

**SHORT  
FILMS  
ABOUT  
CHEMISTRY**

A graphic of a molecular structure with red, white, and blue spheres connected by black lines, positioned to the right of the text.

**DIRECT AIR CAPTURE & THE FUTURE OF CLIMATE CHANGE  
IN THE CLASSROOM**

**IDEAS FOR CLASSROOM LESSON PLAN |**

### Lesson Preparation

- Prepare a monitor with internet access to show the short film DIRECT AIR CAPTURE
- Prepare copies of STUDENT HANDOUTS for distribution
- Assemble materials needs for ADSORPTION LAB

### Key Words and Phrases

Experiment, analyze, carbon dioxide, molecule, capture, equilibrium, surface area, adsorb, bond, intermolecular forces, positive/negative charge, acid, activated carbon, dye, engineering, flow, parts-per-million (ppm).

### Requirements

Time: Two class periods (Three with the engineering challenge)

#### Classroom Materials:

- Whiteboard and markers
- Monitor/Projector, computer with internet or downloaded file of the video DIRECT AIR CAPTURE
- Student Handouts

#### Lab Materials:

##### Dye adsorption/de-adsorption

- Activated carbon, food coloring, test tubes, acetic acid (1 M), digital balance, graduated cylinder, whiteboards/poster paper, markers

##### Engineering Challenge

- $\frac{3}{8}$ " inner diameter plastic (Tyvek) tubing, cotton balls, filter paper, paper clips, wire mesh (or other gas-permeable layer), scented extract (e.g. vanilla), syringe, sticky tack, pipe cleaners, tissue paper, toothpicks, tape, any other common craft materials, digital balance

### Standards

#### HS-PS-1-6

Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

#### HS-PS-1-5

Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

#### HS-PS-1-3

Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

#### HS-ESS2-6

Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

#### HS-ESS3-4

Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

#### HS-ETS1-1 Engineering Design

Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

#### HS-ETS1-2 Engineering Design

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

#### CCSS.ELA-LITERACY.RST.11-12.9

Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

#### CCSS.ELA-LITERACY.RH.9-10.7

Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

#### CCSS.ELA-LITERACY.RST.9-10.7

Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

#### CCSS.ELA-LITERACY.RST.11-12.4

Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

### Teacher Lesson Guide

This lesson plan is semi-modular and you can choose to use just the video/question sheet, the student handout on adsorption/equilibrium, the lab activity, and/or the engineering challenge. The objectives for the lessons are listed below.

Objective #1: Students will be able to describe how direct air capture works to lower the amount of CO<sub>2</sub> in the atmosphere by watching the video DIRECT AIR CAPTURE, filling out the notetaker, and participating in the class discussion.

Objective #2: Students will be able to connect adsorption to a surface with the concepts of charge, polarity, concentration, and equilibrium through a reading/written question activity.

Objective #3: Students will be able to model CO<sub>2</sub> adsorption/desorption onto an amine-modified surface by adsorbing food coloring dye molecules onto the surface of activated carbon and releasing it with an acid treatment.

Objective #4: Students will be able to work in a group to design their own model air capture system for scented molecules using well-dispersed activated carbon with challenges such as quantity removed, cost, and durability.

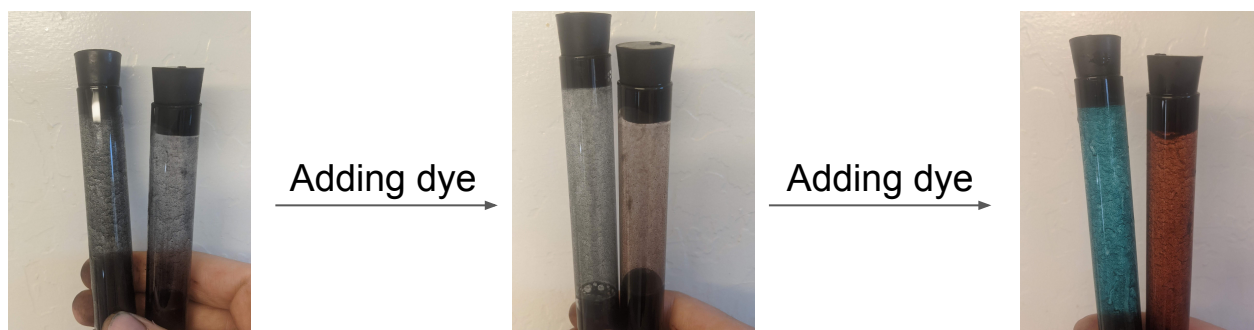
While the lab and engineering challenge list specific supplies, there is much room for modification and substitution if you have other materials more readily available or would like to adjust the activities to suit your classroom environment.

Thank you for working on incorporating university-level research and engineering into your curriculum. Good luck and enjoy the lesson!

### Teacher Lesson Guide Cont.

Tips:

- For the [Adsorption Lab](#), the activity was tested with activated carbon purchased online and is made from wood. Material and method of burning affect the surface chemistry of activated charcoal. Additionally, all dye molecules have different chemical structures and adsorption mechanisms, so it is recommended that you test your charcoal-dye combination before using it for a student activity. We found that red and blue dyes seemed to work the best. When looking for color, it helps to hold the tubes against a bright backdrop (see images below). It takes about 15-20 drops to really show the color.



When adding acid to desorb the dye, a higher concentration might make it more clear, but you should decide what to use based on your students. Also, the reappearance of color is subtle, so direct students to watch carefully. If you have a centrifuge, that would probably be the most clear way to see the color return.



Adding just enough dye before color starts to show

After adding acid, you see some color return as dye desorbs from the carbon



### Teacher Lesson Guide Cont.

#### Tips:

- The [Engineering Challenge](#) has a lot of room for adaptation. The tubing that was found to work best is a  $\frac{3}{8}$ " inner diameter tube because it can seal well with most syringes. Quick connect adaptors (top left) can be used to attach tube segments. A fine wire mesh (bottom left) is recommended so that any air pressure generated by pushing the syringe or blowing through the tube keeps the capture system contained inside (some activated carbon will blow out at first). You can use a variety of substances for the scent source, however ground coffee is easily distinguishable, common, pleasant, and doesn't have other carriers (as do flavor extracts). If removing the scent doesn't work well, you can try attaching a syringe to both ends of the air capture system your students build, push air in with one, let the air sit in the tube for ~20 seconds, and then pull air out of the tube with the second syringe, thus giving the scent molecules more time to adhere to the activated carbon. You can also see one solution that effectively removed coffee scent (center, black tube) with activated carbon stuck onto cotton-ball.



### Day 1

1. Pose the following question to your students: “What are solutions for reducing carbon dioxide in the atmosphere?” If needed, preface this with some information about climate change. Have them list solutions for three min, then have a class share out for three minutes to write ideas on the board.
2. If a student suggests CO<sub>2</sub> capture, ask for the class to elaborate on this idea. Use any/all of the following questions.
  - Do they know the composition of air?
  - How much of the air is CO<sub>2</sub>?
  - How can we selectively pull CO<sub>2</sub> from the air?
  - What can we do with the CO<sub>2</sub> once we’ve captured it?

These are all questions to get students thinking about the problem at hand.

3. Tell students you are now going to watch the film DIRECT AIR CAPTURE. Pass out the worksheet Video Notes for Discussion and inform students to complete the questions as the video runs. You will need to pause the video at 1:54 and 4:12 to give students time to answer the questions related to those segments.
4. After the video, ask students what they thought and if they had questions about any of the worksheet questions. Transition them to the worksheet by informing them that they will be learning a bit about the chemistry behind direct air capture.
5. Break the class into groups of 2-4 and distribute the handout ADSORPTION to each student. Instruct them to read the introduction and begin answering questions 1-3.

## Day 1 cont.

6. Here are some sample answers for questions 1-3.
  - Question 1 examples: frosting adheres to a cake, honey adheres to a spoon, toothpaste adheres to a toothbrush, carbon monoxide sticks to a catalytic converter, perfume adheres to your skin, etc.
  - Question 2: This could be an adhesion vs cohesion vocabulary opportunity or just the idea that some water molecules are touching the glass directly while others are touching other water molecules.
  - Question 3: Key is getting at the idea that bonds between different things have different strengths. In this case, the water-glass bond is stronger.
7. Before having students move on to questions 4 & 5, you may want to introduce the water tank analogy for equilibrium and Le Chatelier's Principle or even have a live demo of this prepared.
8. Have students read the section on equilibrium and then answer questions 4 & 5.
  - Question 4: Just like in the water tank analogy, if  $\text{CO}_2$  is purged from the system, then that is like removing a reactant in the reaction between the surface bound amine and  $\text{CO}_2$ . Removing a reactant causes the system to shift to the left to counteract that change. You could also discuss that lowering the pressure causes a shift to the left as well due to the presence of gas molecules on the reactant side of the equation.
  - Question 5: This is to get students thinking about other uses of direct air capture systems, particularly at the sources of pollution (i.e. power plants).

Whatever they don't complete should be completed as homework.

9. Exit Ticket:
  - What kind of adsorption (chemical or physical) is happening between  $\text{CO}_2$  and the amine surface?
  - Why do they need to use a vacuum when they want to remove the adsorbed  $\text{CO}_2$  and regenerate the system?

### Day 2

- 1) Start off the second day with a refresher question about direct air capture. For example, “Name two challenges that scientists and engineers had to overcome when designing an effective system for capturing  $\text{CO}_2$  directly from the air.”
- 2) Tell students that today they are going to model direct air capture in a lab. However, since  $\text{CO}_2$  is colorless and odorless, they are going to use other molecules in place of  $\text{CO}_2$  to make the lab more interesting. Ask the class if anyone knows what activated carbon is? (Some students may know from previous science lessons, or as dietary supplements or skincare products). Either way, inform them about what it is (charred carbonaceous matter) and that the reason why activated carbon is used in these industries is because it has an extremely high surface area. Go into as much detail about surface area as you feel is needed. As one interesting fact, 1 gram of activated carbon has an approximate surface area of  $1000 \text{ m}^2$ , meaning that 5 grams has roughly the same surface area as a football field. You may want to have 5 g weighed out to demonstrate.
- 3) Make sure students are in groups and pass out the “Adsorption Lab” worksheet. Direct students to read the instructions and gather the needed materials. Then, to follow the directions and work through the questions.
  - Question 1: Encourage students to make a guess in grams and not to change their answer after completing the lab.
  - Question 2: Students might have a difficult time thinking about what makes something high-surface-area from a structural point of view. You may want to provide a template/example of what an activated carbon particle looks like when zoomed in, or you can set up a demo of surface area in the lead-in to the lab.
  - Question 3: Encourage students to look back at their equilibrium questions from last class and to apply what they learned to the question. If they have learned about strong and weak acids, you could also encourage students to think about how  $\text{H}^+$  adsorbing to the surface of the carbon affects the acid equilibrium in solution. Either way, students should at least pick up that if the surface is becoming positively charged and the dye molecule is also becoming positively charged, that the dye will no longer adsorb to the surface.

### Day 2

- 4) After students have completed the lab and the questions, please instruct them to clean up their stations and return to their seats. In groups and on large poster paper or whiteboards, have students draw a four-stage model (divide their workspace into quadrants) that shows what happens with the dye...
  - 1) Before the activated carbon is added
  - 2) After the activated carbon is added
  - 3) As the acid is being added
  - 4) After the acid is completely added.

If you are running short on time, you could also jigsaw this and have different groups complete one or two instead of all stages. You should look for use of unique symbols for dye molecules and activated carbon in the early models. Stages 1 and 2 are the same as what students have already drawn on their sheets. (Refer to Appendix F, Science and Engineering Practices, #2 Developing and Using Models for more guidance on what to look for/emphasize). Stages 3/4 will probably need the most clarification, so be sure to emphasize showing why adding acid causes the dye to desorb in stage 3 and then the result of that process in stage 4. In all stages, be sure that their model drawing matches what they observed in the lab.

- 5) Based on your observations of the groups, have 1-2 groups present their models and ask them to explain how the model connects what they were able to observe in the lab activity to what they cannot see happening on the molecular level.
- 6) Exit Ticket:  
How does the lab activity today help you to visualize and understand the concept of direct air capture that you were introduced to last class?

# Adsorption

Name: \_\_\_\_\_

**Directions:** Read the introduction and then answer the questions based on the reading and also your previous knowledge.

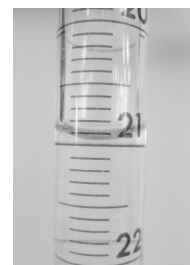
## Introduction to Adsorption:

Have you ever noticed how some things just seem to stick together? Like paint to a surface or water to a mirror? Why is that? It's not like mirrors or water feel sticky when you touch them, so what makes them stick to each other so well? This process has to do with something called **adsorption**. Adsorption is when molecules of a gas, liquid, or solid are attracted to a liquid or solid surface. This is not to be confused with the word *absorb*, which is when one material soaks up a gas or liquid, like how a sponge or paper towel *absorbs* water.

There are two kinds of adsorption, physical and chemical. For chemical adsorption, the thing that is sticking to the surface forms an actual chemical bond through interactions of valence electrons (e.g. a covalent bond) with the surface, sometimes called a substrate. For physical adsorption, the connection between them isn't like the bonds you may have learned about between atoms (e.g. ionic or covalent). Instead physical adsorption is due to intermolecular attractions (e.g. van der Waals).

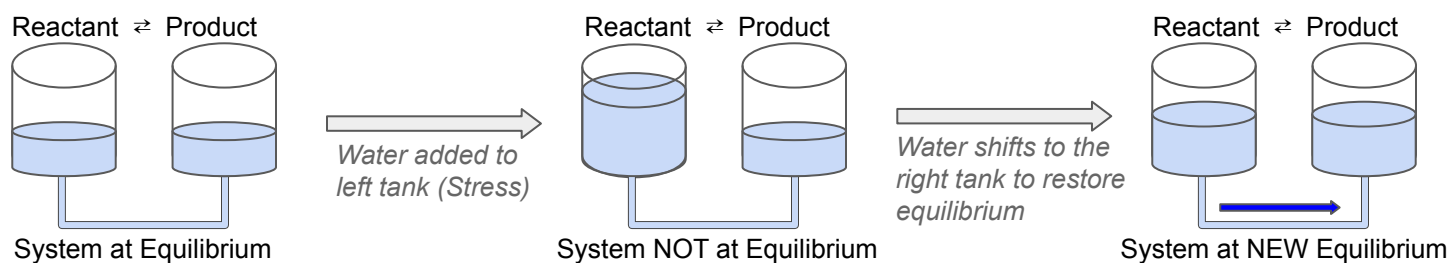
## Adsorption Questions:

- 1) Write down an example, different from the ones above, where one material adsorbs to another.
- 2) If you throw a glass of water at a window, you know most of it will slide off to the floor. What is different about the water that sticks to the window? Explain your thinking around this idea.
- 3) Look at this image of a meniscus of water in a test tube (made of glass). As you can see, the water seems to be crawling up the side of the tube! What does this mean about the attraction between water and glass compared to the attraction between water and other water molecules?



### Introduction to Equilibrium:

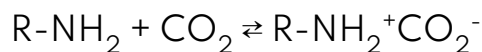
When discussing equilibrium you are discussing a process or reaction that is reversible. This can be a chemical reaction (e.g. an acid gaining or losing a proton) or a process (e.g. adsorption and desorption from a surface). According to Le Chatelier's Principle, as you apply a constraint or a stress to a system at equilibrium, the system will shift to counteract that stress. Examples of stresses can be changes in pressure, concentration of reactants or products, or changing the temperature.



For the following questions, consider the system of direct air capture of  $\text{CO}_2$  and analyze how changes in the system (heating the system or reducing the pressure via vacuum) will alter the previously established equilibrium.

### Equilibrium Questions:

- 4) To remove  $\text{CO}_2$  from the direct-air capture system, they stop new air from coming into and apply a vacuum to the system (with heat). Explain why purging  $\text{CO}_2$  in the system is necessary to desorb all the adsorbed  $\text{CO}_2$  and completely refresh the system? Use the following equation and the concept of equilibrium in your answer. In this case, R represents the attachment of the amine to the surface.



- 5) If removing  $\text{CO}_2$  can cause more desorption from a surface, then increasing the concentration of  $\text{CO}_2$  could increase adsorption. However, the Earth's atmosphere is only 400 ppm of  $\text{CO}_2$ . Where else could direct air capture be used that has a higher concentration of  $\text{CO}_2$ ?

## Video Notes for Discussion

- 1) How did the development of the Haber-Bosch process to make more fertilizer, in part, lead to the greenhouse gas emission problem we have today?
- 2) At the 1:54 mark in the video, there is a graph that shows two possible branches for our future. Looking at the y-axis, how are we going to achieve a temperature increase of less than  $2^{\circ}\text{C}$  (compared with an increase of  $3.3^{\circ}\text{C}$ )?
- 3) In your own words, what does 400 parts per million mean? Is this a high concentration or a low concentration?
- 4) At the 4:12 mark, a  $\text{CO}_2$  molecule bonds to an amine and at that moment you see the shape of  $\text{CO}_2$  change from a linear shape to a bent shape. Explain why this is, using your knowledge of charge and bonds.
- 5) When  $\text{CO}_2$  bonds to the amine-modified surface, heat is released. In order to detach the  $\text{CO}_2$ , they heat up the whole system. Explain how this makes sense using your knowledge of enthalpy (energy of bond making and breaking).

### Video Notes for Discussion cont.

- 6) The goal of direct air capture is to reduce the concentration of  $\text{CO}_2$  in the air. However, heating the direct air capture system requires energy. What sources of energy can scientists and engineers use to make sure that this energy needed to heat the system doesn't contribute to more  $\text{CO}_2$  being released?
  
- 7) List at least TWO things that can be done with the captured  $\text{CO}_2$  to keep it out of the atmosphere.
  
- 8) The end of the video says that chemists will be needed to develop "custom chemical solutions" for each specific place in the world. Why do you think the machines will need to be different in different locations and it can't just be the exact same everywhere?  
*(\*Hint: consider differences you notice when in different places. For example in places: near the ocean; with lots of forests; with lots of farms; with lots of industrial plants; etc. How might these conditions affect direct air capture technology?)*

## Adsorption Lab

### Introduction:

In this lab you will be modelling CO<sub>2</sub> capture by using activated carbon to trap dye molecules. In the video DIRECT AIR CAPTURE, you saw how air was blown through an amine-modified solid where CO<sub>2</sub> became chemisorbed (chemically bonded) to the amine-covered surface. Then, when the amine-modified solid was full of CO<sub>2</sub>, they would heat up the solid and apply a vacuum to release the CO<sub>2</sub> by breaking the carbon-nitrogen bond.

In this lab, activated carbon will act as the amine-modified solid and the dye molecules will act as the CO<sub>2</sub>. To release the dye in the end, we will use a chemical approach by adding acetic acid instead of heating the substance.

### Materials:

Large test tube  
Activated carbon  
Food coloring (red or blue)  
Metal spatula  
Weigh paper  
Acetic acid (1 M)  
Personal Protective Equipment (e.g. goggles, gloves, etc)

### Procedure:

- 1) Fill your test tube with a small amount of activated carbon (~¼ tsp or 1 mL) and about 2-3 mL of water.  
Answer question 1
- 2) Add 3 drops of food dye. Put a stopper in the top of the test tube and shake the tube vigorously. Note the liquid color (it helps to tilt the tube, looking with a bright light in the background). For 3 drops, you should not see any color after shaking.
- 3) Repeat step 2 until you feel you can clearly see the food dye after shaking.
- 4) Answer question 2
- 5) Re-add a small amount of activated carbon to your test tube the make the color disappear again.
- 6) Divide your mixture in 2 parts (so that you can compare the before and after of adding acid)
- 7) Add 5 mL of 1 M acetic acid to one of your solutions. Note any changes to the color.
- 8) Answer question 3

### Questions:

- 1) How many drops of food coloring do you think that the activated carbon will be able to adsorb? (How many drops can you add before you see the dye color in the water)?

## Adsorption

## Lab

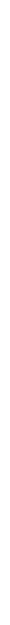
## cont.

### Questions (cont):

- 2) What happened to the dye when you added it to the activated carbon? Draw a model below of what food dye looks like without activated carbon and what it looks like with the activated carbon. Be sure to include labels and annotations in your drawing.

Only Dye

Dye w/activated Carbon



- 3) The following equation is for the dissociation of acetic acid.



Adding  $\text{H}^+$  ions does a lot of things to our solution in this case! The activated carbon can adsorb  $\text{H}^+$  ions, which makes the surface positively charged. Also, the dye molecule you added has the ability to react with  $\text{H}^+$  ions which also leads to a positively charged molecule. Given this information, explain why adding acetic acid caused the color to return to your solution.

## Engineering

## Challenge

### Introduction:

In this Engineering Challenge, you will be working as an engineer on a direct air capture system. Similarly to the engineers that capture CO<sub>2</sub> using a high surface area capture system, you will also be using a high surface area material (activated carbon) to pull molecules directly from the air. Unlike those engineers, your task is not to remove CO<sub>2</sub>, but to remove scent. Your teacher will provide the scented substance, your goal is to completely remove the scent when it passes through the tube and over your molecule capture system. Please keep the following sub goal in mind as well.

### Main Goals:

- Remove the scent completely as it passes through the tube and over your system
- Air must flow through the system and not be blocked completely
- Your capture system must stay in the tube when pressure is applied (e.g loose activated carbon dust will just be blown out of the tube)
- Your capture system must be free from air leaks

### Sub Goal:

- Use as little material as possible (activated carbon and structural materials) to reduce cost

### Description of the setup:

First, the teacher will check the air flow through your tube by attaching a syringe to the end of your plastic (tyvek) tubing and pushing air through. If no air can be heard/felt coming out the end then you must adjust your design before testing for scent removal.

If you pass the air flow test, your teacher will load a small amount of flavor extract (e.g. coffee grounds) into a sample tube. A syringe will then be inserted into your plastic tubing containing your apparatus. The teacher will then push air through using the syringe while a judge (either permanent or rotating from other groups) will determine if the smell still gets through. The teacher will also have a blank “control” tube to calibrate the strength of the smell (and other inherent smells, i.e. plastic) getting through without any capture system.

### Final Note:

Good luck on the challenge, and don't forget to work together as a team. You may want to divide yourselves into roles (i.e. materials handler, organizer, questioner, builder), but regardless of your approach, be sure to brainstorm lots of ideas and then move efficiently toward creating your vision.

Chemistry Shorts™ is a film series that communicates the breadth and depth of chemistry's impact on humankind in an approachable manner, sponsored by the Camille and Henry Dreyfus Foundation. These films will celebrate the science and the people who share a passion for the vital role chemistry plays in the biggest issues, including human health, renewable energy, the nature of life, sustainability, new materials, and climate change. Each film incorporates a lesson plan that offers ideas for ways they may be incorporated into the classroom. We welcome your feedback at: [chemistryshorts.org](http://chemistryshorts.org).

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