



**Learning About
Semiconductor
Technology**

INTRODUCTION TO CLEANROOMS

**HIGH SCHOOL CHEMISTRY
HIGH SCHOOL PHYSICS
HIGH SCHOOL MATHEMATICS**

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Introduction to Cleanrooms

Lesson Overview	Career Highlight
<p>Students will learn about microchip contaminants that can impact the semiconductor manufacturing process. They will then learn about personal protective equipment (PPE) that protects microchips from being contaminated. Students will learn about different aspects of cleanrooms, including positive pressure environments. They will learn about static electricity and explore how electrostatic grounding is effective in cleanrooms. Finally, students will participate in a cleanroom simulation to check for understanding.</p>	<p style="text-align: center;"> Cleanroom Operator Field Service Engineer Facilities Technician Maintenance Technician </p>

STEM Course Connections	21st Century Skills	CTE Alignment
<p style="text-align: center;"> High School Chemistry High School Physics High School Mathematics </p>	<p>Critical Thinking</p>	<p>Health Science and Medical Technology Industry Sector</p>

Engineering Activity	
<p>Science and Engineering Practice #5</p>	<p>Students will participate in a cleanroom simulation and virtual simulation to demonstrate their knowledge of PPE, electrostatic grounding, and positive pressure environments in semiconductor manufacturing.</p>

Materials
<ul style="list-style-type: none"> ● Aquarium/terrarium ● Balloons ● Binder clip/alligator clip ● Cheesecloth ● Cleanroom Simulation Scoring Rubric ● Crayons ● Dry ice ● Fan ● Funnel ● Leaves ● Lego bricks (~10 pieces) ● PPE samples (gloves, hats, booties, gowns, etc.) ● Shoe box

- [Student Handout](#)
- Tongs

Essential Questions

1. How does a cleanroom protect microchips from being contaminated?
2. How is positive pressure used to prevent contaminants from entering a cleanroom?
3. What is the function of Personal Protective Equipment in the semiconductor manufacturing process?

Prerequisite Knowledge

Students should have a basic knowledge of what a microchip is, and the uses for microchips within the semiconductor industry. Students should also have general knowledge about charged ions and energy transfer. Recommended HTU lessons include: Introduction to Semiconductors; What are Semiconductors?; Education and Career Pathways; Semiconductor Industry Introduction + Pathways

Engage

Leaf Imprinting Activity (25 mins)

- Give each of the students two pieces of paper, a large (maple-sized) leaf, and a crayon. Students should peel the paper off of the crayon.
 - *Teacher Note: If possible, students should search for their own leaves to press*
- Have the students lay their respective leaves on their desks, and put one of the pieces of paper on top of it. Each student will then use his or her crayon on its side to rub back and forth across the paper, until the image of the leaf beneath is clearly seen.
- After most of the students are done with their first leaf imprint, the teacher walks around to each of the students and puts a small handful of sand or fine gravel on top of each of the students' leaves. Then, students will place their second sheet of paper over the leaf and attempt to repeat the process.
- After both leaves have been imprinted, students will use a marker to trace the veins of the leaf on the page, being careful to lift their marker whenever a "disconnect" is seen in the vein. The leaf imprint with the sand on it will likely have more breaks in the veins than the first leaf.
- Students will answer Questions 1 through 3 in Section A of the [Student Handout](#).
 - What did you notice about the outcomes between the first and second leaf imprints? *The second one was much more difficult to do because of the small objects in the way.*
 - Which of the leaves had more disconnections between the traced lines, and what caused those disconnections? *The leaf with the sand had more disconnections because the sand caused imperfections in the print.*
 - Imagine the leaf imprint is a highly precise microchip and the sand is a foreign contaminant. What might these disconnections be represented as in a microchip? *It could mean an interruption in the electrical circuit and it could cause the microchip to malfunction.*
 - How could we potentially prevent this problem from occurring in a manufacturing facility? *We could use some sort of cleanroom where there aren't any contaminants around.*

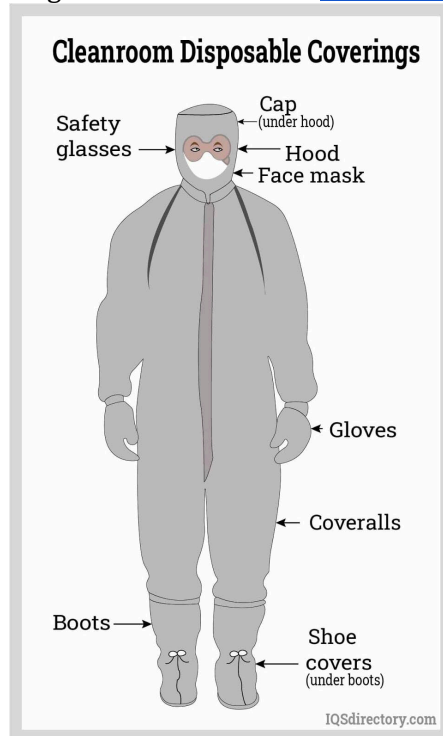
Explore

Microchips Defined (15 mins)

- Students will watch a [Technology Size Comparison](#) video and answer the questions in Section B of the [Student Handout](#).
 - Which of the electronic components shown did you recognize? *Answers will vary.*
 - What surprised you about the size of some of the components relative to some of the other objects referenced for scale? *Answers will vary.*
 - What is the smallest component of a microchip? *A transistor (it's the size of human DNA!)*

Personal Protection (15 mins)

- With partners, students will discuss the following questions and take notes on Section C of the [Student Handout](#):
 - When you want to protect yourself from each of these, what do you do?
 - Germs *Wash hands, wear gloves, wear a mask*
 - Mud *Wear boots or coverings on your shoes, clean them off before entering a room*
 - Smoke/fumes *Wear a mask or respirator*
- What is PPE (Personal Protective Equipment)?
 - *Teacher Note: It is best to be able to model examples for students, including gloves, hats, booties, and lab coats or gowns. If this is not possible, printing out pictures and sharing with students is a great alternative.*
 - Students will label the image on Section C of the [Student Handout](#) with the different types of PPE.



Explain

Why Cleanrooms? (20 mins)

- The teacher will guide the class through a See, Think, Wonder activity.
 - Students will be given two minutes to silently look at and analyze the picture.



- After two minutes, the teacher will guide the students—as a class—through writing their observations, reflections, and questions in the specific categories in Section D of the [Student Handout](#).
- *Teacher Note: See the [Library of Congress](#)' teaching resources for more information about this teaching strategy.*
- The teacher will write down student answers on the board.
- Students will answer the reflection question in Section D of the [Student Handout](#).
 - What else besides PPE is important for a clean work space? *A clean work environment, or a cleanroom.*

What are Cleanrooms? (10 mins)

- As a class, watch the [video](#) and answer the questions in Section E of the [Student Handout](#):
 - What is a cleanroom? *A contained environment in which multiple parameters are precisely monitored and controlled.*
 - What is the purpose of a cleanroom? *To reduce contamination and control conditions within the controlled environment.*
 - What is a contaminant? *Anything that can corrupt a process or product.*
 - What is the primary source of contaminants? *Humans.*
 - How are cleanrooms classified? *By how many airborne particles are detected per cubic foot.*
 - What is the primary difference between a semiconductor processing cleanroom and a biological cleanroom? *Semiconductor processing cleanrooms focus on keeping foreign contaminants out, while biological cleanrooms are primarily concerned with keeping harmful contaminants contained inside of them.*
- Share answers as a class.

Cleanroom Classifications (15 mins)

- Students will walk through a cleanroom classification calculation with a partner.
- Students will work through the problem in Section E of the [Student Handout](#):

- An ISO-8 Cleanroom is one of the least-restrictive cleanroom classifications. It has the following requirements:
 - 20 changes of HEPA-filtered air per hour
 - Fewer than 29,300 airborne particles larger than 5 microns per square meter
- How many airborne particles larger than 5 microns can we expect in a cleanroom environment that is 10x12x2 meters in size? *Fewer than 7,032,000*
- How many changes of air need to be achieved in one day? *480 air changes*

ISO 14644-1 Cleanroom Standards

Class	Maximum Particles/m ³						FED STD 209E equivalent
	>=0.1 μm	>=0.2 μm	>=0.3 μm	>=0.5 μm	>=1 μm	>=5 μm	
ISO 1	10	2					
ISO 2	100	24	10	4			
ISO 3	1,000	237	102	35	8		Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room Air

Teacher Note: Each of the corresponding numbers in the “Maximum Particles per meter cubed” portion of the chart corresponds to a different size of particle. In a 1m x 1m x 1m cube for an ISO 3 cleanroom, for example, there may be no more than 1000 particles .1 micron in size, no more than 237 particles .2 microns in size, no more than 102 particles .3 microns in size, and so on. To calculate the total number of particles of a given cleanroom classification, simply multiply the dimensions of the room by the maximum allowable particles of a given size (ex: an ISO 1 cleanroom of size 1x3x2 would allow 10 .1 micron particles, and 10x1x3x2=60).

- The table above shows the airborne particle standards per square meter for each variety of cleanroom. In Section E of the [Student Handout](#), students will calculate the following for an ISO-2 cleanroom with the dimensions 15x20x2 meters:
 - Number of particles .1 microns in size: *60,000*
 - Number of particles .2 microns in size: *14,400*
 - Number of particles .3 microns in size: *6,000*
 - Number of particles .5 microns in size: *2,400*
 - Number of particles 1 micron or larger in size: *0*
- Which has fewer airborne contaminants? An operating room or a semiconductor manufacturing facility? Students will answer the question in Section E of the [Student Handout](#).
 - If an operating room requires 10,000 particles per cubic meters, and a semiconductor manufacturing facility is rated to 100 particles per cubic meters, which is considered the cleaner room? Why? *Semiconductor manufacturing components work on scales smaller than even bacterial or viral cells, requiring more strict elimination of smaller particles.*

Academic Vocabulary Development (20 mins)

- In Section F of the [Student Handout](#), students will develop their academic vocabulary.
- Students share their definitions with a partner.

Elaborate

Static Electricity (10 mins)

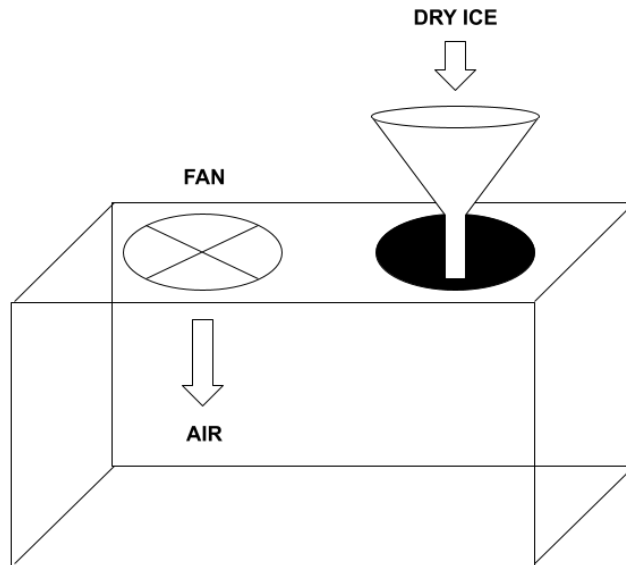
- Allow students to inflate a balloon between each pair of students.
- **Predict** - What will happen when the balloon is rubbed against someone's head? Students will make their prediction on Section G of the [Student Handout](#). Share out predictions with a partner. *Students may predict that the static electricity generated by the balloon will cause the hair to stick to the balloon.*
- **Observe** - Choose one student to rub the balloon on the top of their head for 30 seconds. Students will then place the balloon a few inches above the top of their head after 30 seconds. Students will take notes on their observations in Section G of the [Student Handout](#).
- **Explain** - Teacher will explain that when the balloon is rubbed against the hair, electrons are transferred from the hair to the balloon, causing the balloon to become negatively charged and generating static electricity. Students will summarize this explanation in Section G of the [Student Handout](#).
- **Reflect** - Students will answer the following question in Section G of the [Student Handout](#). Based on the demonstration, what conclusions can you draw about potential negative effects of static electricity in the semiconductor manufacturing process? *Electrostatic discharge can potentially cause microchips to short out and be destroyed.*

Electrostatic Grounding (15 mins)

- Students will watch a [video about Electrostatic Discharge](#) and will answer the following questions in Section G of the [Student Handout](#).
 - What are some of the hazards of Electrostatic Discharge? *ESD may cause damage to both electronic components and the operators of the manufacturing equipment.*
 - What can we do to protect manufacturing equipment and operators from Electrostatic Discharge? *We can ensure that both the equipment and the operators are properly grounded at all times.*
- Students will then watch a [video](#) about anti-static grounding strips and will answer the following questions in Section G of the [Student Handout](#).
 - How does an anti-static grounding strip work? *Wearing the strap tight around the wrist, attach the other end of the strap (alligator clip) to a common ground.*

Positive Pressure Environment (25 mins)

- *Teacher Note: This demo requires items that may not be regularly available in every classroom. Recommend acquiring materials prior to the demo and use caution with dry ice.*
- Before the start of class, teacher will assemble the simulated positive pressure cleanroom set up:
 - Using an empty aquarium or terrarium, place a lid or makeshift lid on the top and seal the system as much as possible.
 - Set a fan up to direct air into the sealed terrarium.
 - On the other side of the terrarium, insert a small hole where the carbon dioxide gas from dry ice could be filtered into the terrarium. Place a cheesecloth or another filter material inside a funnel, and insert the funnel into the terrarium.



- **Predict** - What will happen if the fan is turned on (actively blowing air into the terrarium) and carbon dioxide gas is passively funneled into the terrarium? Students will make their prediction in Section H of the [Student Handout](#). Share out predictions with a partner. *Students may predict that the carbon dioxide vapor will enter the environment, be expelled from the environment, or various other predictions.*
- **Observe** - Teacher will carefully use tongs to place dry ice inside the funnel and students will observe what happens to the carbon dioxide. Students will take notes on their observations in Section H of the [Student Handout](#).
- **Explain** - Teacher will explain that when air is actively pushed into a sealed environment, this positively pressurized environment will prevent other gasses from entering, therefore maintaining a sterile environment. This is how a laminar flow hood works. Students will summarize this explanation in Section H of the [Student Handout](#).
- **Reflect** - Based on the demonstration, what conclusions can you draw about positive pressurization in large-scale Semiconductor manufacturing processes? *Positive pressurization can be used by large cleanrooms to ensure that contaminants are less likely to affect the manufacturing process.*

Evaluate

Semiconductor Cleanroom Virtual Simulation (25 mins)

- Students will independently work through the [virtual cleanroom tour](#) and answer questions in Section I of the [Student Handout](#).
 - What do you immediately notice about all of the work spaces in the facility? *They are all very clean and free of clutter.*
 - What are three pieces of equipment that you can see throughout all of the rooms in the facility? *Laminar flow hoods, refrigerators, scales, sinks, computers*
 - From the large air vents in the facility, what assumptions can be made about the ventilation system? *The system is positively-pressurized to minimize introduction of foreign contaminants.*
 - What additional types of equipment would you expect to see if this were a Semiconductor manufacturing cleanroom? *Wafer fabrication equipment, photolithography equipment, cleaning/inspection equipment, ion implantation equipment, testing/packaging equipment*
 - Draw and label a mockup of a cleanroom.

Semiconductor Cleanroom Simulation (2 mins per student/simultaneously with Virtual Simulation above)

- *Teacher Note: Set up a portion of the classroom as a mock cleanroom. Use the fan from the demo to simulate an air shower. Provide students with gloves, boots, hat, gown, etc. (use mock items like snow gloves as an example if actual PPE cannot be used). Set up a workstation with lego bricks and a pass through window (shoe box makes a great makeshift window). A binder clip or alligator clip can be used as an anti-static grounding strap.*
- While the rest of the class is participating in the cleanroom virtual simulation, students will be called individually to be evaluated on their cleanroom etiquette.
 - Students will first don PPE, place Lego bricks in a pass through window, walk through the air shower, receive materials in the pass through window, and then sit down at their work station. Remembering to ground themselves using the grounding tool, they will carefully construct the small Lego structure (a simple 5-10 bricks is sufficient). When their “microchip” has been assembled, they will doff their PPE.
- Teacher will score the student based on the [Cleanroom Simulation Scoring Rubric](#).

Cleanroom Simulation Reflection (10 mins)

- Students will respond to the reflection prompt in Section J of the [Student Handout](#) after their individual cleanroom simulation experience.
- Students will share their experiences participating in the cleanroom simulation to the group.

Extend

Using cardboard, foamboard, or a virtual software like AutoCAD or Google Draw, students can design their own semiconductor cleanroom.

CA NGSS Standards

HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

CTE Alignment

D2.0 Students understand the protocols and practices necessary to maintain a clean and healthy work environment.

Resources

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Name		Date	
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Introduction to Clean Rooms Student Handout

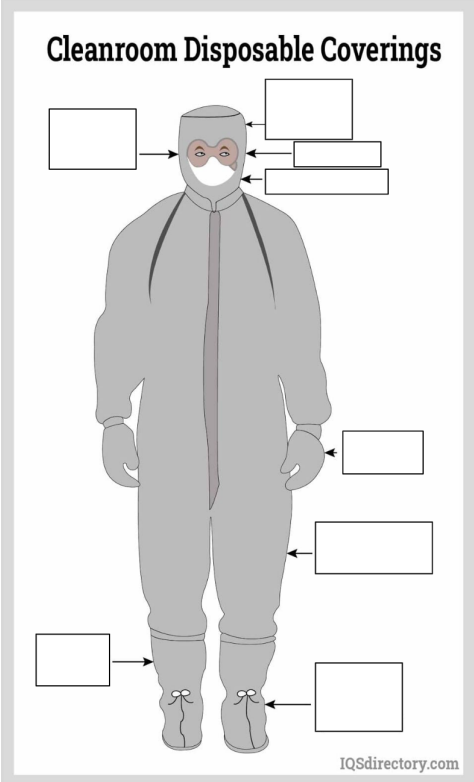
Directions: Students read the prompts and answer in complete sentences in the box to the right.

Engage

Section A: Leaf Imprinting Activity	
What did you notice about the outcomes between the first and second leaf imprints?	
Which of the leaves had more disconnections between the traced lines, and what caused those disconnections?	
Imagine the leaf imprint is a highly precise microchip and the sand is a foreign contaminant. What might these disconnections be represented as in a microchip?	
How could we potentially prevent this problem from occurring in a manufacturing facility?	

Explore

Section B: Microchips Defined	
Which of the electronic components shown did you recognize?	
What surprised you about the size of some of the components relative to some of the other objects referenced for scale?	
What is the smallest component of a microchip?	
Section C: Personal Protection	
When you want to protect yourself from each of these, what do you do/wear?	
Germs	

Mud	
Smoke/Fumes	
<p>Label the following parts in the diagram on the right:</p> <ul style="list-style-type: none"> ● Shoe Covers ● Safety Glasses ● Coveralls ● Gloves ● Face mask ● Hood ● Boots ● Cap 	<div style="border: 1px solid gray; padding: 10px; text-align: center;"> <p>Cleanroom Disposable Coverings</p>  <p style="font-size: small;">IQSdirectory.com</p> </div>

Explain

Section D: Why Clean Rooms

<p>What do you see?</p>	
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<p>What do you think?</p>	
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What do you wonder ?	
Reflection: What else besides PPE is important for a clean work space?	

Section E: What are Clean Rooms?

Watch the video and answer the following questions.

What is a cleanroom?	
What is the purpose of a cleanroom?	
What is a contaminant?	
What is the primary source of contaminants?	
How are cleanrooms classified?	
What is the primary difference between a semiconductor processing cleanroom and a biological cleanroom?	

Calculating clean room classification: An ISO-8 Cleanroom is one of the least-restrictive cleanroom classifications. It has the following requirements:

- 20 changes of HEPA-filtered air per hour
- Fewer than 29,300 airborne particles larger than 5 microns per square meter

How many airborne particles larger than 5 microns can we expect in a cleanroom environment that is 10x12x2 meters in size?	
How many changes of air need to be achieved in one day?	

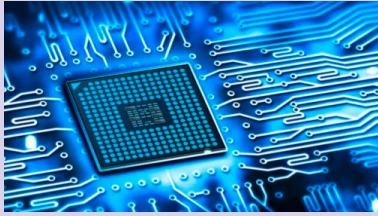
ISO 14644-1 Cleanroom Standards

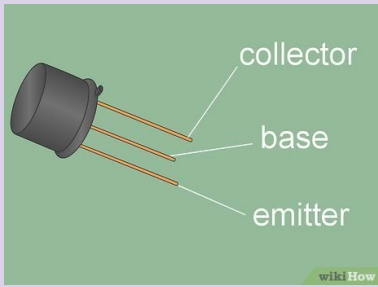
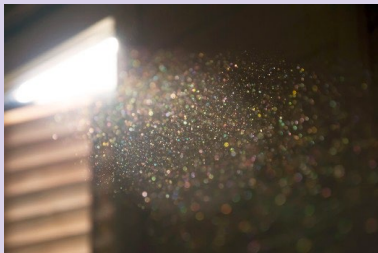

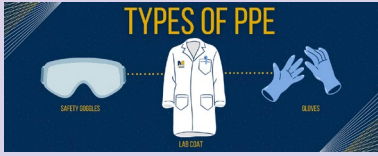

Class	Maximum Particles/m ³						FED STD 209E equivalent
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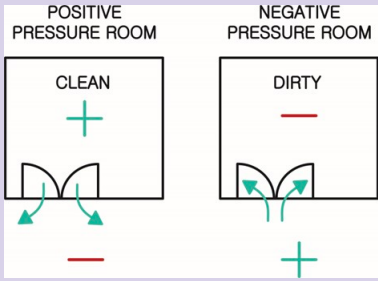
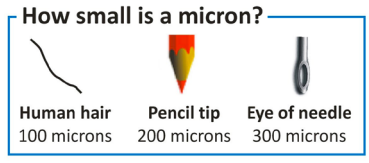
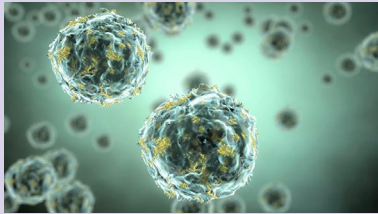

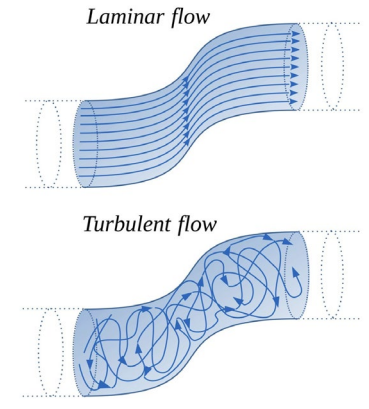
The table above shows the airborne particle standards per square meter for each variety of cleanroom. Calculate the following for an ISO-2 cleanroom with the dimensions 15x20x2 meters:

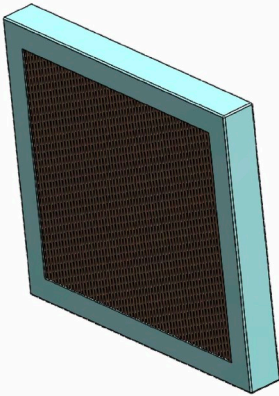


Number of particles .1 microns in size:	
Number of particles .2 microns in size:	
Number of particles .3 microns in size:	
Number of particles .5 microns in size:	
Number of particles 1 micron or larger in size:	
Which has fewer airborne particles? If an operating room requires 10,000 particles per cubic feet, and a semiconductor manufacturing facility is rated to 100 particles per cubic feet, which is considered the cleaner room? Why?	

Section F: Academic Vocabulary

Term	Definition	Image	Description in Own Words
Microchip	A tiny <u>wafer</u> of <u>semiconducting</u> material used to make an integrated circuit.		

<p>Transistor</p>	<p>A miniature semiconductor that regulates or controls current or voltage flow in addition amplifying and generating these electrical signals and acting as a switch/gate for them.</p>		
<p>Contaminant</p>	<p>a polluting or poisonous substance that makes something impure.</p>		
<p>Cleanroom</p>	<p>A room, enclosure, or any other environment where contaminants are controlled within specified limits. Air is directed through the room to control the airborne particle levels and in some cases temperature and humidity.</p>		
<p>Personal Protective Equipment (PPE)</p>	<p>Clothing and equipment that is worn or used in order to provide protection against hazardous substances or environments.</p>		
<p>Garments</p>	<p>Special cleanroom apparel that is made of synthetic fiber, such as nylon, Tyvek or Dacron that are lint-free and limit contamination from personnel.</p>		

<p>Positively-Pressurized</p>	<p>Pressure that exceeds the surrounding pressure of any room, chamber or confined space. Positive pressure is maintained in a closed zone to ensure no outside contaminated gaseous or liquid substance can get into that protected zone.</p>		
<p>Micron</p>	<p>A micron is a millionth of a meter, or a micrometer. To compare, a human hair is about 100 microns wide.</p>		
<p>Particulate</p>	<p>Contamination in the air, or contamination generated from a process.</p>		
<p>Air Shower</p>	<p>An air shower is a room attached to a cleanroom that acts as a buffer zone between the cleanroom and outside space. Air showers have interlocking doors that keep the cleanroom pressurized and particle free during the transfer of objects or personnel and are commonly used for gowning.</p>		
<p>Laminar Flow</p>	<p>Unidirectional airflow. In a cleanroom, it is filtered air flowing vertically or horizontally with uniform velocity in a single direction. Filtered air flows through your cleanroom and back to an air return, to be re-filtered and returned to the room. Laminar flow is a major part of keeping your cleanroom contaminant free.</p>		

<p>High-Efficiency Particulate Air (HEPA)</p>	<p>An air filter composed of a mat of dense fibers arranged in folds, designed according to federal standards to trap at least 99.97% of airborne particles measuring 0.3 microns in diameter:</p>	<p style="text-align: center;">Hepa Filter</p> 	
<p>Pass-Thru</p>	<p>A chamber for passing items between the cleanroom and outside room. The higher pressure in the cleanroom forces particles out when the inner door opens. Less traffic in and out of a cleanroom means fewer chances for contaminants to enter.</p>		
<p>Abatement</p>	<p>The process of reducing or removing contaminants from the air or surfaces of a cleanroom to maintain its desired level of cleanliness.</p>		

Elaborate

<p>Section G: Static Electricity</p>	
<p>Predict: What will happen when the balloon is rubbed against someone's head?</p>	
<p>Observe: Write down your observations during the activity.</p>	
<p>Explain: Explain what happened during the demonstration. Use evidence and scientific language to describe this</p>	

phenomenon.	
Reflect: Based on the demonstration, what conclusions can you draw about potential negative effects of static electricity in the semiconductor manufacturing process?	
Understanding electrostatic grounding.	
What are some of the hazards of Electrostatic Discharge?	
What can we do to protect manufacturing equipment and operators from Electrostatic Discharge?	
Anti-static grounding strips.	
How does an anti-static grounding strip work?	
Section H: Positive Pressure Environment	
Predict: What will happen if the fan is turned on (actively blowing air into the terrarium) and carbon dioxide gas is passively funneled into the terrarium?	
Observe: Write down your observations during the demonstration.	
Explain: Explain what happened during the demonstration. Use evidence and scientific language to describe this phenomenon.	
Reflect: Based on the demonstration, what conclusions can you draw about positive pressurization in large-scale Semiconductor manufacturing processes?	

Evaluate:

Section I: Semiconductor Clean Room Simulation

Use the attached QR Code to access a Virtual Clean Room tour and answer the following questions.



What do you immediately notice about all of the work spaces in the facility?

What are three pieces of equipment that you can see throughout all of the rooms in the facility?

From the large air vents in the facility, what assumptions can be made about the ventilation system?

What additional types of equipment would you expect to see if this were a semiconductor manufacturing cleanroom?

Draw and label a mockup of a cleanroom using the components below.

Include:

- Air shower
- Pass through window
- Vent hood
- Manufacturing equipment
- Air inlet/filtration system
- Extra PPE

Section J: Reflection on Semiconductor Clean Rooms

How does a clean room protect microchips from contamination?

How is positive pressure used to prevent contaminants from entering a clean room?

What is the function of Personal Protective Equipment and clothing outer-garments in the semiconductor manufacturing process?

Clean Room Simulation Scoring Rubric

As students make their way through the mock clean room, score their progress with each activity. Student should be tasked to do the following:

1. Don PPE equipment using the proper procedure.
2. Place the “decontaminated” Lego bricks in the pass through window.
3. Walk slowly through the air shower to ensure all particles are removed.
4. Remove the “decontaminated” Lego bricks from the pass through window and transfer them to the sterile workbench.
5. Ground themselves before handling the Legos.
6. Carefully assemble the Lego pieces into a microchip that matches the example photo.
7. Doff PPE equipment using the proper procedure.

Task	Task Accomplished	Needs Improvement	Notes
Donning PPE	Student correctly puts on PPE without contaminating any external facing equipment.	Student struggles to put on PPE or contaminates external facing equipment.	
Air Shower	Student walks slowly and purposefully under the air shower to remove any particles.	Student walks too quickly or doesn't expose all sides to the air shower.	
Using the Pass Through Window	Student opens the pass through, places the bricks inside, closes the door, and then opens the pass through on the inside and closes it behind.	Student places the bricks inside the pass through but neglects to close the door to the external environment before opening the internal side.	
Electrostatic Grounding	Student grounds themselves before building.	Student forgets to ground themselves before building.	
Assembling the Microchip	All steps of the assembly process are accurately followed, including a final product with all bricks in the correct position.	Students place one or more bricks in the wrong place or need to reassemble the microchip at any point during assembly.	
Doffing PPE	Student correctly takes off PPE without contaminating any external facing equipment.	Student struggles to take off PPE or contaminates external facing equipment.	