## HOW DO GECKOS WALK ON THE CEILING?

## DAY 1

## LESSON OVERVIEW

Lesson Description
Students are introduced to the driving question for the unit: “How do geckos stick to surfaces?” and are asked to generate possible mechanisms for gecko adhesion after observing a short clip on gecko motion. Students will write a small paragraph explaining why they think their mechanism explains gecko adhesion. Students also consider how to craft evidence-based explanations by comparing two examples and determining criteria. Finally, students address the mechanism of claws and brainstorm how they could find evidence to support or refute this mechanism.

### Learning Goals

Students construct sound explanations by supporting claims with evidence and detailing the reasoning (connection to generally accepted scientific principles).

## LESSON PREPARATION

### Teacher Background Content Knowledge

Teachers background knowledge
Some students will think that the gecko sticks to the wall or ceiling by means of its claws, like the claw shown in the following figure from Dellit (1934). This idea can be challenged by the fact that the gecko leaves no marks on surfaces when moving across them.

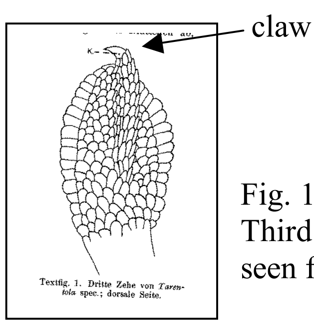


Fig. 13
Third toe of a tarentola gecko
seen from above (Dellit, 1934).

Dellit, however, suggested that tiny hairs on the gecko’s feet, *setae*, work as microscale hooks, which because of their small size would not leave visible marks. One argument against this explanation is that the gecko still adheres after being inverted on polished glass, a surface thought too smooth to allow for microscopic interlocking. Autumn *et al* (2002) showed that strong adhesive forces were present even on a molecularly smooth $SiO_2$ surface, where no irregularities suitable for the setae are found. As this research shows, geckos do not use their claws or their setae as hooks to grip surfaces.

## Student Prior Knowledge Expectations

Students know that claws can be used to grip surfaces. Because they often are sharp, claws may leave indentations on surfaces.

## Potential Student Alternative Ideas

Pilot interviews and a pilot study of a related curriculum indicate that many people initially believe that geckos stick to surfaces via claws, glue, or suction. More rarely, people cite static electricity. These alternative ideas are not dismissed in this unit but are actually considered as possible mechanisms. Students learn more fully about these mechanisms before being given evidence they must interpret. This evidence does disconfirm these alternative mechanisms, but by affording students the opportunity to reason about data, we hope to facilitate the uptake of the normative explanation for gecko adhesion.

## Potential Student Difficulties

People often argue very poorly, not providing any evidence for their claims, even on social issues where they do not need to know any specialized content knowledge (Kuhn 1991). However, research suggests that giving students ample opportunities to produce argument is an effective means for improving their argumentation skills even without any direct instruction in argumentation (Kuhn 1997). Other work shows that combining a brief episode of direct instruction in argument quality with multiple opportunities to argue can produce significant gains in argumentation ability (Zohar 2002). Our approach involves more scaffolding for students. Students in the second lesson will consider what constitutes a good argument, and then will over the course of the unit, produce argumentation related to gecko adhesion six more times. During the beginning of class each day, the teacher will select a student or ask for volunteers to share their arguments. The class will then discuss the strengths and weaknesses of these examples in order to model best practices.

## Materials

| Item | Number/Amount |
|---|---|
| Gecko | 1 |
| Terrarium, etc. | 1 |
| Laptop | 1 |
| LCD projector | 1 |
| Cloth cover for the terrarium | 1 |
| Insects for feed | See pet store or the web for guidance |

**Cautions/ Potential Pitfalls**

When choosing a gecko, make sure to choose a diurnal species (many geckos are nocturnal and will hide from the class during the day). In addition, check on the temperament (the Tokay gecko on which so much research has been conducted is actually fairly vicious and is known to bite). Day geckos are ideal for classroom environs.

## Pre-Class Preparation

## Getting the Materials Ready

Set up the terrarium and add the gecko. Cover the cage before class and place at the front of the room.

## Safety Issues

Geckos like many lizards can carry salmonella. If you do handle the gecko, handle with care and wash hands well after contact. See the pet store or a guidebook for detailed instructions on handling and care of the gecko species you purchase.

### DOING THE LESSON

| Opening | Notes |
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| Introduce the unit and **invite students up to the front to look at the gecko.** You might ask students what the animal is and if they know anything interesting about geckos. Some students may have or have had them as pets. The geckos in this unit are lined day geckos (*Phelsuma lineata*) and are originally native to Madagascar.<br><br>While students are up at the front, **ask them to make observations** about the gecko. Have a student volunteer list observations. | This section **tries to elicit students' prior knowledge** about and experiences with geckos. |
| Students might be confused about why they are looking at a gecko in chemistry class. You might reply:<br>"You might be wondering why I am showing these to you—you would expect to see these animals in a biology class, not a chemistry class. Right? But there is a lot of chemistry involved with geckos. In fact, these animals have been the subject of a great deal of research recently. Though chemistry can seem quite removed from reality, I hope that after we finish this unit, you will see how chemistry can explain things that are very real. | The divides between the traditional disciplines of science such as chemistry and biology are actually falling away. Much research today is **interdisciplinary**. |

### *Activity 1 – Tricky Feet Video*

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| Teacher will show a short 30 sec clip on geckos called Tricky Feet. The **gecko portion of the video starts about halfway through**, so the teacher should cue to that part of the clip.<br><br>**Have students write down observations** about the geckos from this video. Students should write these observations and other written work from this lesson on the student materials entitled: “Investigating the Gecko.”<br><br>Ask students to share their observations with the class. Where applicable, add observations to the list on the board. To help students be more reflective about observations, the teacher might want to ask : “Are these all the observations we could take? Why or why not? Are we limited in our taking of data?”<br><br>Give students a few minutes to **generate three questions** they could ask about the geckos. How and why questions are very valuable.<br>Students then share out their questions. Teacher tries to tie as many of these questions to the unit’s question of how geckos stick to surfaces. | See Curriculum Materials CD. In the folder entitled “Multimedia”, you will find a file called “Tricky Feet”. This is a .wmv file and should play on Windows Media Player.<br><br>Humans can be very focused on visual observations. Also the nature of the data, a video, also leads the other senses to be overlooked.<br><br>This last activity is meant to help build ownership. Some students will have questions about gecko adhesion. The teacher can then link these questions into the unit’s goals. |

### *Activity 2 – Why care about gecko adhesion?*

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| Teacher engages students in an imagination activity in which they consider how understanding the mechanism of gecko adhesion would be advantageous to humans.<br><br>Have students consider why this area of research has fascinated scientists for decades. You might ask: “Why do you think people, including scientists, are interested in this? Said another way, what could we humans do with this knowledge, the knowledge of a how a gecko sticks to ceilings? Take a minute and discuss this with the person next to you and come up with some ideas.”<br><br>Teacher then leads a **short discussion of the value of this knowledge to humans**. Teacher could even lead the class in an imagination activity where they think about what it would be like | NOTE: This activity can be skipped if one is running out of time. However, it builds a justification for the unit.<br><br>The Pentagon has recently become interested in |

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| to be able to walk on walls and ceilings: "Close your eyes, and imagine placing your hand on the wall and being able to pull yourself up because it stuck there. Imagine yourself clinging to the ceiling, like Spiderman." | developing robots that can stick to walls and are also interested in creating gecko suits for humans. See Multimedia file for photo of the geckobot to show to class. |

### *Activity 3—How Do Geckos Stick?*

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| Students are then asked to brainstorm individually about how the gecko adheres to the ceiling.<br>Teacher then has them **write a small paragraph in which they explain why they think the gecko sticks this way**. Tell them to imagine they are trying to convince someone else of their viewpoint. AT THIS POINT, DO NOT OFFER ANY SPECIFICS ON HOW TO PRODUCE AN ARGUMENT.<br>After everyone has finished, students then discuss their ideas with a partner. **Pairs share and explain hypotheses with the class**. **Teacher records these hypotheses on butcher paper**. This will become a point of return for the first week as the class investigates several of these hypothetical mechanisms. | This small paragraph is crucial to our study. It provides a baseline from which we can measure gains in student argumentation. |

### *Teacher Talk on Argumentation*

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| Teachers should refer students to the page in their packet entitled "Writing Scientific Explanations." **Teacher should state the purpose of the activity**: People, in general, and scientists specifically make arguments all the time. We are perpetually involved in trying to convince others of our viewpoints. In science, we often create explanations, which we then must persuade others to believe. One of the goals of this unit is to develop student's ability to make scientific explanations and arguments.<br>Have **students read the two example explanations and compare and contrast the two**. Students should then decide which one they think is stronger and why.<br>Ask students to share their thoughts and record the qualities they evoke when contrasting the two cases.<br>At this time, have them take notes on the components of scientific argument:<br><br>Scientific arguments have 3 parts:<br><br>A **claim**— It's a **position or stance** that one is taking. It is a statement that one believes and is arguing for. **The more specific** | Having students produce distinctions in contrasting cases primes them for lectures on material. |

**the claim the better.**
Both arguments have similar claims about oatmeal, but the second explanation is more specific—oatmeal is good for your heart, not just good for you in general.

**Evidence**—data or **information that one uses to support one's claim.** One should use as much evidence as possible to support the claim.
The second explanation has clear data showing that eating oatmeal lowers one's cholesterol. The first explanation has very weak evidence—doctors say it is good. But the reader doesn't know why the doctors recommend it and therefore, can't judge for themselves.

Reasoning—a statement that demonstrates why the evidence supports the claim. It links the evidence to the claim.
For example in the second example, one might ask why does it matter that oatmeal lowers cholesterol. This example provides the link—cholesterol is associated with heart disease, so lowering cholesterol should reduce the risk of heart disease. The first example doesn't provide any reasoning—it's hard to when the evidence is lacking. The author of this statement assumes that everyone follows his or her doctor blindly.

Now **have students analyze the bottom two contrasting cases** and identify circle or underline the claim, evidence, and reasoning if present.
Case 1: Stronger Example
Claim is in the last sentence: bats use sound waves (echolocation) to navigate at night.
Evidence is in the first sentence: plugging bat ears eliminates their ability to fly at night.
Reasoning is in the middle sentence: Since they cannot hear sound waves, they cannot use them to navigate, which causes them to crash.

Case 2: Weaker Example
Claim is in the first sentence: bats do not use their eyes to fly.
Evidence is next: taking away a bat's vision does not affect their flying.
Reasoning: They do not need their eyes because they have other visual sensors on their noses.

Reasoning is provided in case 2; it's just not scientifically sound. Bats do not have light sensors on their noses . Also bats fly well during the new moon, when there is very little ambient light to

This example highlights the fact that the reasoning we use is also built upon previous experimentation and inquiry. In case two, experiments must have been done to see if bats could fly

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| navigate by.<br><br>Stress to students that they not only must have the parts of an explanation, but that those parts should be as accurate as possible. The reasoning in particular should reflect scientific principles. | in complete darkness before echolocation could be completely accepted. |

## Closure

Teacher should describe the goals of the unit at some point during the introduction. They are:
•Learn how geckos stick to surfaces and in the process explore the many different forms of adhesive or attractive forces between objects.
•Investigate possible answers to a question using scientific practices
•Develop the ability to construct scientific explanations based on data.

## Homework

Students will craft an argument about whether geckos use their claws to stick to surfaces. They should make sure their arguments have at least one claim, provide evidence, and detail how the evidence supports the claim.

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## DO GECKOS STICK BECAUSE OF GLUE?

## DAY 2

## LESSON OVERVIEW

### Lesson Description

Students review the parts of a scientific explanation. They then explore the hypothetical mechanism that geckos use a type of biological glue to stick to surfaces. They do so by using tape to model such a mechanism. Students then compare the properties of their tape model with evidence from research on gecko adhesion.

### Learning Goals

1. Students construct sound explanations by supporting claims with evidence and detailing the reasoning (connection to generally accepted scientific principles).
2. Students will be able to evaluate how the conditions of a surface affect adhesion to it.

## LESSON PREPARATION

### Teacher Background Content Knowledge

If the gecko's ability to stick to almost any type of surface were due to some glue-like secretion, then we would expect to find traces of this secretion on places where the gecko had been running. Also, we should be able to find glandular tissues near their toes, which produce the sticky substance.

**Figure 14.**
No trace of glue is left behind the gecko.

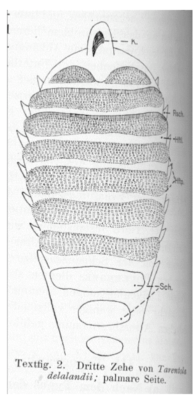


**Figure 15.**
The gecko has no glandular tissues under its toes. Drawing taken from Dellit (1934).

The gecko does not leave any residue or secretion behind it, nor did microscopic examinations of the gecko toe carried out by the end of the 19th century find any glandular tissues. Therefore, the gecko does not stick by means of a biological "glue".

### Student Prior Knowledge Expectations

Students should have a conceptual understanding of force as a push or pull that causes objects to change velocity (either through a speed or direction change). They should also know that force is measured using the unit of Newtons.

### Potential Student Alternative Ideas

Little is known about student alternative ideas about glue or adhesives.

### Potential Student Difficulties

None reported in the literature.

### Materials

| Item | Number/Amount |
|---|---|
| Scotch tape | 1 roll per every four students |
| Duct tape | 1 piece per pair |
| Single hole punch | 1 per every four students |
| Spring scale (5 N) | 1 per pair |
| Sand or flour | Small cup per every four students |
| Paper towels | a roll |
| Glass cleaner | 1 |

### Cautions/ Potential Pitfalls

At the beginning of the lab, students should clean the table surface to remove dirt or dust before they stick the tape down. The teacher can quickly come around to each group's work area and spray the area to save time.

## Pre-Class Preparation

### Getting the Materials Ready

If teacher chooses to do so, assemble lab kits according to the materials list above.

### Safety Issues

N/A

### DOING THE LESSON

Day 2 has been built to have spare time in case Day 1 was not finished. If students finish early, have them begin their homework.

| Opening | Notes |
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| Teacher **reviews the overarching question, refers to the list of possible explanations for gecko adhesion, and asks students to share their answers to the homework** concerning gecko adhesion and the claws of the animal. | Teacher may want to identify a student before class and ask them to quickly copy their argument onto a transparency to share with the class. |
| Teacher refers the class back to the discussion from the previous day about the components of a good explanation: evidence, reasoning, claim. Teacher asks students what each of these mean. | Claim = specific stance<br><br>Evidence = support for claim<br><br>Reasoning = links evidence to claim with clear logic. |
| Begin analysis of a volunteer's homework answer by asking the class **what the claim is**. Ask students if the claim is **sufficiently specific** and if not, ask for ways to make it more so. Invite multiple responses and where possible have students critique and comment on each other's ideas. | Claims aren't necessarily the first statement a student writes.<br><br>Teacher should try to engender **cross talk** i.e. having students talk to each other about their work. For example, if one response is in opposition to an earlier response, the teacher can ask the first student to comment on the latter students' work. |
| Repeat this process with any evidence that was provided. Teacher should note that the homework sheet offered the evidence. Students should mention it in their arguments. At this point students may complain that the homework contains more information than is required. **Stress to them that part of the process of arguing is to locating the relevant information**! | |
| Repeat discussion with the reasoning. **Ask students if they think her reasons are scientifically sound.** How does one determine this? | |
| Close by asking the class what they would add to her explanation. Teacher can also draw in students who provided explanations that involved components missing from the example. | |
| If time allows repeat with another volunteer. | |
| Teacher then **states a model explanation** if one is not provided in class. One example might be:<br>"Geckos don't use their claws to stick to surfaces, because they can stick to ultra smooth surfaces and leave no claw marks on regular surfaces. Since claws would leave marks on the walls or would need the surface to have some roughness to grip, geckos can't use their claws to stick. | Provide a model as students begin to develop new abilities. |

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| "What is my claim? What is my data? Where is my reasoning? Remember that the reasoning links the claim to the data. Sometimes the reasoning is obvious, but sometimes it isn't. To make sure everyone understand, we provide the reasoning.<br><br>Some students may harbor a relativist view i.e. they may think that all explanations are valid even contradictory ones. To unearth this sentiment, a teacher can ask: "Is there one way to answer this question? Are all ways of answering equal? How do we judge?" | |

***Transition to Lab***

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| Teacher prefaces today's lesson by stating that the class will act as scientists do when they try to learn about a phenomenon. They make hypotheses which are predictions based on information that they already have. They then design experiments to test the hypotheses. If the predictions match the findings, then we are encouraged to believe in the hypothesis. If they do not, then we discard the hypothesis. The **explanations that stand the tests, that aren't falsified, contribute to how scientists officially explain a phenomenon.** | |
| Teacher then introduces the lesson by **telling students that they will explore the hypothesis that gecko adhesion is because of an adhesive that the gecko releases.** *Refer back to the list of possible explanations from day 1.* Since we can't experiment on the geckos, we are going to use a model, Scotch tape, to stand in for the gecko foot. Teacher might ask students whether this is a good model for the gecko feet. Discuss the limitations of the model and what alternatives could be explored in the future. | |
| There are many types of glue, but for practical reasons and safety this activity uses tape. A **possible connection to the previous day** might involve a dialogue like the one below: | Scientists often approximate real life with simplified models. |
| "Where is the glue on a piece of tape? [Students respond –"On the bottom"]. I just heard a bunch of claims—"the glue is on the bottom"—just in case you didn't know; we are making claims all the time. How do you know the glue is there? [That is the side that is sticky]. Great, I believe I just heard some evidence as well. What ties these two statements together? Well, glue is sticky. Something we all know, so it doesn't seem necessary to offer this reasoning. But if someone weren't familiar with glue, we would need to add this extra piece." | Remind student that argumentation is something they already do. |

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| Have students break up into their lab groups and go back to the lab stations. | |

*Activity 1 – How Hard Does Tape Stick?*

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| In this inquiry lab (adapted from Ristvey 2007), **students determine the effects of dirt on the force required to remove a piece of tape from a tabletop.** They use a spring scale to measure the force in Newtons.<br><br>**Students may struggle with determining the levels of dirtiness**. One level should be zero dirtiness, but the other two can vary. In pilot tests of this lab, some students decided to have fingerprints be the medium level of dirtiness, and actual dirt be the highest level. We have also included flour as a possible, cleaner substitute for dirt or sand. One might also use two types of sugar: powdered and granulated.<br><br>You may also want to remind students to label their graphs completely.<br><br>**Suggested Answers to Analysis Questions**<br><br>1. Based on the information above, what is the answer to the initial question? Suggest a reason for why this is the case.<br><br>[The dirtier the surface the less force is required to remove the tape. The dirt prevents the glue from binding to the surface of the table. So there is less attachment to the table. ]<br><br>2. Do you expect that your results will be the same or different than other groups? Why?<br><br>[We didn't standardize the angle of pulling, how much tape was attached to the table (the contact area), or how we determined 'dirtiness.']<br><br>3. If geckos did use glue to stick, what would your experiment lead you to predict about geckos?<br><br>[They would not stick as well to dirty surfaces. | |

## *Post-lab Extension*

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| Students engage in a **brainstorm where they suggest what evidence might be collected to support the hypothesis about glue and gecko adhesion** by focusing on what the hypothesis would predict.<br><br>You may want them to consider the following questions:<br><br>**How does glue (in our case the glue on tape) behave?**<br>**Where would it come from in the case of the gecko?**<br>**What evidence would we have that glue is involved?**<br>**Where would we look for that evidence?**<br>**What kind of experiment could we conduct?**<br><br>Teacher circulates and supports students. Students might say that they don't know what glue is made of. Teacher assures them that this isn't necessary. Rather what are the properties of glue?<br><br>One might ask them: "What kind of evidence could we look for? Where would we look? Is there an experiment we could do with the gecko?"<br><br>*Possible evidence and sources*: look for remains of glue on the feet of the gecko or on the surfaces on which it walks. Dissect the feet of the gecko to try to find glue glands.<br><br>*Possible experiments:* let the gecko run through dirt and see if this reduces the force of its adhesion | Prepare a transparency or write these on a piece of butcher paper before class to save time. |

## *Homework*

Students are asked to make an argument about the role of glue in gecko adhesion.

## *References*


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# Do Geckos Stick Because of Suction?

# Day 3

## LESSON OVERVIEW

### Lesson Description

The goal of this lesson is to have students understand how suction works, so that they can eventually be able to interpret research on whether geckos use suction to adhere to surfaces. Naturally, this topic relates to pressure and the gas laws, and it would be of use to draw on students' prior experiences with pressure in the course.

The teacher will start the lesson with a demonstration on the strength of suction cups, and then students will explore a short lab in which they investigate factors that affect the force required to remove the cup. The teacher will then perform a second demonstration in which a suction cup is attached to the inside of a bell jar, which is then evacuated with an air pump. The class will construct a model of how suction cups work and apply this model to explain the results from the lab.

#### Learning Goals

1. Student will explain air pressure as the sum of the force of all the collisions of gas molecules in the atmosphere against a surface.

2. Students will explain how a vacuum occurs as a result of a decreased amount of molecules leading to a lower pressure.

3. Students will compare the air pressure applied to the exterior of a surface with the air pressure applied to the interior of a surface when explaining suction.

## LESSON PREPARATION

### Teacher Background Content Knowledge

#### Teacher's background knowledge

In the early studies of the gecko it was suggested by Wagler (1830) that the toe pads of the gecko acted as suction cups. This mechanism is illustrated in the figure below, where we assume that a gecko is hanging from the ceiling using only one foot.

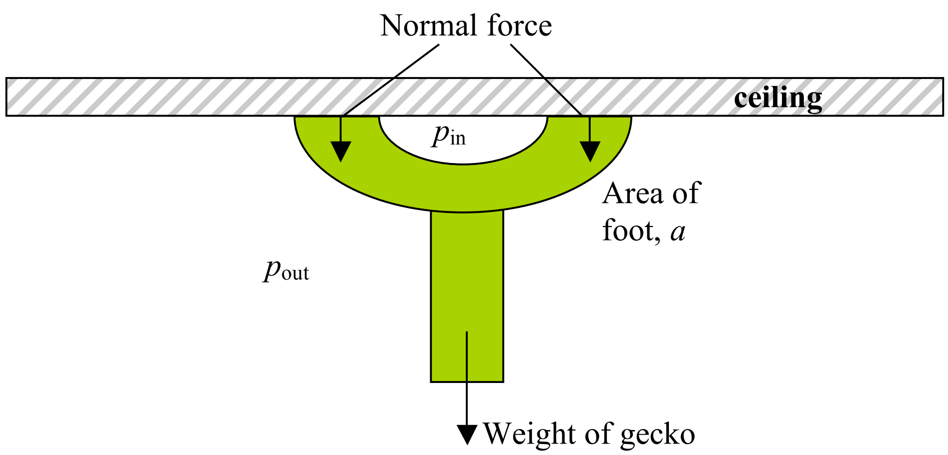


**Fig. 16** When the gecko stick to the ceiling, the force from the outside pressure, $p_{\text{out}}\cdot a$, balances the sum of the weight of the gecko, the reaction from the ceiling, and the force, $p_{\text{in}}\cdot a$, from the pressure of the air locked between the foot and the ceiling.

When the gecko stick to the ceiling, the force from the outside pressure, $p_{\text{out}}\cdot a$, balances the sum of the weight of the gecko, the normal force from the ceiling, and the force, $p_{\text{in}}\cdot a$, from the pressure of the air locked between the foot and the ceiling. Basically, the force from the outside pressure must at least equal the weight of the gecko. If we keep lowering the outside pressure, then at a certain point it can not support the gecko, and the gecko will fall down unless *another mechanism* than suction helps the gecko to stick to the ceiling.

In 1902 F. Weitlaner carried out this type of experiment, placing an amputated foot with a 10g-weight attached to it into a closed chamber that was evacuated to a pressure of 650 mmHg. He did not see the gecko fall down! However, critics complained that the vacuum used was not sufficient to rule out suction as a mechanism.

Later, in a similar experiment, W.D. Dellit (1934) was able to improve the vacuum bringing it down to 0.5 mmHg[1]. Dellit used the whole body of a dead gecko with a mass of 12 g and with a foot area of 7 mm$^2$. A 12 g gecko requires a supporting pressure force of 0.1 N or about 200 times the actual force inside the vacuum chamber in this experiment. According to suction theory, the gecko should fall to the bottom of the chamber – but it did not!

This experiment ruled out suction as an explanation for the stickiness of the gecko.

[1] Dellit does not document the procedure of his experiment is details, but somehow the procedure must have allowed the air captured inside the dead gecko to be released before vacuum was achieved.

## Student Prior Knowledge Expectations

Students should have a particulate model of matter (matter is made of atoms) and this should extend to gases. In particular, they should conceptualize gases as matter in which the space between individual atoms or molecules of the gas is quite large. Gas molecules move relatively fast and independent of each other, and are free to collide with surfaces and with one another.

## Potential Student Alternative Ideas

Several studies have shown that students harbor many non-normative notions about suction. Brook and Driver (Brook 1989) found that students believe that a suction force requires air to work. As they mature, students begin to evoke the idea of a vacuum in their explanations of the mechanism of suction. However, only a third of 16 year olds discuss air pressure or differences in air pressure when explaining suction. (Lee 2007) and (Engel Clough 1985) also note that many children when employing the term ‘suction’ refer to a **pulling force** that is created by lowering the pressure. These authors as well as (Tytler 1998) show that students have a range of ideas about suction from naïve (those that do not mention air) to more advanced conceptions that include air (competition for space, action of enclosed air, pulling force, action of outside air, differential pressure). Suggestions for how to support students in moving away from their alternative ideas are provided in the directions for the lesson. However, the demonstration involving the suction cup in the bell jar is intended to question this notion of a pulling force and replace it with a model that recognizes differential air pressures.

## Potential Student Difficulties

Discussing suction may be difficult because it requires explaining macroscopic phenomena with microscopic entities. Moreover, the macroscopic content itself, air and air pressure, is not easily sensed by humans. This lesson attempts to overcome these difficulties by asking students to construct a drawing of gases that helps them develop a model of air pressure that is based on particles of matter. It also has them consider the *effects* of air pressure through visual observations that are much easier to track. Though some students will have an understanding of gases and pressure, they may fail to consider the air trapped under a suction cup when reasoning about suction since this air is hidden away. It is not that there is simply pressure on the exterior surface of the cup; it is that this is greater than the pressure that is pushing back on the interior surface of the suction cup.

## Materials

| Item | Number/Amount |
|---|---|
| Large hinged suction cup (used for moving glass—available at hardware stores) | 2 |
| Spring scales (5N range) | 1 per every 3 students |
| Small suction cup w/ hook (1cm diameter) | 1 per every 3 students |

| | |
|---|---|
| Medium suction cup w/ hook (2cm diameter) | 1 per every 3 students |
| Large suction cup w/hook (3 cm diameter) | 1 per every 3 students |
| Bell jar | 1 |
| Vacuum pump | 1 |

**Cautions/ Potential Pitfalls**

The bell jar may need to be waxed on its bottom edge to help create a seal. In a pinch, hair pomade or petroleum jelly should work. Also, depending on the strength of one's vacuum pump, you may not want to press the small suction cup down hard against the interior of the bell jar. Also be prepared to hang a weight from the suction cup to help it fall.

**Pre-Class Preparation**

## Getting the Materials Ready

For the introductory demonstration, find a sturdy table and check to see if the handled suction cups adhere strongly to its underside. You may want to preassemble lab trays with one of the each of the following: a spring scale, and a small, medium, and large suction cup. For the last demonstration, make sure the vacuum pump is working, set up your demonstration space, and test the seal on the bell jar to see if the suction cup falls when the vacuum is applied.

## Safety Issues

The introductory demonstration involves asking a student to grab handled suction cups that have been placed under a table and to pull themselves up from the ground as if they were doing a reverse pushup. There is a small chance that the cup could detach, and the child could land roughly on the ground. If one is concerned about this, one can modify the introductory demonstration: one can attach the handled suction cup to solid but heavy objects and ask a student to lift these instead. Examples objects, which might work, could be gallon containers of water or a plastic tub, say filled with laundry powder, or a table or desk.

**DOING THE LESSON**

| ***Opening*** | ***Notes*** |
|---|---|
| After going over the homework in the manner modeled in lesson 2, the teacher begins by returning to the poster containing the possible mechanisms for gecko adhesion and reminds students that the goal of this unit is to determine how geckos stick by testing out various hypothetical explanations. The teacher then states that **today's lesson** | The teacher introduces the **purpose of the lesson** to the student. |

| | |
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| **will consider the hypothesis that suction is why the gecko sticks to the ceiling.**<br><br>The teacher then asks a student to come up to the front of the classroom. Under a table, two handled suction cups have been affixed. The teacher shows these to the class and asks students to take a minute to **predict if their classmate will be able to pull himself or herself up** from the ground by grabbing these two suction cups. Students are also asked to explain **why they have made their prediction**. The teacher briefly asks for predictions and their attendant reasons. The teacher then asks the student to lie down on the floor and attempt to pull himself or herself up from the ground. If the student is strong enough, they can pull in their legs and pull up their entire body weight by the handles of the suction cups. The teacher then returns to the class and asks them to **explain how their fellow student was able to pull themselves up and why they believe this**. Teacher focuses on extracting children's ideas about suction. Students' ideas are written on the board. | The teacher activates students' **prior conceptions** and elicits the reasons for their predictions. |

### *Activity 1 – How Do Suction Cups Work? Lab*

| | |
|---|---|
| Students engage in a brief activity where they look at factors that determine the force of adhesion of a suction cup using a spring scale. Students also are asked to describe what suction is and explain how suction works.<br><br>The teacher should tell the student the purpose of this lab is to explore how suction works.<br><br>As students finish, remind students to find the trend(s) (if any) in the data and describe this trend in their own words.<br><br>The teacher should finish the lab by going over the predictions students had and their reasoning. Then the class should discuss the trends they see and their reasoning. Don't miss the opportunity to ask students whose predictions were false why they think they were wrong. | See student lab sheet entitled: "How Do Suction Cups Work"<br><br>Factors they could explore: cup size, angle of removal, wetting the cup, surface dirtiness. Try to insure that a number of different factors are explored.<br><br>Sharing and amassing data will prevent students from being misled by an outlier in their own data.<br><br>Probe student responses to insure that they are defending their claims using their data. |

### *Activity 2 – Suction in a Vacuum Demonstration*

Teacher takes a bell jar and tells the class she is going to create a vacuum using a pump. She asks students what a vacuum is. She hooks up the hose and starts the pump. She then asks students to observe the jar.

Teacher might ask the class what they see and if they can detect any changes. How could the class test if whether a vacuum exists?

Teacher takes ideas and attempts several of the suggestions- for example, trying to pull apart the bell jar and its base. The teacher then asks the class to quiet and to listen carefully. The teacher removes the hose and releases the vacuum.

The teacher might ask: “What did you hear? Why do we hear this noise? Where does it come from?”

Move around the class and choose three students to present their drawing. Provide them with a transparency and have them copy and finish their drawing on it.

T has class consider what a vacuum is and asks students to **draw representations of a bell jar filled with air and one under a vacuum**. T tells students to use small dots to represent the particles in air.

Teacher asks a few students to share their drawings with the class and **discusses whether the particles are moving** (and asks for suggestions on how to represent this).

T also explains how the vacuum apparatus works and selects a normative illustration in which the **number of gas particles has been reduced (but not completely eliminated**) after the vacuum has been applied.

**Key idea**

Teacher **then discusses the models used** to represent air particles by asking several questions:
(1) Can we actually see air? So what is one criticism of our drawing?
(2) If we could see air particles, would they look like dots? What is air made of?
(3)Using answers like oxygen or nitrogen, T writes the formula of these compounds and asks whether we could improve on our representation. What could we use instead of a dot to represent a molecule like oxygen and nitrogen?
(4) What are the good things about the representation?

The critique of the representation could be omitted if time is running short. However, this critique offers an opportunity for students to interrogate their pictures and for teachers to clear up misconceptions that arise from these drawings.

| | |
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| T engages in a POE about the behavior of a suction cup adhered to the inside of the bell jar during a partial vacuum. T asks students to refer back to their ideas about suction and the representation they just discussed. Ask the students to talk to their partner about **whether the vacuum will affect whether the suction cup sticks?**<br><br>Teacher demonstrates the effect of a vacuum on suction. | **POE** = Predict, Observe, Explain<br><br>This could also be whole class. |

### *Activity 3 – Discussion of Vacuum Demonstration*

| | |
|---|---|
| Ask students to think about why the suction cup fell.<br><br>Teacher takes responses and adjusts talk accordingly. Rather than accepting the response of a student who is correct and elaborating on this, take a non-normative response and discuss this. It is likely this student is not the only one to harbor this conception.<br><br>What follows is an example of how a teacher could lead a discussion that helps students interpret the results of the demonstration without merely telling them what happened.<br><br>"**Before and after** we apply a vacuum, **what** about this setup **doesn't change**?"<br><br>"**Some have said that suction pulls things**—if this is the case, would the vacuum cause the pull to change? Why or why not?"<br><br>-**If a student responds that the pulling force would go down when the vacuum occurs**, the T should ask why and follow up with several questions:<br>What has changed about the suction cup (is it bigger, smaller, etc)? What has changed about the space under the suction cup—isn't it sealed away from the other space where the vacuum is being applied? So it appears that nothing about the suction cup or what is underneath it has changed, so why should the pulling force change? | Teacher uses the diagram created earlier and represents the pulling force as an arrow underneath the suction cup.<br><br>At this point the teacher should remind students that sometimes **our ideas don't explain everything**. Rather than seeing this as a problem, it **should be seen as an opportunity.** If we can find an idea that can explain more situations, then we have made progress. Teacher should move to the next question to |

capitalize on this disequilibrium.

"**What if instead of suction being the result of a pull, it was the result of something pushing on the outside of the cup, holding the cup there**. What would do the pushing? If the vacuum causes the push to be reduced, how does it do it? What is being reduced during a vacuum (refer back to the drawings)?

**Teacher does some telling** about atmospheric pressure and the pressure in the bell jar and how this relates to suction cups. They can denote the pushing force in their diagrams using arrows, but should explain how the pushing force is derived by explaining atmospheric pressure.

**Note**: teachers will have covered gas laws by this point, so this should be a review.

***Example Content Talk***

Depending on the discussion above, provide students with an explanation of the suction cup.

"Remember that air is composed of tiny molecules that are in constant motion. Billions, perhaps trillions, of these exist in a sample of air. Every second a fraction of these moving molecules collide with other objects. Those collisions impart a force that when summed up over a surface constitute pressure. Pressure is the result of all these little collisions. When we pump out the air during a vacuum, we reduce the number of gas molecules inside the bell jar and thus reduce the number of collisions against the inside surface of the bell jar. Since the suction cup is also inside the jar, we also reduce the number of collision hitting the cup's surface. Eventually, the pressure pushing up on the suction cup lowers so much that gravity is able to overcome it.

**Note**: the sum of the force from the pressure inside the suction plus the force of gravity should equal the pressure of the atmosphere (neglecting friction). This isn't dealt with explicitly as it isn't necessary for the purposes of the lesson.

"Yet, the picture is not quite so simple. Let's focus in on the suction cup. What is underneath the suction cup in the bell jar? There is a small space. When you place a suction cup, you expel most of the air underneath it, BUT NOT ALL.

**Teacher draws three pictures**: one before the suction cup has been pushed down, one while it has been pushed down, and one after it has recoiled a bit.

"A suction cup sticks tightly to non-porous subjects forming

| | |
|---|---|
| a seal or barrier that prevent air from the atmosphere from joining the air underneath. The air underneath is under less pressure than the atmosphere, and so though it is applying pressure downwards, it is weaker than the pressure of atmosphere pushing up.<br><br>"So, why does the cup fall off during the vacuum? [Teacher adds down arrows to the diagrams of suction cup in the bell jar on the board].<br><br>"Does the pressure between the suction cup and the wall change because of the vacuum? Why or why not? [Teacher tries to encourage students to critique each other's responses but if this fails, stress that the seal prevents air from moving from underneath the cup through the pump and out of the bell jar. One might do this by asking how the air would get out from underneath the cup rather than telling directly.]<br><br>"So the pressure underneath doesn't change but the pressure outside does. The pressure outside of the cup goes down. Please take a minute then to explain in your own words why the cup falls down." [Teacher circulates to help students.] | **Note**: There is space on the lab sheet for this explanation to be written. |

## Wrap-up

Students integrate this new understanding of suction with their results in the first activity. Have the class return to the discussion portion of their lab sheet. Have them identify any misconceptions in light of the vacuum demonstration. They should revise their answer.

Teacher circulates and asks kids when they struggle to explain suction using the notions of air pressure inside and outside.

### Homework

Students are asked to construct an argument on whether geckos use suction to stick to ceilings.

## RESOURCES


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## DO GECKOS STICK BECAUSE OF STATIC ELECTRICITY?

## Day 4

### LESSON OVERVIEW

### Lesson Description

In the next two lessons, students will explore static electricity and determine if it explains how geckos adhere to surfaces. In today's lesson, the teacher will begin with a short demonstration on static electricity and elicit students' ideas on the subject. Then students will explore charging by friction by testing materials and finding combinations that allow one to pick up small pieces of paper. The teacher and students spend time developing a representation of charging that cites the movement of electrons from one surface to another. Finally, students spend time interacting with a computer simulation on the charging of a balloon with a sweater to continue the ideas developed earlier in the lesson.

### Learning Goals

1. Students will explain the neutrality of most objects as resulting from a balance in the number of electrons and protons.
2. Students will explain the production of charge on a neutral object by describing the motion of electrons away from or onto the object.

### LESSON PREPARATION

### Teacher Background Content Knowledge

H. Smith (1905) proposed that electrostatic interaction between the thousands of tiny endpoints of the setae and the surface is what allows the gecko to freely run up and down walls and across ceilings. He speculated that static electricity is formed when the endpoints are rubbed against the surface. This idea makes electrostatic charging and interaction important for the unit.
An object, be it metal, semi-conductor or insulator, can obtain a net charge by

1. **friction** - this is useful for charging insulators. When rubbing one material with another, electrons tend to be transferred from one material to the other. For example, rubbing a plastic straw with hair, the straw gets negatively charged and the hair positively charged.

2. **contact** - useful for charging metals and other conductors. If a charged object touches a conductor, some charge will be transferred between the object and the conductor, charging the conductor with the same sign as the charge on the object.

3. **induction** - also useful for charging metals and other conductors. A charged object is brought close to, but not touching, a conductor. If the conductor is connected to ground (a radiator or your hand will do, as they are neutral and can give up electrons to, or take electrons from, the conductor), electrons will either flow on to it or away from its surface.

Removing the ground connection, will leave the conductor with a charge opposite in sign to that of the inducting object.

In all three cases only electrons are moving. Which way the electrons will move when charging two pieces of material by friction, is determined by the work function of the two materials, i.e. the amount of energy required to remove an electron from the two materials. Electrons will move from the material with the smallest work function to the material with the largest work function. Below are some common materials listed in order of increasing work function, forming the so-called *Triboelectrical Series* ("tribein" meaning "to rub" in Greek).

| | | |
|---|---|---|
| **lower work function** | rabbit fur | + + + |
| | glass | |
| | human hair | |
| **setae**   | nylon | positive end of series |
| | wool | |
| | silk | |
| | Aluminum | + |
| | paper | |
| | cotton | |
| | wood | |
| | rubber balloon | - |
| | Copper | |
| | polyester | |
| | polyethelen | negative end of series |
| | silicon | |
| **higher work function** | teflon | - - - |

**Fig. 17** Triboelectrical series. A material from the positive end of the series will be positively charged when rubbed against a material closer to the negative end. Setae, made of $\beta$–keratin, would be placed around human hair and wool. The insert showing a single seta is from Autumn *et al.* (2000).

The hypothesis of Schmidt that the gecko sticks to the ceiling because of electrostatic forces was challenged by Dellit (1934). Dellit utilized the fact that any static charges between the setae and the surface would be neutralized in an atmosphere of ionized air, i.e. a gecko would loose its "grip" to the ceiling in such an environment, if Schmidt's hypothesis was correct. Air can be ionized in many ways, e.g. a Bunsen burner ionizes the air in its immediate neighborhood, *X*-rays and any radiation from a radioactive source ionizes likewise the air. Dellit used *X*-rays as his primary source and a Radium isotope as control source. A dead gecko was placed on chrome plated metal piece, which in turn was located just above the *X*-ray source.

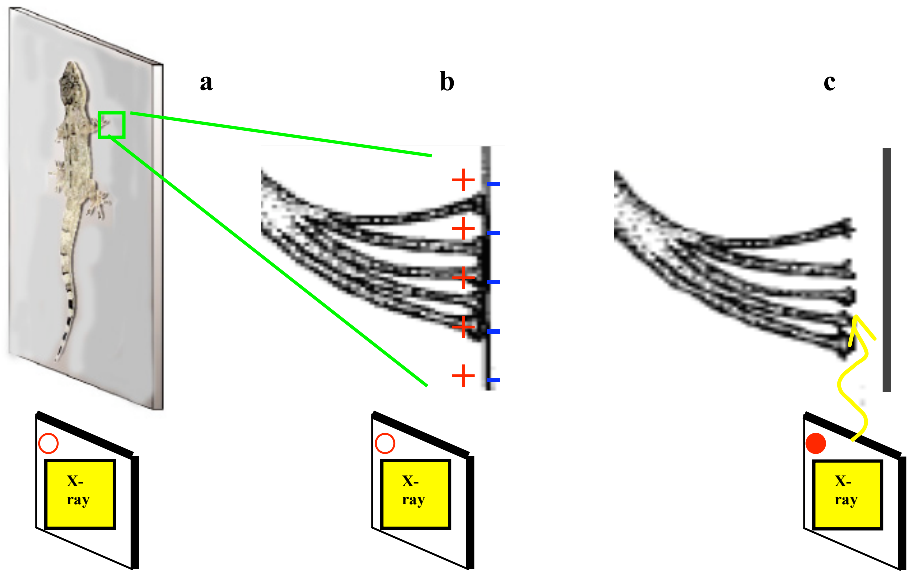


**Figure 18**. Dellit's experiment testing Schmidt's hypothesis on electrostatic force as the source to the gecko's stickiness. The series of figures show what would happen in the experiment, *if* Schmidt's explanation were valid. a) *X*-ray source is off, gecko sticks to wall b) Zoom in on Schmidt's static charges, *X*-ray is off c) *X*-ray is on and ionizes the air. The ionized air neutralizes the static charges on gecko setae and wall, and gecko is detached from wall. (Drawing of gecko in a) is from Autumn *et al*. 2006 J. Exp. Bio.; drawing of gecko foot in b-c) is from Dellit 1934).

Even after one minutes exposure to 25 MA radiation the gecko was still hanging from the metal piece. To make sure that the radiation indeed could neutralize a system of static charges, Dellit replaced the gecko and the metal piece with pieces of paper attached to a glass rod by rubbing. The paper pieces fell to the ground as soon as the *X*-ray source was turned on. A control run of the experiment with the Radium source gave exactly the same result. Schmidt's hypothesis was refuted – static charges cannot alone explain the stickiness of the gecko.

## Student Prior Knowledge Expectations

Students should have a particulate model of matter and be able to represent matter as composites of atoms. Students should also know about subatomic particles and have studied their charge, their location in the atom, and their behavior (especially, their movement). Students in their mathematical knowledge should be fluent with the multiplication and adding of integers.

## Potential Student Alternative Ideas

Research on student alternative ideas in static electricity and charge is sparse. The basics of static electricity—that charge has two values and that opposite charges attract while like charges repel—seems to be easily apprehended by students (Gutwill et al. 1999). However, some students believe static electricity to be a "substance-like power" that moves between objects (Grotzer & Perkins, 2000). Most of the research on student conceptions has been done on electricity (usually work with circuits) and in electrochemistry. Some of that research, though, applies to static electricity. For example, students often believe that electrons flow through a wire, moving great distances as they cause a light to glow or a motor to spin (Slotta & Chi, 1997 as cited in Grotzer & Perkins, 2000). During induction, when a neutral object becomes attracted to a charged object, electrons in the neutral material do move, but students may think that all the electrons flee to other side of the neutral object, when in fact the electrons move only tiny distances.

### Potential Student Difficulties

As mentioned before, we explain a macroscopic phenomena using miscroscopic entities. Bridging that gap between these two scales is difficult for students, requiring them to be able to "zoom in and out" between these scales. In this lesson, we ask students to co-create representations with their teachers, and we also give them access to a simulation that allows for dual representation of the micro and macro simultaneously.

### Materials

| Item | Number/Amount |
|---|---|
| Transparency | 1 |
| Piece of wool or fur | 1 per three students |
| Piece of polyester cloth (5' x 5') | 1 per three students |
| Plastic straw | 1 per three students |
| Glass stirring rod | 1 per three students |
| Small piece of paper (or confetti) | 1 per three students |
| Styrofoam cup | 1 per three students |
| Access to a computer lab with internet access | 1 |

### Cautions/ Potential Pitfalls

Generating static electricity is very dependent on humidity. This lab should be avoided on a rainy day. With the wool and fur, the finer the hairs the better the charge will evolve. Rabbit fur works particularly well.

### Pre-Class Preparation

## Getting the Materials Ready

Cut the polyester and fur into squares, and if you choose, assemble small kits that contain all of the materials save for the transparency and computer lab.

## Safety Issues

Please ask students to watch where they put the glass rods. They are liable to roll off a desktop and break. Though this isn't a major hazard, clean-up of glass shards takes valuable time from the lesson. Also make sure they are careful as they charge the rod. They could break it or jam their hand into it.

## DOING THE LESSON

### Opening

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|---|---|
| Teacher reviews the overarching question, refers to the list of possible explanations for gecko adhesion, and asks students to share their answers to the homework concerning why gecko adhesion does or does not involve suction.<br><br>Teacher briefly mentions the scientific process of hypothesis testing that guides the structure of the unit. | |
| Teacher begins this lesson by stating that the lesson will consider the hypothesis that geckos stick because of static electricity. | Teacher provides the purpose of the lesson. |
| Teacher begins a discussion where they ask about static electricity with a small demonstration: [Teacher rubs a transparency with fur or a sweater and sticks it to the wall or white board.]<br><br>Teacher asks students to explain how the transparency sticks to the wall. In the process, the teacher should also ask in some form the following questions:<br><br>**“What is static electricity?**<br>**“Where does it come from?**<br>**“How do you create it?**<br>**“What can you do with static electricity?**<br>**“What are charges?**<br>**“Where do the charges come from?”**<br><br>Teacher elicits students’ ideas but does not provide answers. Teacher might want to record these ideas on a sheet of butcher paper so that they can keep track of the ideas and incorporate them in the discussions over the next two days. | The demonstration and discussion are meant to elicit student ideas |

### *Activity 1 – How Does Static Electricity Develop?*

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|---|---|
| Students rub fur against several materials—a straw, a Styrofoam cup, a glass rod—to determine if the any of these items are capable of picking up small pieces of paper. | See student materials entitled “How Does Static Electricity Develop?” |
| The focus of this initial activity is determining that rubbing is | **Note**: Students have probably |

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| important to creating static electricity, but that not all substances respond to rubbing and create charge. After the activity and teacher talk, student should be able to answer the question: what does rubbing do to cause an object to become charged.<br><br>Pass out student lab sheets and have students start. | done something similar to this activity before in their school career. The point of this lesson is not to establish that charging occurs, but to help build a particular model of charging ie. charging by friction involves the movement of electrons (and only electrons)from the surface on one object to another. |

### *Discussion with Students*

| | |
|---|---|
| Depending on the your students, one might be able to have a discussion in which the students provide much of the content based on prior knowledge, intuition, and reasoning.<br><br>Below are some possible discussion questions: | Why certain materials gain electrons whereas other lose electrons is beyond the level of this course. |
| **Why would rubbing affect one thing differently than another?**<br>**What's happening when we rub?**<br>**What does it mean 'creating charge'?**<br>**How does something become positive or negative?**<br>**Why does it happen when you rub?**<br>**What's moving—the protons, neutrons, electrons—all, none?**<br>**Then back to:**<br>**Why doesn't it always seem to happen to every substance.**<br><br>If this discussion is not fruitful, you may want to use a more structured approach in which you impart more information. What follow is an example of this:<br><br>**Example Teacher Talk** | As before the teacher is eliciting students' ideas. |
| The teacher zooms in onto the surface of the straw, symbolizes atoms, and reminds students that atoms have a positive nucleus and a negatively charged electron cloud. The teacher should help students recall that electrons are mobile whereas the protons in the nucleus do not move. Finally, the class should discuss that rubbing allows for one of the materials to remove electrons from the other. However, the teacher should then lead students to understand how charge is created from an imbalance in the numbers of protons and electrons.<br><br>"**What did people see when they rubbed the straw**? The pencil? The cup? **Why did these react differently**?<br><br>-If a student provides a response like 'the wool only works with the straw', remind him that we are interested in cause | Teacher attempts to guild metacognitive awareness: what do I need to learn about? |

| | |
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| and that he is simply restating the observation.<br><br>"Why would the wool only work with the straw and Styrofoam, but not the stirring rod? Is it the shape?<br><br>-Students may scoff at this, but ask them to make an argument for why this is not the case. If students need help, suggest that they make some predictions based on shape, assuming that shape did matter.<br><br>"We know that it isn't shape, and we know that not any combination of material works. **What other information do we need to explain this phenomenon**? [Teacher takes suggestions]<br><br>"Let me suggest that we talk about how charging happens. Here we are discussing this concept, but we don't know a great deal about it. Once we know more, maybe we can relate this back to the materials we used.<br><br>"This is a chemistry class, and it seems that everything goes back to atoms. We have studied this topic before, and we have established that all matter is made of these tiny little particles.<br><br>So let us consider the case of the straw and the wool. So let's **zoom into the surface of the straw**. If we zoom in far enough, we can imagine the atoms on the surface of the straw as circles. What else can we add to these circles? Protons would go where? The electrons? Neutrons? Remember that the electrons move around the nucleus, which is where the protons and the neutrons reside.<br><br>[*You may be tempted to make the atom carbon and put six electrons, six protons, and six neutrons in the picture. However, the wool is also largely made of carbon as well. So this may become a source of confusion for students later when you explain that electrons are being transferred. Students may struggle to understand why one carbon would give its electrons to another. To explain you would have to resort to talking about how carbon changes its behavior based on the other elements it is bound to, etc. This is perhaps too much at once. Better to not identify the element.*]<br><br>"So we know that the number of protons and electrons in normal matter are equal. So let's say we have six electrons and six protons. Though the neutron number doesn't have to be the | Students have trouble zooming to a surface and imagining the atoms there. |

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| same, we'll make it six too. The neutrons are actually not important for our discussion of charging. Does anybody know why? Right, it's neutral, so it can't do anything to change charge because it has no charge.<br><br>"**What about the proton and the electron? How are they charged?** Right, the proton has a +1 charge and the electron has a -1 charge, so when if we have the same number of electrons as protons that means their charges completely cancel each other. They have the same magnitude of charge just different signs. So if we took the absolute value of the charge of a proton, it would equal the absolute value of the electron:<br><br>**\|charge of proton\| = \|charge of electron\|**<br><br>So for our drawing, we have six protons, which if each is positive, that means we have a +6. Similarly, if we have six electrons, which if each is negative, that means we a -6. So when we add a +6 and a -6, we get zero. Remember, and this is very important, that in almost all situations including the ones we will be studying, the **only source of charge in matter is the proton and the electron**. | Though neutrons can generate charge when they decay, we will ignore this as it a rare occurrence. |
| Possible accounting of charge :<br><br>6 electrons = 6 x (-1) = -6<br>6 protons = 6 x (+1) = $\underline{+6}$<br>0<br><br>"Now let's add a representation for the wool. Wool is the hair of sheep, so I will just draw one of these hairs in contact with the straw. Again I will use circles to represent the atom, dots to represent the electrons, and a larger dot in the middle for the nucleus.<br><br>*[insert example drawing]* | Multiple representations help some students. This use of familiar mathematical notion may be particularly effective in helping students. |
| "We know that charge is produced when rubbing these together. So let's go back to our math here. Let's assume the straw becomes negatively charged. **How could we create a negative charge on the straw in our drawing**?<br><br>-**if there are no responses**, teacher might prompt students by reminding them that something must have changed. Ask them to think about what could change. Also remind | Teacher will move back and forth between the drawing of the straw and wool and the calculation of net charge. |

them that the only source of charge in matter is from electrons and protons. There isn't a mystery particle that will bring in additional charge.

-**if a student says change the number of electrons**, then follow through with a calculation like the one above:

| | | |
|---|---|---|
| 7 electrons | = 7 x (-1) = | -7 |
| 6 protons | = 6 x (+1) = | +6 |
| | | -1 |

-**What about the protons?** Show them that the math would also create a charge. At this point, tell them that changing the number of protons doesn't happen. Ask for suggestions about why this isn't an option. If no answers are forthcoming, tell them that protons are held very tightly in the nucleus, and it takes tremendous amounts of energy to remove them. Electrons, however, are on the exterior of the atom and are relatively easy to remove in some substances.

"But do we have a problem? I showed how we could get a negative charge by changing the number of electrons. How do we get a positively charged substance, by moving electrons?

-**if no responses**, note that in the example above we added an electron. What else could we do with the electron number?

Show the calculation:

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| 5 electrons | = 5 x (-1) = | -5 |
| 6 protons | = 6 x (+1) = | +6 |
| | | +1 |

"Ok, so we have a means for charging a substance and that means requires us to change the number of electrons, either by adding or subtracting electrons. How does this relate to rubbing wool with a straw?

--**if there are no responses**, ask students to make the straw atoms negative. If necessary refer back to the calculations above and focus the students on the one with a negative charge.

"So (student's name) said that we need to change the number of electrons, and (student's name) suggested we add electrons

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| to the straw. This would work, we'd have more electrons than protons, and since these electrons are negative, we would have a charge imbalance. More negative than positive charges. But where are these electrons going to come from?<br><br>"Right. The electrons don't just pop out of thin air. They must come from the other surface. So in this scenario, the electrons would come from the wool and move to the straw.<br><br>*If one is short on time, one can skip the next section…*<br><br>"Is this the only way to create charge between the wool and the straw? Take a second with your group and find the other way to create charge between the wool and the straw.<br><br>"After you come up with the other scenario, think about a test you could do which would tell you which scenario was the true scenario?<br><br>[Teacher circulates and asks students to think about what are the differences between the two scenarios and imagine a test that would capitalize on these differences. For example, the major difference is the charge on the straw would be different. In one scenario, it would be negatively charged; in the other, it would be positively charged. So one test would be to bring a negatively charged object near the straw and watch its behavior near the straw.]<br><br>Students share ideas and teacher moderates discussion. | Draw in movement and do the calculation for the atom drawn on each surface. |

### *Clearing Up Student Misconceptions*

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| What follows in an example dialogue on the misconception that heat causes charging. You may find this helpful.<br><br>T: We know that rubbing these together produces charge. So let's go back to our math here. How could we get a negative charge on a straw? (1)<br><br>S: No, it's the heat, when you rub them, the heat causes the charge. | (1) is a general prompt issued during a period in which the teachers is working with the students to understand the mechanism of charging by friction. At this point, she has already reminded students of the electrons and protons in matter and their respective properties followed by some mathematical notation demonstrating that neutrality arises from equal numbers of electrons and protons.<br><br>(2) is a reflective toss, in which the teacher |

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| T: **Heating them causes the charge. How does heat do that?** (2)<br><br>S: Well, when you rub things they get hot and in this case they get charged. They have to go together. | repeats the students' idea and asks for clarification and elaboration. |
| T: Does heat have a charge? Do we have positive heat or negative heat? (3)<br><br>S: We have hot and cold.<br><br>T: OK. Is being hot and cold the same as being negative and positive? (4) | Moves (3) and (4) are intended to probe the student for misconceptions—does the student confuse heat with charge? |
| S: Well, they both have opposites. But they're not the same.<br><br>T: **Ok. If we rubbed the materials when they were cold, would it change their behavior**? (5)<br><br>S: No… | In move (5), the teacher asks the student to predict. In the provided dialogue they guess correctly, but the teacher could alternatively tell them the correct result if they misguess. |
| T: So, if we prevented the heat from building up, say by starting with a cold straw, we would still get charge. (6)<br><br>S: Yes, I think so. | Move (6) involves a restatement of the child's ideas followed by a pause, which invites the student to elaborate. |
| T: You're right to say that heat and charge are produced together. But you just said that we could limit the heat produced but still get charging to happen. (7)<br><br>S: Wait. So the rubbing causes them both, but they don't relate to each other. | Move (7) highlights the contradiction the student has generated between his initial idea and his later prediction. By highlighting this, the teacher hopes the child will inspect his earlier ideas. If they child fails, the teacher should ask him to about whether he sees this as contradictory. |
| T: What I hear from you is that just because two things happen simultaneously doesn't mean that one is caused by the other. One can't assume that. **So why did you change your mind?** (8)<br><br>S: Well, like you said, if heat really matters to charge, then you have to have it to get a charge. But I think that you could charge something even when it's cold, so you don't need heat. | The final move (8) asks the child to be reflective and to restate the new thinking he has. |

## *Activity 2 – Balloon Simulation*

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| Students then use the balloons and static electricity Java application from PhET and answer the following questions.<br><br>The website is on the student handout. | See student materials from earlier. |

**Suggested Answers to the Student Handout**

*1.What do the (+) and (–) charges represent?*
[The signs represent protons and electrons. Atoms are not represented here, but if we zoomed in we could imagine something similar to the drawing provided in the teacher talk above. The + and – sign just represent charge and would not be visible.]

*2.Why do the positive charges not move in the application, but the negative charges do?*
[The positive charges reside on the proton, which are located in the nucleus. They are tightly held there and so they do not move. The electrons are not tightly held to the atom and can move and even be removed from an atom. Since the negative charge resides on electrons and electrons are mobile, the negative sign do move.]

*3.Why does the balloon move towards the sweater after rubbing?*
[The balloon has more electrons than protons now, so it has an overall negative charge. The sweater has fewer electrons than protons, so it has an overall positive charge. Opposite charges attract, and so the balloon moves toward the sweater. ]

*4.When the rubbed balloon is brought towards the wall, what happens to the wall? Why?*
[The electrons in the wall move away from the balloon because the negative charge on the balloon repels them. The electrons in the wall don't leave the wall, but are shifted towards away from the surface. They don't actually all move to one side… more of an electron shuffle

*5.Why does the balloon stick to the wall?*
[The wall experiences charge separation, where electrons move away from the surface of the wall. However, although parts of the wall do have a charge, if you add up the charge over the entire wall, everything cancels out–the wall is neutral,. The surface nearest the balloon has lost electron density so it is positive and this is attracted to the balloon. The process of creating charge separation in neutral object by a charged object is called induction]

*6.How is the balloon sticking to the wall different from when the balloon sticks the sweater?*
[The sweater is always positively charged regardless of whether the balloon is close to it or not. However, the wall loses its charge separation as the negative balloon is removed. For the

Students may ask about whether the balloon will stick to the wall forever. The balloon eventually discharges. Some of this is because the extra electrons on the balloon migrate onto the wall. But much of the discharge comes from air molecules colliding with the balloon, picking up the extra electrons, and taking them with them as the air molecules bounce

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| sweater and balloon, we have an attraction between positive and a negative object. But for the wall and the balloon, we have an attraction between a negative object and a neutral object.<br><br>*7.What would happen if we brought the sweater near the wall instead of the balloon?*<br>[The positive charge in the sweater would cause the electrons to migrate towards the side of the wall nearest to the sweater. Like with the balloon, there would be an attraction, since the side with all of the additional electrons would take on a temporary negative charge while the positively charged sweater is nearby.<br><br>*8.Think about how this could relate to the gecko sticking to the wall. Assume the wall is initially neutral.*<br>[If the gecko had a charge on its feet, it could produce an attraction like the balloon or the sweater did. Electrons would move either away or towards the gecko's feet depending on the charge of the gecko's feet.]<br><br>Teacher walks around class and helps students. If time permits, teacher goes over answers with students. | off the surface of the balloon. |

### *Homework*

At this point, we have considered claws, glue, and suction as possible explanations for gecko adhesion. In the next phase of this unit, we will consider several other mechanisms for adhesion. Knowing what you have learned thus far and consulting the information given above, discuss what you think might allow geckos to stick to ceilings and walls. Remember that you are trying to persuade other people, and so your explanation is in competition with other explanations. A strong argument not only discusses your position and supplies evidence, but it also makes sure to consider alternative explanations and provide counter evidence. Support what you believe, but do not forget to disprove or question the competing claims.

## *References*


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# DO GECKOS STICK BECAUSE OF STATIC ELECTRICITY?

## DAY 5

## LESSON OVERVIEW

### Lesson Description

Students will continue to develop this notion that charge arises from the movement and imbalance of electrons. However, they will spend time using this idea to explain induction of charge in this lesson. They will then apply and extend their ideas about static electricity by investigating the production of charge when tape is quickly ripped off a surface. Finally, they will use their knowledge to interpret data about the gecko and whether static electricity explains its adhesion to surface.

### Learning Goals

1. Students will explain the neutrality of most objects as resulting from a balance in the number of electrons and protons.
2. Students will explain the production of charge on a neutral object by describing the motion of electrons away from or onto the object.
3. Students will contrast induction to charging by friction by citing differences in overall charge and movement of electrons.

## LESSON PREPARATION

### Teacher Background Content Knowledge

See Day 4

### Student Prior Knowledge Expectations

See Day 4

### Potential Student Alternative Ideas

See Day 4

### Potential Student Difficulties

Induction differs from the charging by friction seen yesterday in that the electrons from one surface do not move to another surface. In fact, induction occurs even when the surfaces have never been in contact. So the mathematics developed yesterday to explain how charge develops does not apply to induction because the total number of electrons in the neutral substances doesn't change as it undergoes induction. Rather the movement of electrons *within* the material creates *local imbalances*. The same number of electrons are in the material, but they have simply been located onto or away from the surface of the material (depending on the charge of the object being brought near the neutral object). Students will have to be able to switch perspectives from the overall object (no net charge) to smaller areas that due to electron movement have become opposite in charge.

### Materials

| Item | Number/Amount |
|---|---|
| LCD projector or overhead and transparency | 1 |
| Scotch tape | 1 roll per group |
| Pencil | 1 per group |
| Index cards | 1 per group |
| Ruler | 1 per group |
| Heavy book | 1 per group |
| String (8 in. piece) | 1 per group |
| Small piece of card stock (1cm sq.) with hole punched in it. | 1 per group |
| Scissors | 1 per group |

### Cautions/ Potential Pitfalls

This lab will generate a bit of tape waste—have a trash can ready. Also precut the index cards to save time. If not, have plenty of scissors on hand.

### Pre-Class Preparation

## Getting the Materials Ready

If one wishes, put together lab trays with one roll of Scotch tape and a sharpie.

## Safety Issues

**N/A**

### DOING THE LESSON

### Opening

| Opening | Notes |
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| Teacher goes over the homework from the night before. The class will then review induction by re-examining the balloon simulation.<br><br>Teacher displays the Balloon simulation for the class using a laptop and projector. Alternatively, the teacher can show a transparency of a screen shot from the simulation | See the appendix for the screen shot of the Balloon simulation. |

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| Show them the point at which the charged balloon is drawn to the wall. **Ask them why the balloon is drawn to the wall?**<br>**-if a student says because the wall is opposite in charge**, ask them why they think that. Ask them if the wall is giving up electrons? How could it be charged if it hasn't lost any electrons? [Remind them of the math from the previous day: when the electron and proton number are the same there is no charge].<br><br>**-if the student says that the electrons are driven away,** ask again how this explains why the balloon sticks. The positive charge is being exposed, and this is causing the attraction between the negatively charged balloon.<br><br>**-if no responses**, ask students if the balloon has a charge, what that charge is, and why. If the balloon is negative in charge, what would it need to form an attraction? Repeat the simulation and ask them to watch the electrons in the wall.<br><br>***Example Teacher Talk***<br>"So we can create small pockets or areas of charge in the wall by rearranging where the electrons are. Since like charges repel, the electrons on the balloon repel the electrons in the wall. The electrons in the wall don't move out of the wall. They just move away from the balloon, but stay within the wall. But this makes a deficit of electrons, producing a partial positive charge. Since protons are positive and the balloon is negative there is an attraction that causes the balloon to stick to the wall. The other side of the wall where the electrons went is now negative because it has more electrons than protons.<br>"This process of creating areas of charge within a substance that was neutral before is called induction because a charged object induces charge in a neutral object. But remember when we add up the charges of the two sides of the wall, we get zero. So overall, the wall is still neutral. | Students may think the wall has an overall charge. Rather it has areas of localized charge–areas that are positive because electrons have shifted away because of repulsion from the balloon's electrons, and areas of negative charge where the electrons have migrated. But when the charges of these smaller areas are added together, the overall charge is still zero.<br><br>It might be wise to refer to the negative charges in the simulation as electrons to reinforce what the symbols represent. |

## *Activity 1 – Induction Storyboards*

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| The teacher returns to the earlier activity from yesterday. He asks students to use their understanding gained from the Java tool to explain why the small pieces of paper stuck to the straw. He asks them to construct a comic strip or a series of pictures in which they show how charge distributions in the paper change over time as the lab activity was performed. If students wish to demonstrate | See student sheet entitled "Induction Storyboards." |

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| induction with another scenario, just have them discuss the scenario with you beforehand.<br><br>Ask them to take the ideas just covered and apply them to the lab they did at the beginning of class yesterday. Remind them that the pieces of paper were neutral when they started, much like the wall.<br><br>A **storyboard is like a comic strip**. It has pictures that show actions and a description at the bottom to narrate the story. Movie directors often story board in order to plan the shots, scenes, and camera angles for their movies. Tell them they are doing the same thing—capturing details and showing how the pieces of paper become attracted to the charge straw or glass rod. Like the simulation from yesterday, stress that you want to see both the objects and the movement of charges. **Start from the very beginning when you are rubbing, say the rod with the cloth**."<br><br>Students work on storyboards with a partner or in a small group. The space underneath each square is for a caption.<br><br>***Possible Rubric for the Storyboards:***<br>-All objects involved are included.<br>-Charge is represented somehow.<br>-At some point charge is related to subatomic particles.<br>-Charging by friction is explained.<br>-Charging by induction is explained.<br><br>The teacher should walk around, answering questions and offering hints. If time allows, students share their comic strips. | Teacher should share this rubric with students by writing it on the board or a piece of butcher paper. |

### *Activity 2— Electric Tape Lab*

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| This lab has been borrowed and modified from *Interactions in Physical Science*.<br><br>In this lab, students generate charged pieces of tape simply by pulling them apart from each other. They label each piece of tape by whether it was on the top or bottom. They then investigate whether this position or the sides of the tape affect how the pieces of tape interact. The goal is to have students apply and extend their thinking on static electricity.<br>You may want to demonstrate steps 4-7 for the students. | See student materials entitled "Electric Tape Lab"<br><br>The teacher may want to pre-cut the pieces of index card to save time. |

**Suggested Answers for Lab Questions**

1. What effect does the side of tape have? Why?
   [It has no effect. When they rotate sides they see the same pattern of repulsion or attraction]
2. Ignoring the card on the string for now, what did you see occur between the various pieces of tape.
   [The tops repel each other but attract the bottoms, and the bottoms repel each other and attract the tops.]
   Why do you think it occurs?
   [When we pull the pieces of tape apart we create charge; one piece has one charge and one has the other charge. Since the tops have the same charge they repel; likewise with the bottoms. But since the tops and bottoms have opposite charges they attract.]
3. We didn't rub the pieces of tape together but ripped them apart. How can we explain that they became charged?

[If one of the pieces of tape held on or stripped some electrons from the other piece of tape, then this would cause an imbalance in the number of electrons and protons on the pieces of tape. For example, if the sticky side from the top piece removed electrons from the bottom's smooth side, then the top tape would become negative and the bottom tape would become positive.]

Students may struggle with this question. They must remember that rubbing isn't important by itself. What is important is that it leads to the removal of electrons from one object onto another. In the tape lab, one piece of tape, the top piece removes the electrons from the bottom piece. The general principle of moving electrons to create an imbalance in charge still applies here. It is just done through a different mechanism.

4. What can you tell about the charge of B1, B2, T1, and T2? Explain.

[B1 and B2 are the same charge because the repel each other. T1 and T2 are the same charge for the same reason. However, B1 and B2 are opposite in charge from T1 and T2 because they attract each other, and opposites attract. ]

5. What can you NOT tell about the charge of B1, B2, T1, and T2? Explain.

[We don't know whether B1 and B2 are positive in charge or negative in charge. All we know is that they have the same charge and it is opposite from that of T1 and T2. The same logic applies to T1 and T2's charge.]

Students have never had to explain induction by a positive object (B1) before. Be prepared for questions. Stress that electrons are the only subatomic particles that move during induction.

6. Explain the behavior of the neutral piece of paper on the string as it interacted with the B1. Be sure to define any assumptions that you make. Feel free to draw a picture or two.

[This is induction. So when T1, which is negative since it has more electrons than protons, comes toward the paper, its electrons cause the electrons in the piece of paper to be repelled. This makes the side of the paper closer to T1 positive, which is then attracted to T1. With B1, it has a positive charge since it lost electrons and has more protons than electrons. So when it comes towards the paper, the electrons move to the side next to B1, since

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| the negative electrons are attracted to a positive charge. ]<br><br>As time permits go over the answers to these questions. | |

## Homework

Use your understanding of static electricity from today's activities and the information provided above to determine if static electricity explains how geckos stick. Write an argument in which you persuade another person of your viewpoint.