanoscale** are being developed, which are 100–1000 times smaller than the computer chips used presently. Presently there are transistors being manufactured in the size of 45nm, 32nm, and 22nm. The miniaturization of electronic technology at the nanoscale allows for smaller and faster devices.

One of the limiting factors to scaling down devices is the photolithography process. To make smaller features requires the use of smaller wavelengths. The typical photolithography system uses light sources with wavelengths of 300 to 400 nanometers (nm).



This is an example of a mask. The features on the mask are so small—on the order of microns to nanometers—that they are not visible to the eye.

Factors such as the sensitivity of the photoresist to light and various chemicals and the wavelength of the exposure light affect how small the stencils can be. One method of assessing the quality of the pattern in the resist is to trace the **profiles** of the features created. Straight sidewalls and clean edges in the stencil allow for better control of the shape and size of the pattern.

Background to the ultraviolet beads: Ultraviolet light is defined by a wavelength range of 10–400 nm. Depending upon the quality of the glass, most glass is partially transparent to UV wavelengths above 300 nm. UV wavelengths below 300 nm are mostly absorbed by the oxygen in the air. The ultraviolet detecting beads contain molecules that absorb the energy from the UV light and are temporarily altered so that the molecules absorb a certain wavelength. For example, a bead that has molecules that are altered to absorb red wavelengths will appear blue when placed in UV light.

Background to the solar print paper: The solar print paper is coated with a solution of Potassium ferrocyanide and Ferric ammonium citrate. Exposure to UV light reduces the iron(III) to iron(II), which is followed by a reaction with the ferrocyanide. The product is a blue dye called Prussian blue (ferric ferrocyanide), which is insoluble in water. Using the solar print paper simulates a negative photoresist because the exposed area remains.

Though the solar print paper will not have a developed "photoresist layer" as seen in the third step of the diagram above, the students will draw a profile of the cross section to help reinforce the understanding of the chemistry that is occurring. In an actual research environment, an

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instrument to trace the profile of the developed photoresist layer is useful in determining the height of the photoresist and the sharpness of the edges, often on the nanoscale.

Materials per class

- 2 packs of solar print paper
- 1 pack ultraviolet (UV) beads
- 3–4 transparency sheets
- Sharpie® fine point markers
- 5 shallow pans each with 2 cups of water (can be aluminum or plastic about 8” × 11”)
- paper towels
- *Silicon Run Lite* DVD ($150) or alternatively You Tube or other internet video sources on how silicon chips are made:
    - http://www.youtube.com/watch?v=aWVywhzuHnQ
    - http://www.youtube.com/watch?v=6hcZq2fMN-o
    - http://www.youtube.com/watch?v=lrsPzbUJwl8
    - http://www.stupidvideos.com/video/science_technology/Making_A_Memory_Chip_At_Lexar/#332217
    - http://www.youtube.com/watch?v=wPHD1r0KR7k
    - http://www.poloniusficklebottom.com/Chip.html
- sun or UV flashlight
- class set of digital timers
- 1 cleanroom suit (optional)

Materials per lab group of 2 students

- 2 pieces of small solar print paper (2” × 2”)
- 1 piece of large solar print paper (2” × 5”)
- 1 mask printed on a transparency
- 2 blank small pieces of transparencies (2” × 2” and 2” × 5”)
- 1 Sharpie® fine point marker
- paper towels
- 1 digital timer

Advance Preparation Materials can be purchased from many educational supply companies. The sources/websites below are suggested places to start shopping.

Material	Source/Website
ultraviolet detecting beads	**Educational Innovations** (http://www.teachersource.com) **Steve Spangler** (http://www.stevespanglerscience.com/)
solar print paper	**Science eStore** (http://www.physlink.com) or the above vendors
transparencies and Sharpies®	office supply store
Silicon Run Lite DVD	**Silicon Run Productions** (http://www.siliconrun.com) Or Internet videos on computer chip fabrication
UV Flashlight and Holder (optional)	**Arbor Scientific** (http://www.arborsci.com)
cleanroom suit (optional)	**Arrayit Corporation** (http://arrayit.com)
mini longwave UV lamp	**Ward Science Company** (http://wardsci.com)

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1. ***Purchase ultraviolet detecting beads.***
   These beads come in packages of about 240 beads. They can come in a single color or a variety pack of colors. When purchasing the beads, choose a single color in which the color change has a large distinct range. Purchase enough beads so that each student can have at least two beads (a control and a variable) with which to experiment at home.
   To get the students started, brainstorm as a class different experiment ideas and encourage them to test items at home. For example, sunscreens, eyeglasses, sunglasses, and car windows are known to block some UV light.

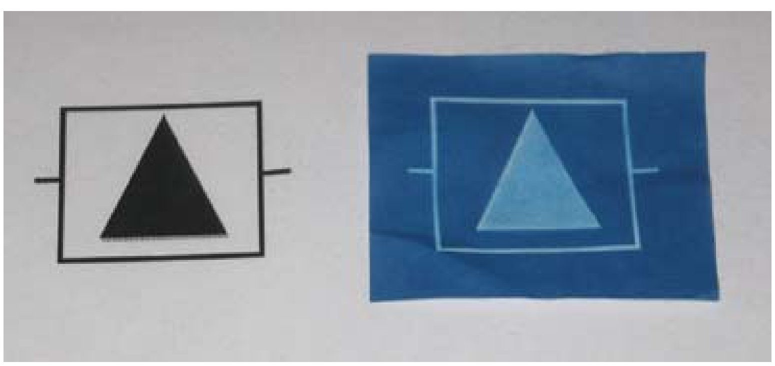
This pair of safety glasses blocks some UV light as seen with this simple set up.

2. ***Purchase and cut solar print paper.***
   Solar print paper comes in packages of 5” × 7” sheets (40/pk). Cut the sheets in sixths to hand one to each student, so two packs will accommodate more than one class for the lab and for the homework.

These are examples of solar print images made with toys, children’s jewelry and plants around the house.

Encourage students to use items with small features. The toy astronaut was 3-dimensional, but because of the shadowing caused by the angle of sunlight some features can be revealed.

3. ***Print out masks on transparencies.***
   You can use the simple design below to create one mask for each lab group. A sheet of designs is included with this lab packet. Print out the masks on transparency sheets and cut up individual masks to hand to each group. Cut up 2 blank (2” x 2” and 2” x 5”) pieces per group as well for the latter portion of the lab.



This is a sample mask and the resulting image.

The small horizontal bars are to indicate start and end points of the profile sketch.

4. ***Prepare areas in which to expose images and develop prints.***
   Plan locations to send students to expose their images. Each image will take approximately 3 minutes to expose. The paper should turn white when exposure is finished. If sending students outdoors is problematic, then consider setting up an ultraviolet (UV) light area in the room. Using the sun is less expensive and also allows discussion on topics such as why UV

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light is available even though it is cloudy or why UV rays are harmful. Also, set up pans of shallow water in which to develop the images. Each image will take 30–45 seconds to develop. Have paper towels ready to dry the solar prints.

5. ***Obtain cleanroom suit.*** **(optional)**
   One way to bridge the environment shown in the video and the classroom is to don a cleanroom suit and start class. This can definitely start discussions as to the importance of the suit for cleanliness and the microscopic size of particles that can damage the production of computer chips that often have features smaller (micro and nano in size) than the particles coming from the body. New suits can be purchased through a variety of companies. If there are local companies or universities that have cleanroom facilities, try contacting them with a request for a used cleanroom suit for teaching purposes. Teaching an entire class in a cleanroom suit may be uncomfortable however for it retains heat. To tour a cleanroom visit: http://www.mcrel.org/nanoleap/remote_access/cleanroom.asp. To have the students see a cleanroom in action visit Georgia Institute of Technology's cleanroom webcams: http://grover.mirc.gatech.edu/cameras/.

Safety Information: There are chemicals on the surface of the solar print paper that are washed off when developed in the pan of water. Be careful not to splash the water into the eyes or onto the body. Rinse with water if that should occur.

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Instructional Procedure

Time	Activity	Goal
Prior to lab		
Homework	Experiment with UV beads: Students will take home two UV beads and design a simple experiment to see what materials filter or block UV light.	Certain materials can "mask" ultraviolet (UV) light. UV light can be used to make patterns on materials.
10 min	Ask students: What things are in cell phones and computers that make them work? *integrated circuits* What has recently changed that allows cell phones and computers to be smaller and more complex? *Components on integrated circuits are smaller and can do more functions.* Introduce key terms/concepts (see *Guided Dialog* section).	Provoke thought and review what students already know.
26 min	View *Silicon Run Lite* video (or other online videos noted above), which discusses how computer chips are made. Ask questions in *Teaching Strategies #5* to ensure understanding.	Masking/Etching are important processes in the production of computer chips.
Day 1		
8 min	**Review process steps from video, scene 5 Fabricating Transistors.**	Review fabrication steps; point out patterning with masks.
35 min	**Mask Lab:** Students use a mask to create an image, and then design two masks.	UV light can be used to create images. Masks can be used in different ways to create desired effects.
Homework	Students take a small sheet of solar print paper home to develop prints of objects from home.	Objective is to reinforce the idea of masking.

Guided Dialog *Before* beginning the lab, review the meaning of these terms:

Mask *A material that contains a pattern to be transferred.*
Profile *The side view of an object—in this case, a cross-sectional view.*
Positive image *An image that is an exact duplicate of the pattern.*
Negative image *An image that is the inverse of the pattern.*

Teaching Strategies

1. ***Jump start UV beads homework.*** Hold the bag of beads in sunlight or UV light to let the students see the change as it occurs. As a class explore what may be triggering the change in color. Then ask the students to play with the beads as their homework. Challenge them to find materials that may filter part of the UV light or completely block the UV light. Sunscreen and sunglasses may be obvious materials to play with but car front windshields might not be. Some other materials to try may be different glass containers and fabrics. Remind them to write up one of their discoveries formally using the lab sheet included. The lab sheet is designed around science fair project boards. To quantify their experiment, have the students establish a color scale to approximate the amount of UV light exposure.

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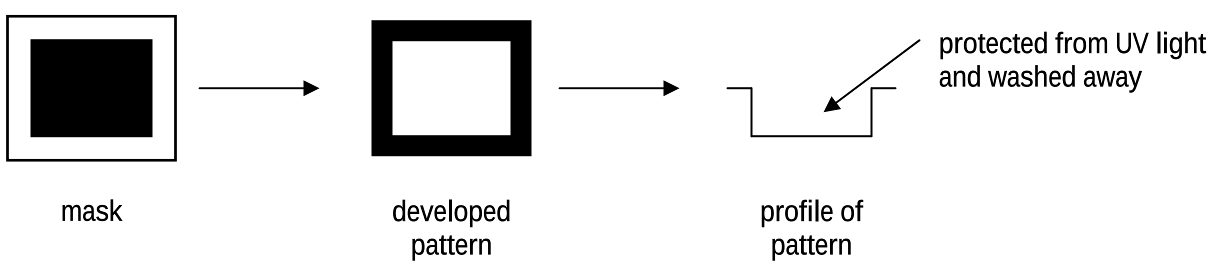
2. ***Keep solar paper for homework in a dark flat place.*** Help the students find a safe spot for their solar print paper. Instructions for exposure and development are on the backside of the homework sheet provided.
3. ***Preface the Silicon Run Lite video.*** The questions provided in the Instructional Procedure may help students understand the content to be addressed. In addition, mention the growth of the computer chip industry and then describe the location of Silicon Valley. The labs shown are slightly dated but the technology has not changed too much.
4. ***Review processing steps.*** Before the activity, it would be helpful to either replay the few minutes of process animation that is relevant to the lab or discuss as a class for reinforcement and review. Though the students will have seen *Silicon Run Lite,* the process outlined in the video goes by quickly and can become overwhelming.
5. ***Pose questions before the lab.***
   a. Why are multiple masks used to form one computer chip? *One device consists of many layers of materials that are connected together in a complex fashion. Each layer requires one or more masks to form the required connections.*
   b. Why is it important that masks be precise? *Errors or defects in the masks will result in a breakdown of connection from one layer to the next.*
   c. Why is UV light used to expose photoresist? *UV light has shorter wavelengths than visible light, enabling more precise exposures for smaller features.*
6. ***Drawing Profiles*** – Students may have trouble drawing profiles from their solar prints. Going over a simple print as a class before starting that section of the lab may be useful for the students. During the lab itself, have student groups check each other's profiles to help confirm the correct answer.
7. ***Optional – Wear a cleanroom suit.*** If possible, obtain a simple version of the cleanroom suit shown in the video to wear into class for the lab. This will help students bridge the gap between the classroom and the high tech labs shown in the video. It will also spur the discussion of why such protection is needed. When making extremely small devices, something as small as a dust particle on a mask or embedded in one of the layers of materials is catastrophic to the resulting computer chip.
8. ***Demonstrate how to draw a profile of a pattern.*** Drawing profiles allows the students to better understand the chemical reactions that are taking place in the development of the solar print paper. Areas that are exposed to UV light become insoluble in water and therefore remain; whereas, the areas not exposed to the UV light wash away with the rinse water. In the mask below, the dark regions protect the solar print paper from the UV light.



9. ***Show positive and negative images.*** Students may have trouble with the concept of negative images. Perhaps showing actual negatives from photos on the projector may help.
10. ***Keep solar print paper from UV light before actual exposure.*** Have students keep solar print paper faced down or covered before actual exposure.

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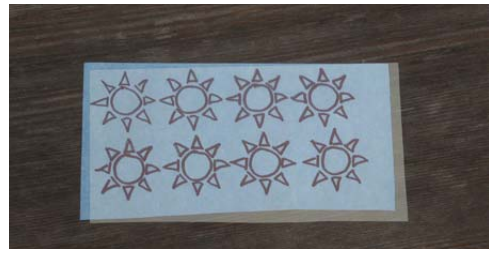
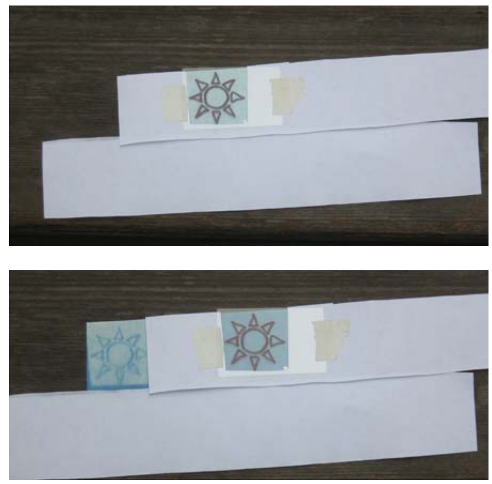
11. ***Hint at possible solutions to the challenge.*** Students will be asked to image multiple patterns on one solar print paper as a challenge. Here are two possible solutions if the students are struggling.

   A. The students can hand draw the pattern to be copied multiple times on the blank transparency, then expose the entire pattern once. In this simplest method, the drawbacks will be inconsistency with the pattern features; however, only one exposure is needed. In the cleanroom, this method is called **contact printing**.



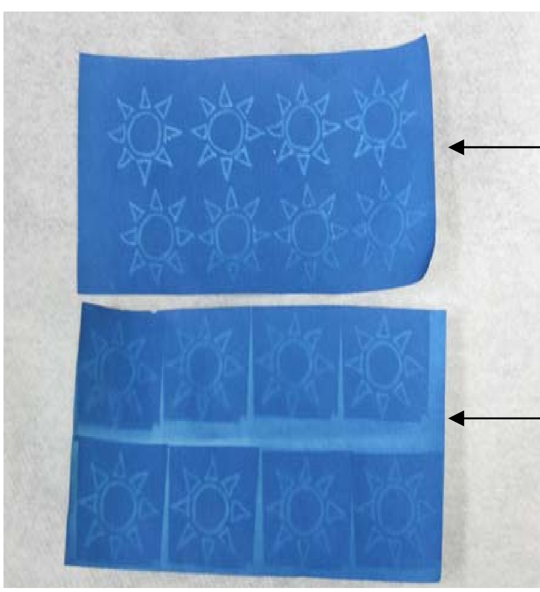
multiple patterns on one mask with one exposure

   B. In another method, multiple chips are made on a single wafer using a **photostepper**. As shown in the video, one pattern is shrunk using a series of lenses and exposed on one section of the wafer, then the wafer is moved and the pattern is exposed on the new section. By this method of "stepping" around the wafer, one pattern is copied multiple times. This method can be applied to the solar print paper (though without the lenses) by carefully protecting the unexposed parts of the paper while exposing a small section to the pattern. The advantage to this method is that each pattern made is an exact copy of the first pattern; however, there are multiple exposures needed.



One pattern is exposed multiple times on the solar print paper. You need to keep rest of the solar print paper covered during each exposure.

The picture below shows the difference between the two types of masks and exposures.



Method A: multiple images on one mask

Method B: single pattern and multiple exposures

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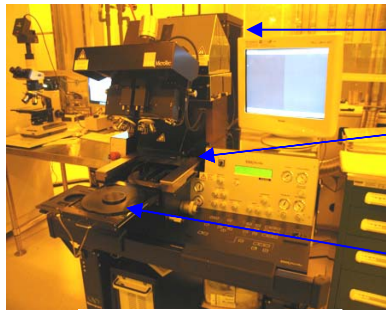
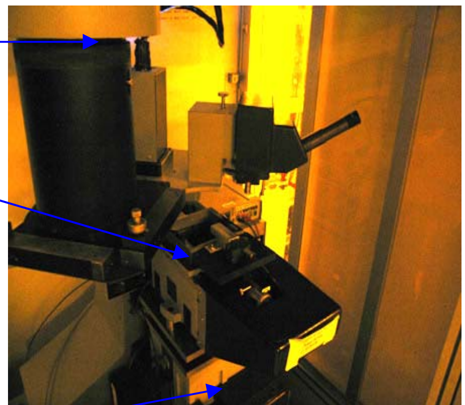
As seen in the *Silicon Run Lite* video, the photolithography in a production facility is largely automated. There are different machines for each type of mask/exposure method. The following pictures were taken in the University of California Santa Barbara Nanofabrication Facility. Note that the rooms housing the machines have special lighting; this is to ensure that accidental exposure of the photoresist does not take place.

The machine that is most similar to Method A is the **Contact Aligner**. The mask is literally in contact with the photoresist layer as it is exposed with UV light.



Contact aligner



Photostepper

This machine is called the **Photostepper**. The UV light is housed on top, while a special arrangement of lenses guides the light to the sample below.

List any last minute details that the students must remember. Now, begin the lab.

Cleanup Students should clean up their lab tables and wash their hands. The pans of water used to develop the solar paper can be rinsed down the drain.

Enhancing Understanding Cover this section *after* the activity.

> Some students may have developed a stepping method of exposure that allows the same image to be exposed repeatedly over a sheet of solar print paper. This process is similar to what was shown quickly in the video and uses a machine called the photostepper. You can review this portion of the video after the class shares results to show students how their solutions are similar to the solutions arrived by engineers.

Going Further If aligned with an optics unit, this activity could be offered to challenge students:

Create a photostepper as seen in the *Silicon Run Lite* video using the materials in the lab and some lenses.

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You may not have enough UV light to create an image on the solar print paper, but a simple stepper can be built with a magnifying glass imaging distant objects onto a piece of paper.

Assessment: Students should be able to explain how photolithography (chemical and light interaction) is used in creating computer chips and how UV light creates an image on solar print paper. Advanced students should be able to identify positive and negative images.

Resources: You may wish to use these resources either as background or as a resource for students to use in their inquiry-based design.

- Photolithography
  http://www.ece.gatech.edu/research/labs/vc/theory/photolith.html
- Computer Chip Thermochemistry: How Can We Create an Integrated Circuit from Sand?: Exploration 1C: How are integrated circuits built?: Using Photolithography
  http://chemlinks.beloit.edu/Chip/pages/photo_.html
- Center for Hierarchical Manufacturing: Photolithography
  http://www.umassk12.net/nanodev/NanoEd/Photolithography

National Science Education Standards (Grades 5–8 and Grades 9–12)

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Properties and changes of properties in matter

Content Standard E: Science and Technology

- Abilities of technological design

California Science Education Standards (Grade 8)

Physical Sciences, Content Standard 5: Reactions

b. Students know reactant atoms and molecules interact to form products with different chemical properties.

Investigation and Experimentation, Content Standard 9

a. Plan and conduct a scientific investigation to test a hypothesis.
b. Evaluate the accuracy and reproducibility of data.
c. Distinguish between variable and controlled parameters in a test.

California Science Education Standards (Grade 9–12)

Physics, Content Standard 4: Waves

a. Students know waves carry energy from one place to another.

Investigation and Experimentation, Content Standard 1

d. Formulate explanations by using logic and evidence.

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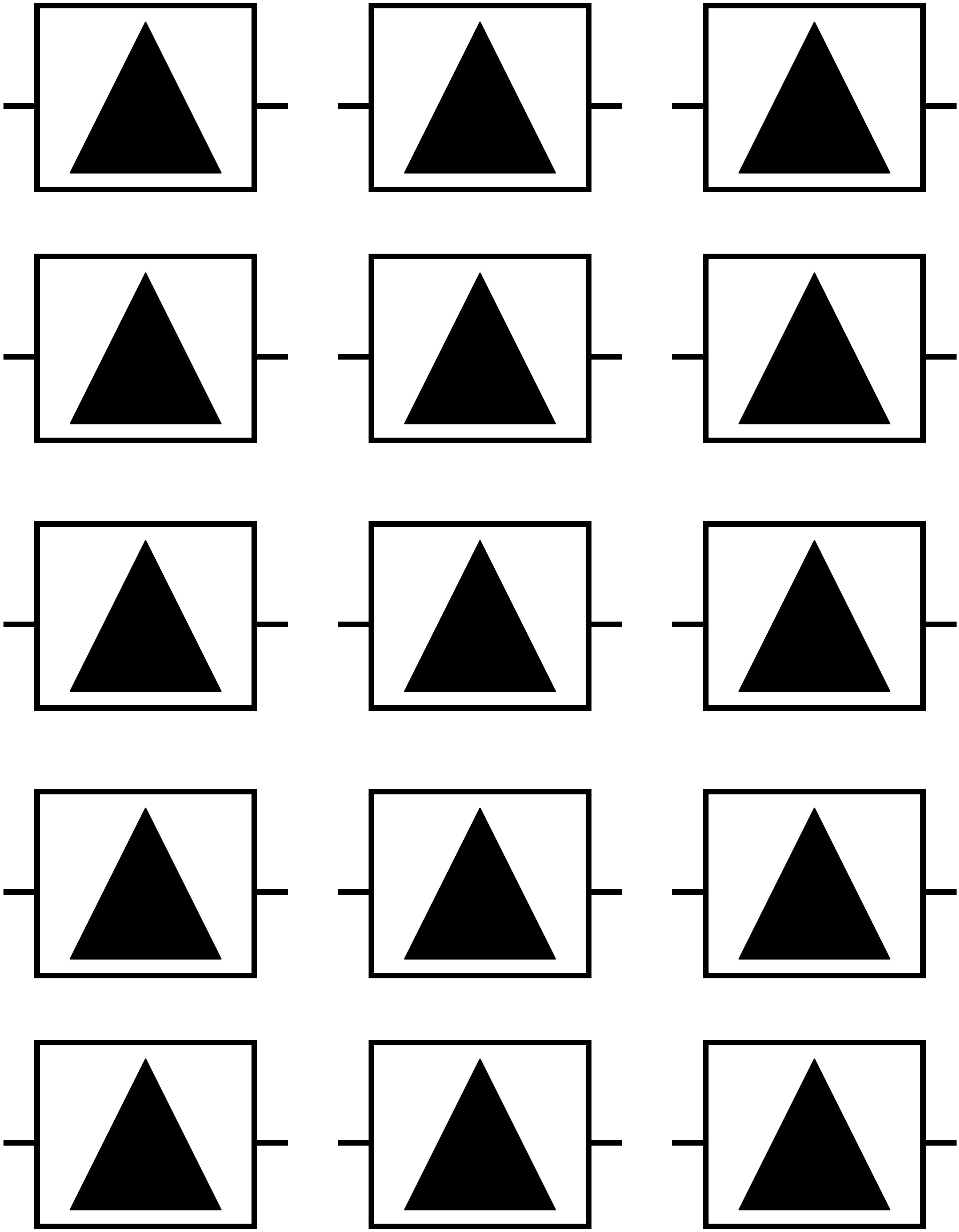

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