

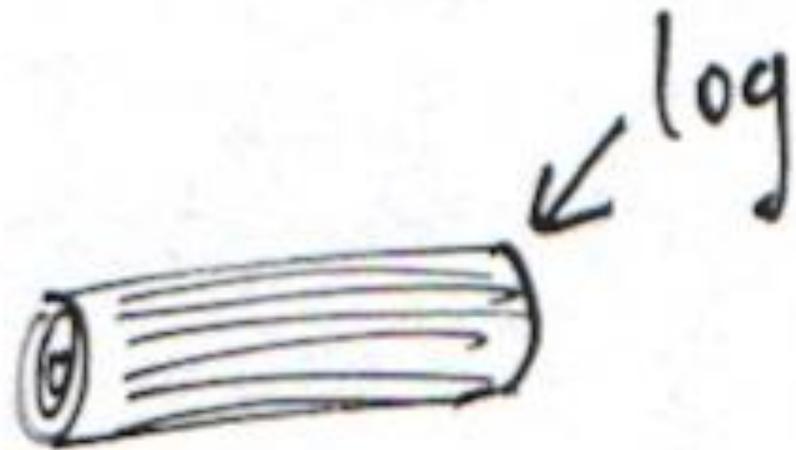
Process and Products

**Engaging Students with
Authentic Scientific Thinking**

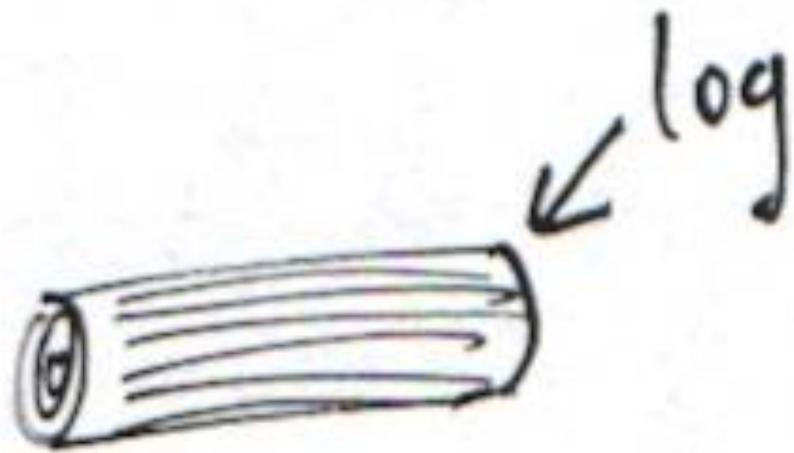
Tyler DeWitt, Ph.D.

Irony:

**As a teenager, I
hated school, and
particularly science.**



what do plants eat?



what do plants eat?

what do they eat to get
the nutrients to build wood
and other parts of their "bodies"?

I think:

“The plant absorbs most nutrients from the dirt. In other words, it eats dirt.”

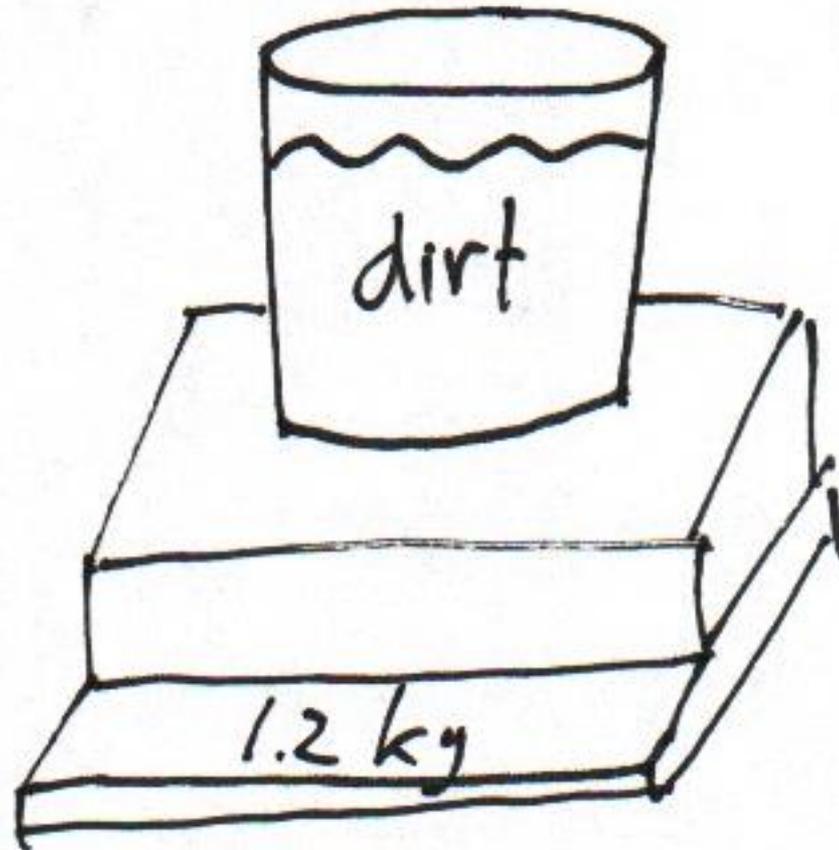


Prove it.





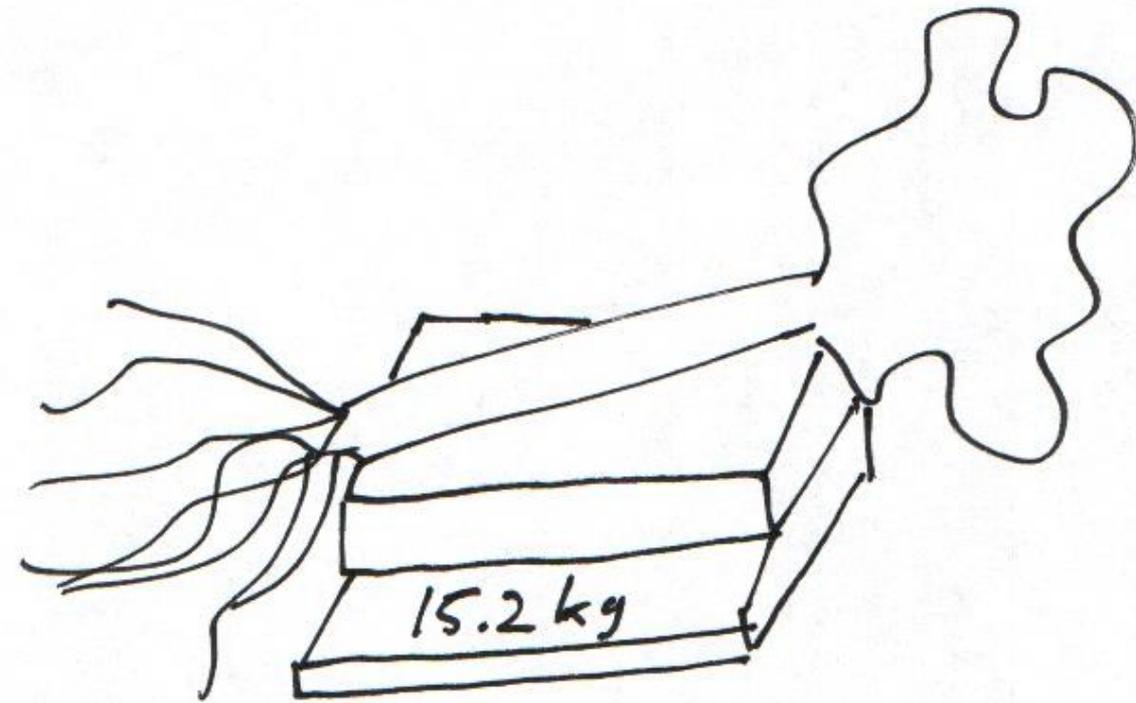
We weigh the dirt.



We plant a small seedling in the dirt and let it grow.



In a few weeks, the plant had increased in mass, but the mass of the dirt was exactly the same!



Mind-altering realization:

Plants do not eat dirt.

Plants can take liquid water (H_2O) and carbon dioxide (CO_2) gas, and turn them into solid wood.

**How does the
color of light affect
plant growth?**



Does the color of light affect how a plant grows?

violet



blue



green



yellow



orange



red



Does the color of light affect how a plant grows?

violet



blue



green



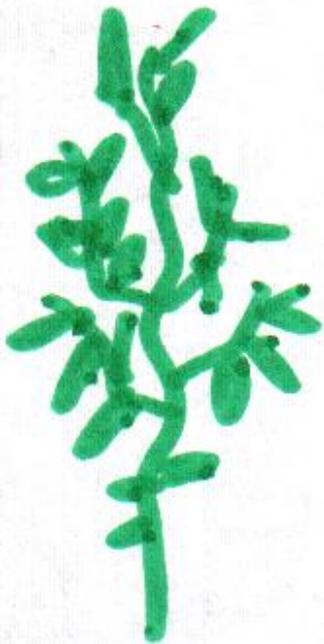
yellow



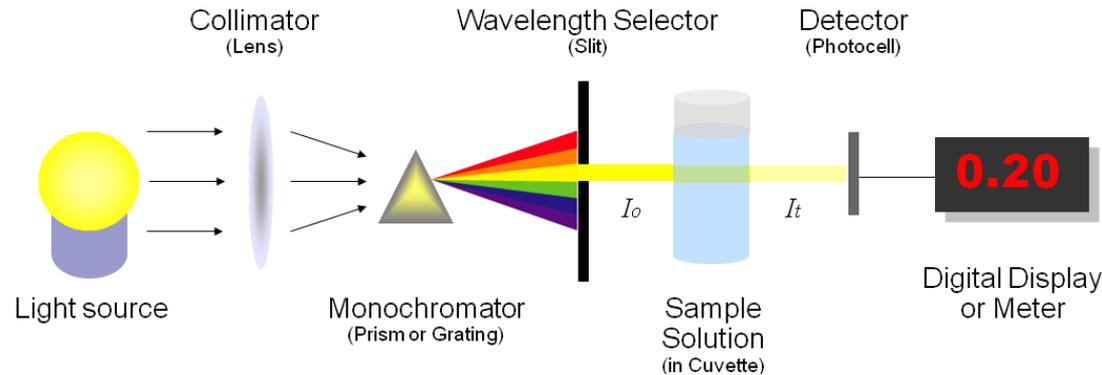
orange



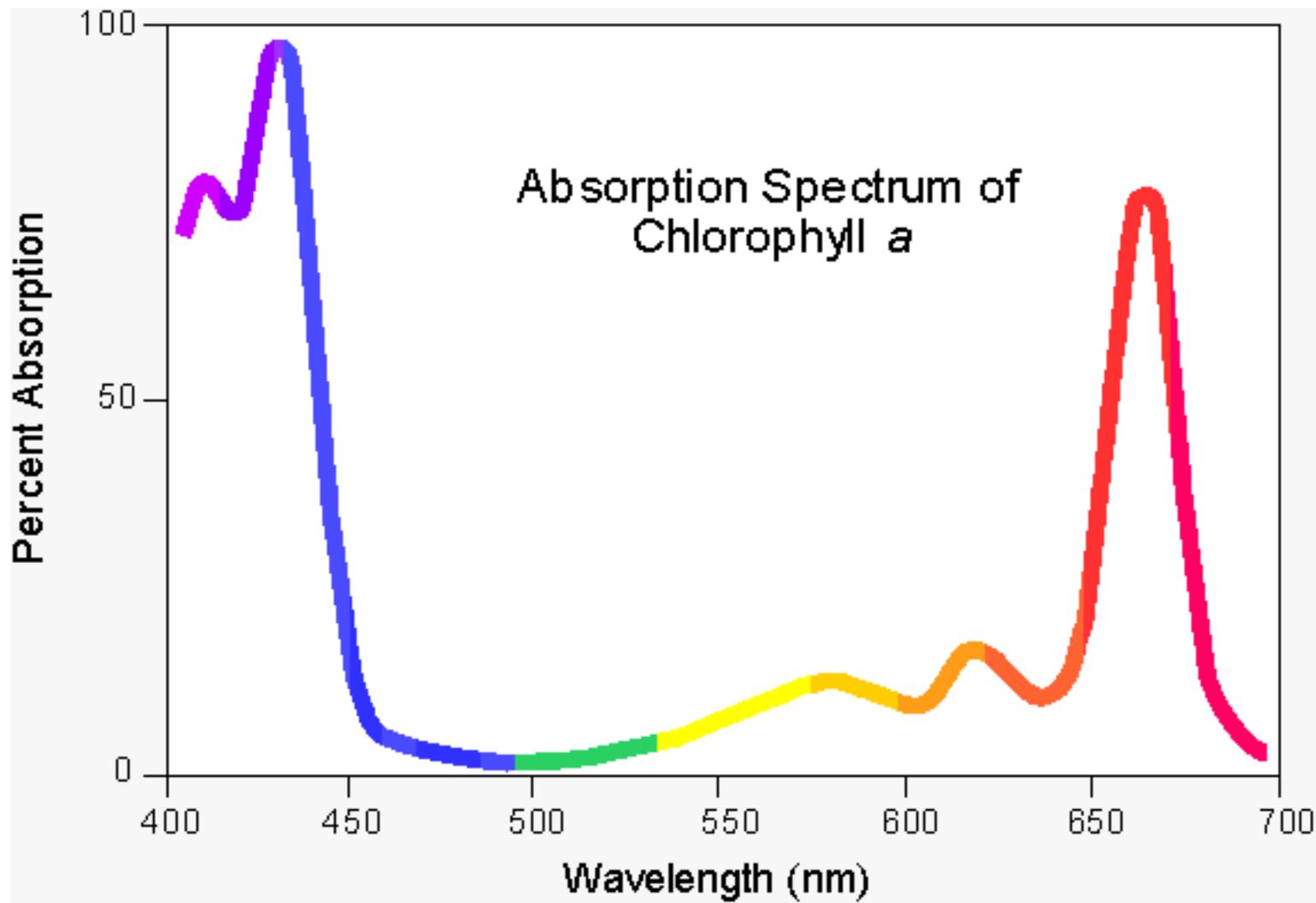
red



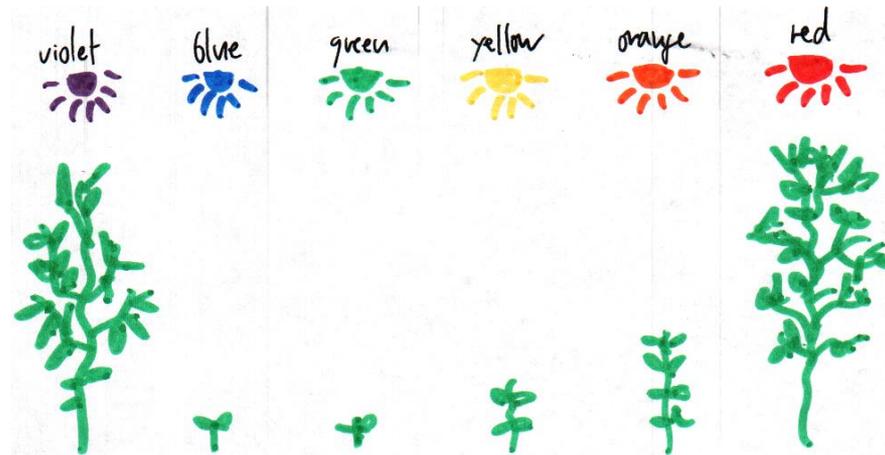
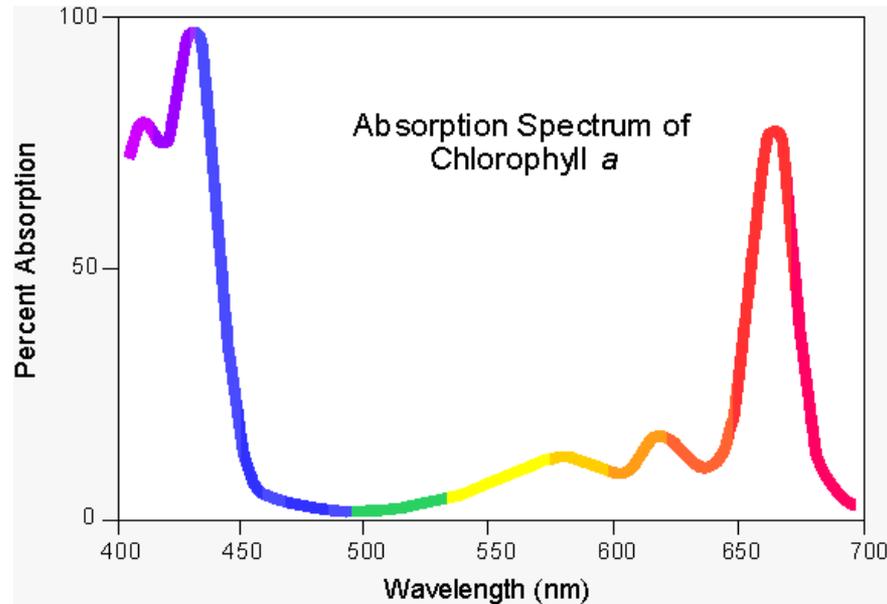
A Spectrophotometer measures how much light of different colors (wavelengths) a sample absorbs.

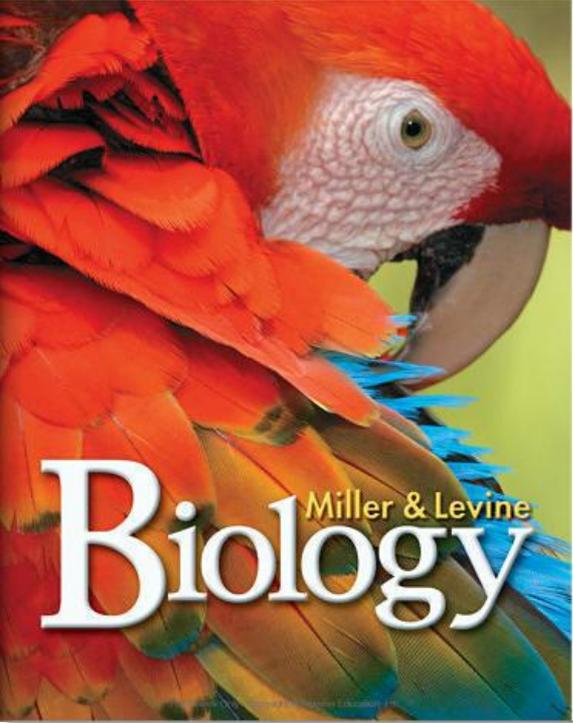


We grind up leaves, make a solution, and measure absorbance with the spectrophotometer.



Plant growth is directly related to the color of light that chlorophyll absorbs.





An Overview of Photosynthesis

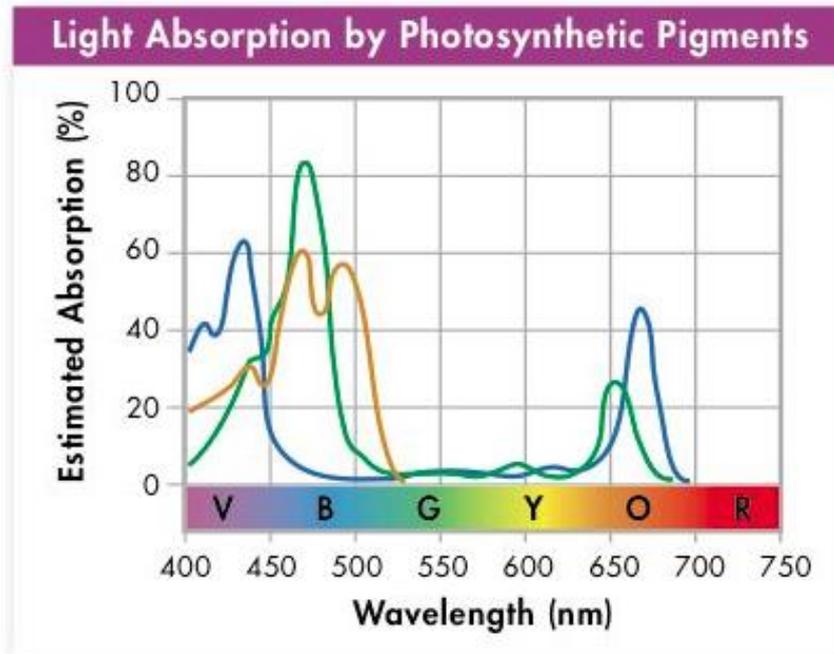
What are the reactants and products of photosynthesis?

Many steps are involved in the process of photosynthesis. However, the overall process of photosynthesis can be summarized in one sentence. *Photosynthesis uses the*

energy of sunlight to convert water and carbon dioxide (reactants) into high-energy sugars and oxygen (products). Plants then use the sugars to produce complex carbohydrates such as starches, and to provide energy for the synthesis of other compounds, including proteins and lipids.

Pigments

Photosynthetic organisms capture energy from sunlight with pigments.



- 1 Chlorophyll a
Chlorophyll b
- 2 Carotenoids

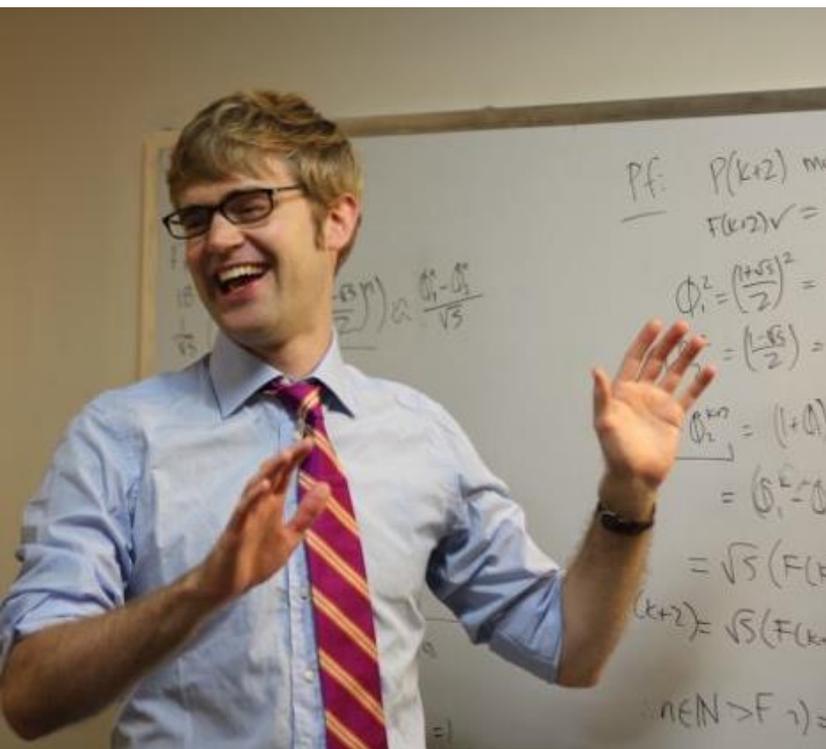
Cell Phone Spectrophotometer

A Guided Inquiry Approach to Teaching How to Think About Analytical Instrumentation

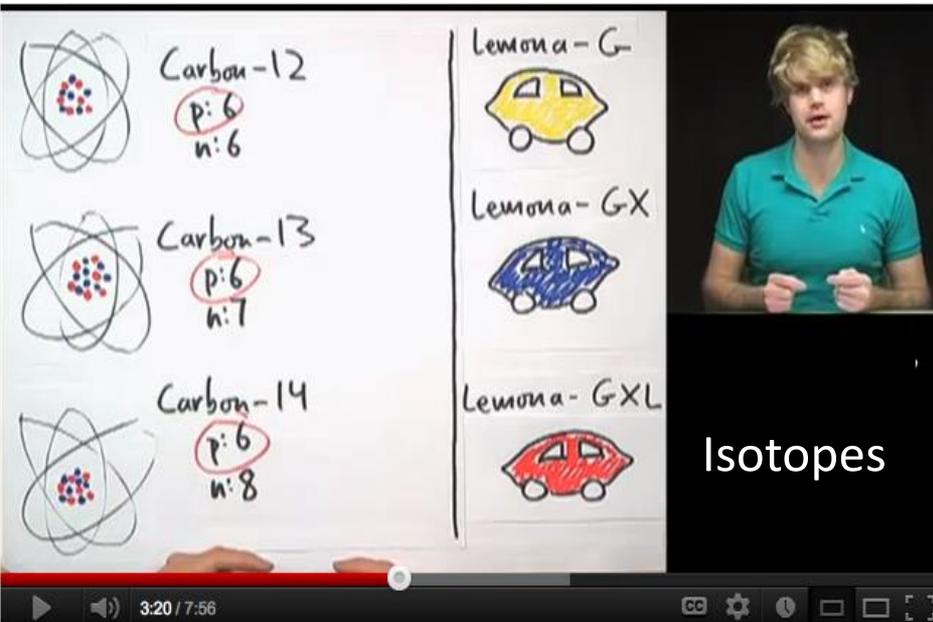
Alexander Scheeline and Kathleen Kelley

Department of Chemistry
University of Illinois at Urbana-Champaign
600 S. Mathews Ave.
Urbana, IL 61801 USA





I make Chemistry, Biology and Physics tutorial videos which are on YouTube:



Carbon-12
p: 6
n: 6

Carbon-13
p: 6
n: 7

Carbon-14
p: 6
n: 8

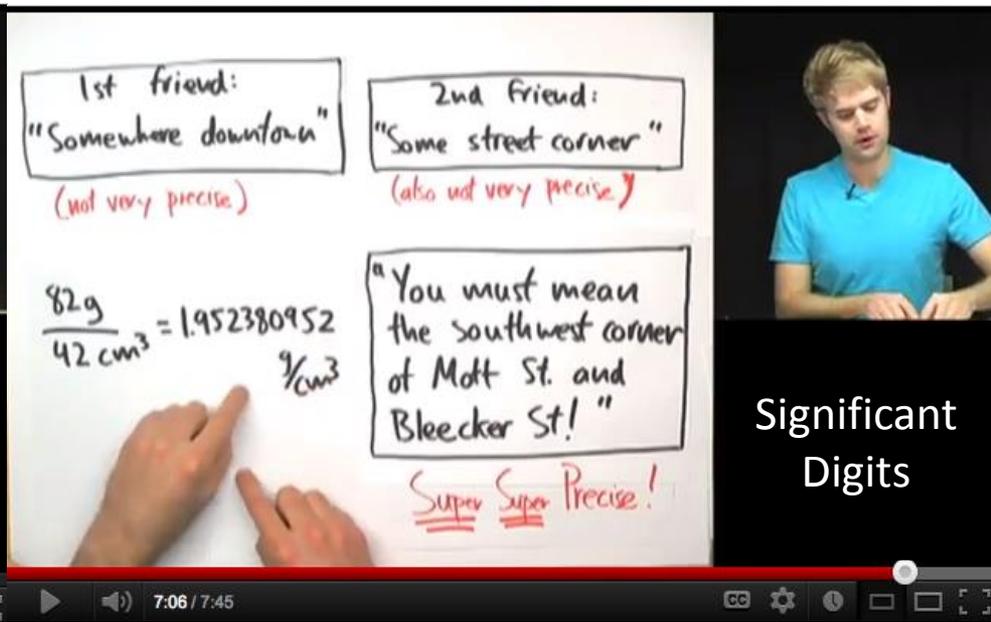
Lemon a-G


Lemon a-GX


Lemon a-GXL


Isotopes

3:20 / 7:56



1st friend:
"Somewhere downtown"
(not very precise)

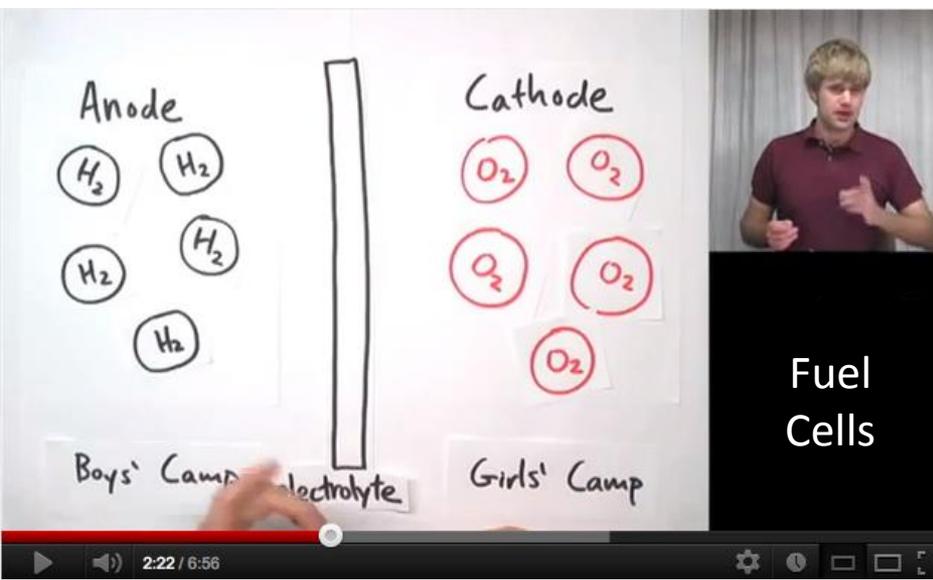
2nd friend:
"Some street corner"
(also not very precise)

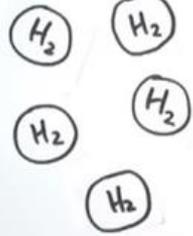
$\frac{82\text{g}}{42\text{cm}^3} = 1.952380952 \frac{\text{g}}{\text{cm}^3}$

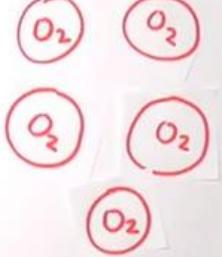
"You must mean the southwest corner of Mott St. and Bleeker St!"
Super Super Precise!

Significant Digits

7:06 / 7:45



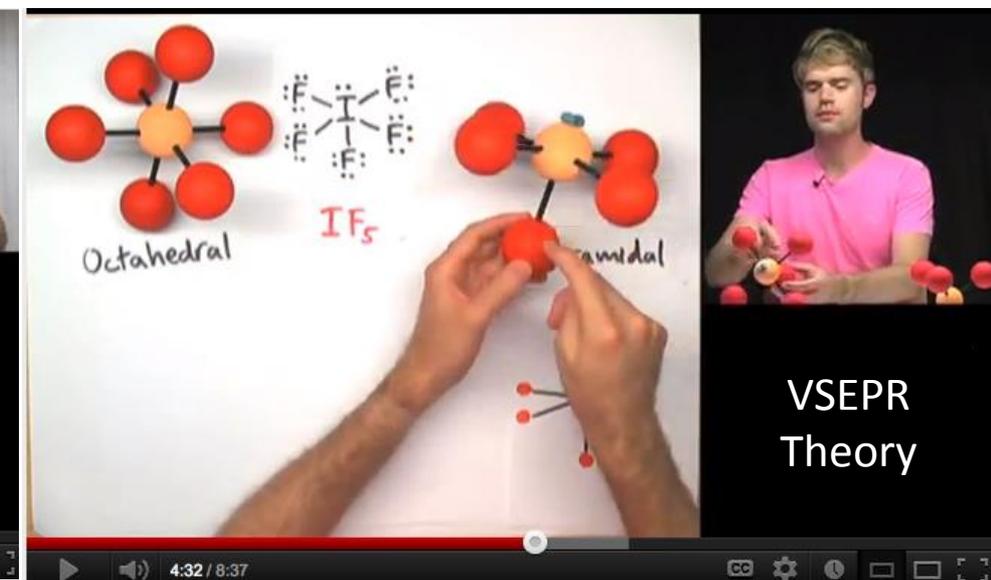
Anode


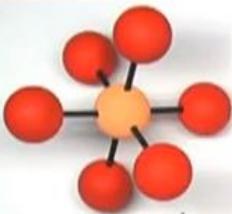
Cathode


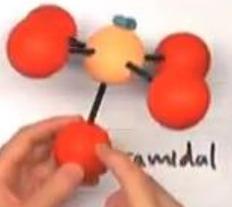
Boys' Camp | electrolyte | Girls' Camp

Fuel Cells

2:22 / 6:56




Octahedral


Trigonal bipyramidal

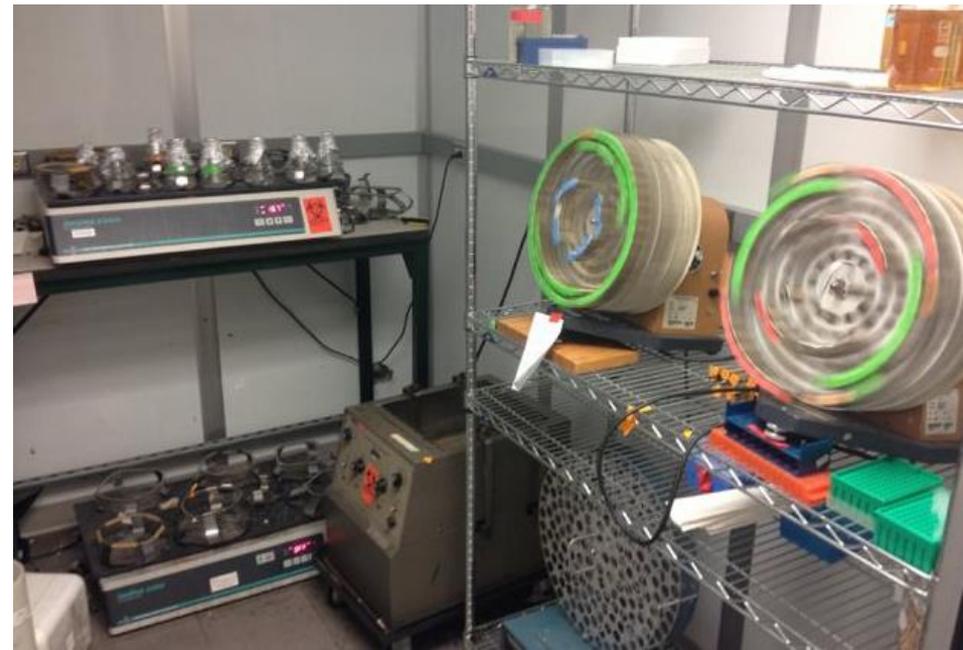
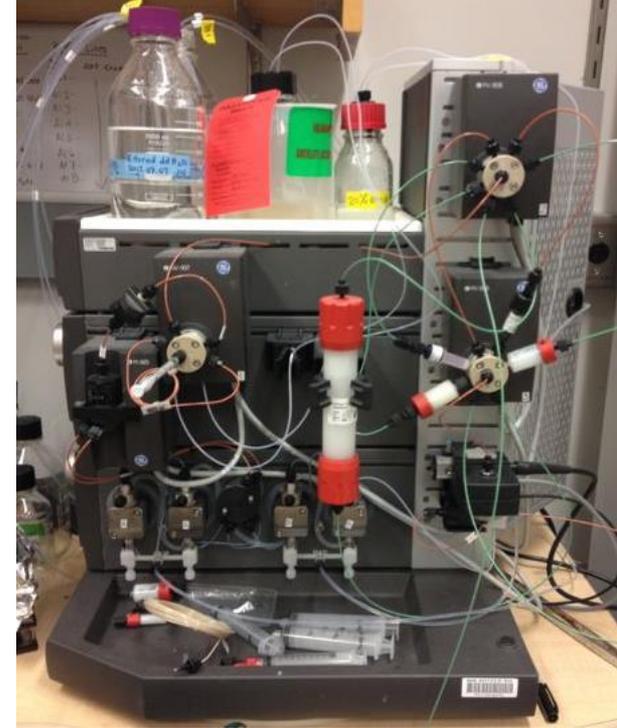
IF₅

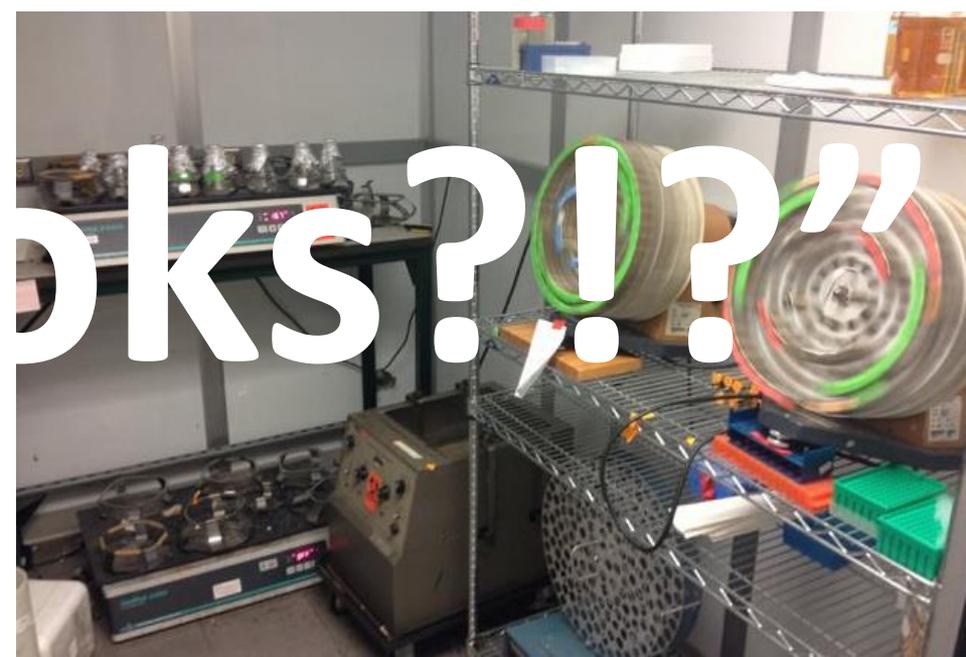
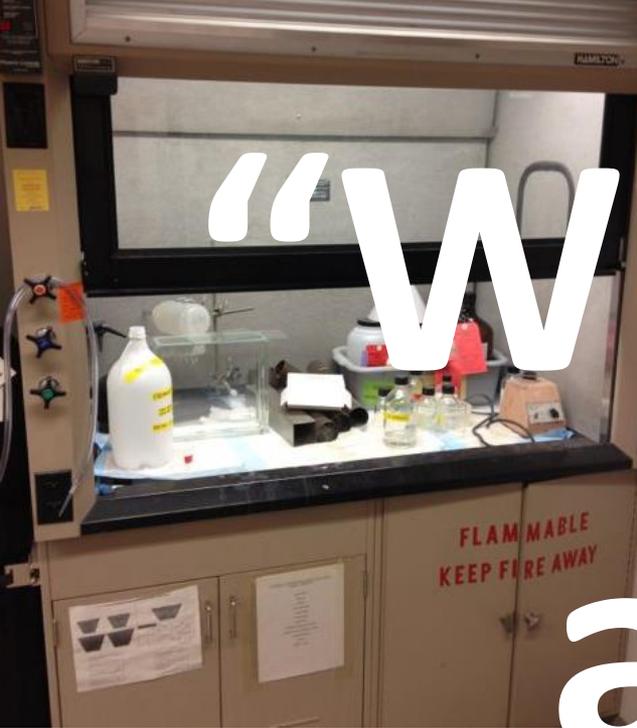
VSEPR Theory

4:32 / 8:37



Photos of My Microbiology Lab





“W
a
e
r
textbooks?!?”

Scientific

Process vs. Products

Scientific

Process vs. Products

Scientists ask and answer questions about the world, using:

- scientific method
- experimental tools and techniques
- critical thinking
- problem solving
- collaboration
- creativity.

Scientists present, debate, and discuss their findings.

Scientific

Process vs. Products

Scientists ask and answer questions about the world, using:

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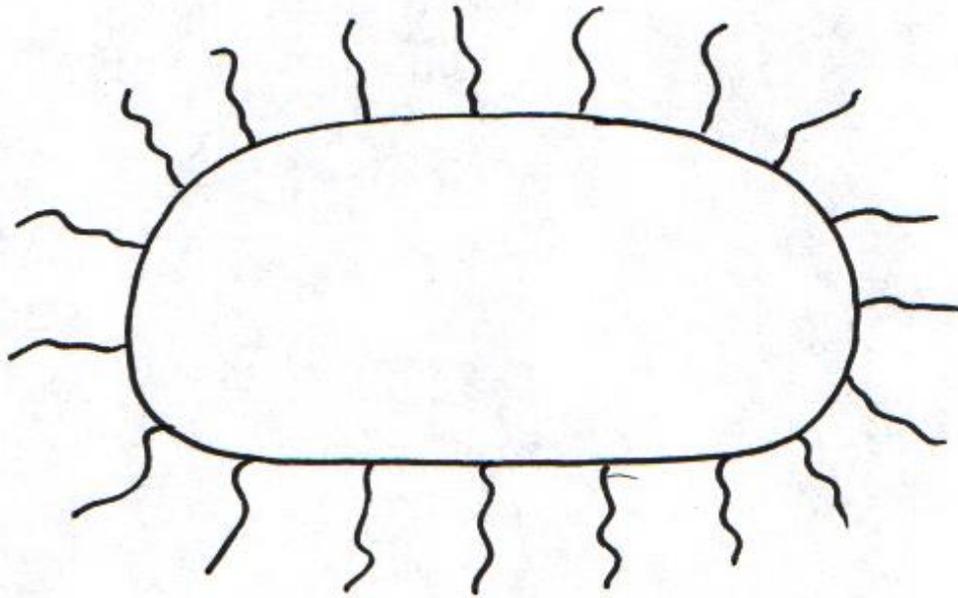
The results of scientific process, the findings, are presented as facts in a textbook or science course.

**Illustration of products
and process:**

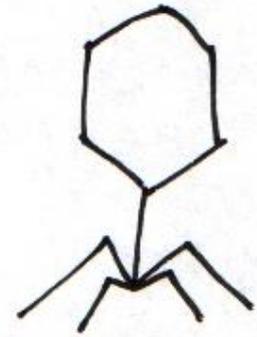
**I am a scientist. Here is
what I do all day long.**

Products

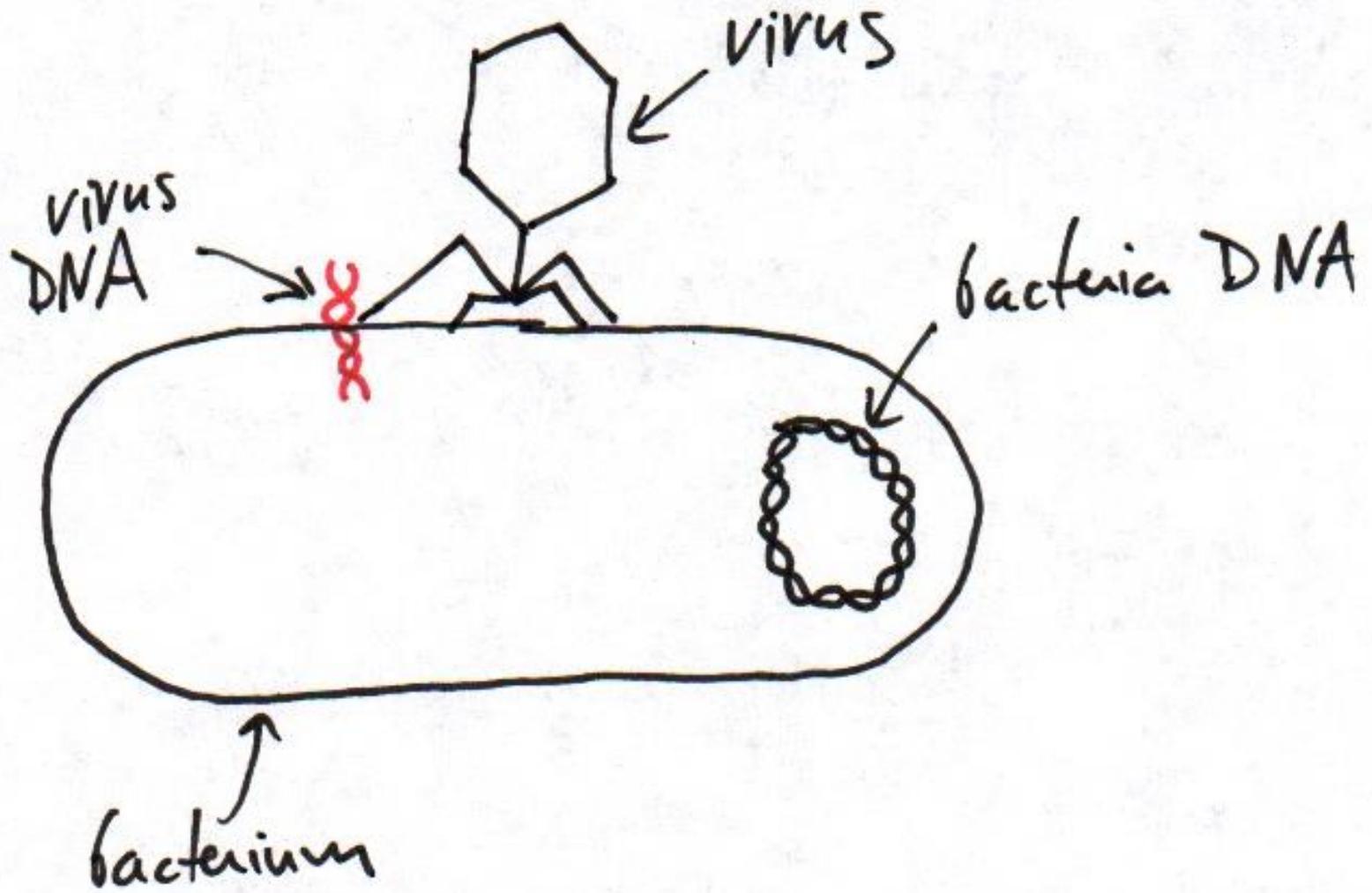
Facts we already know



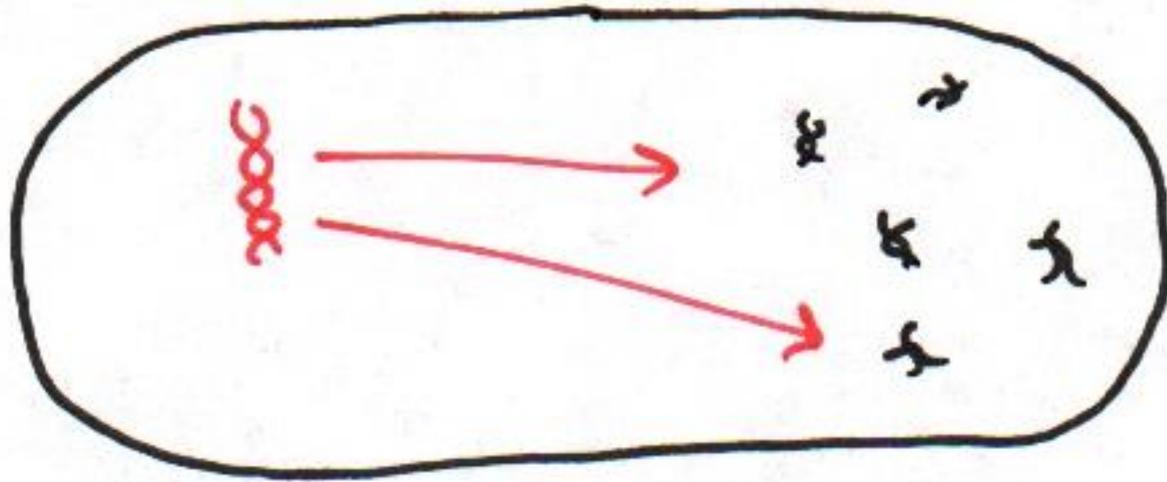
bacteria



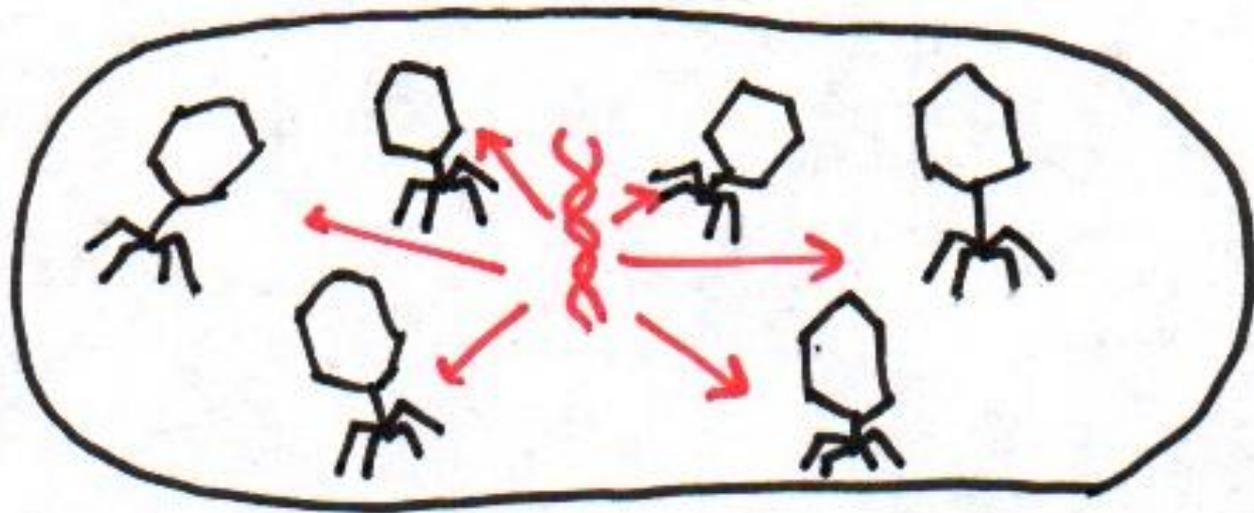
virus



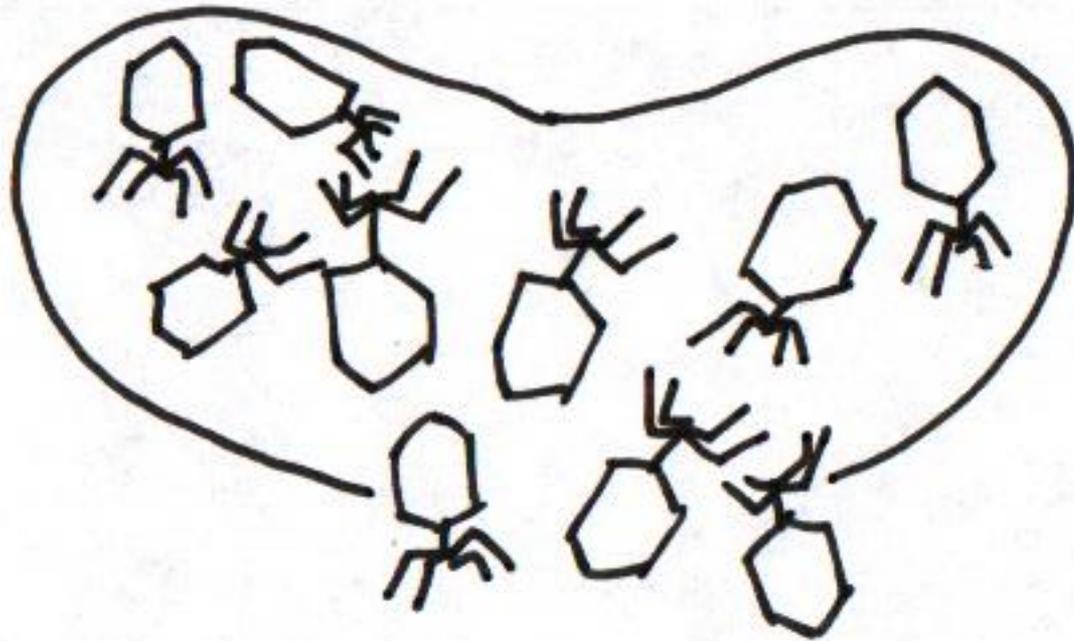
virus slips its DNA into bacterium



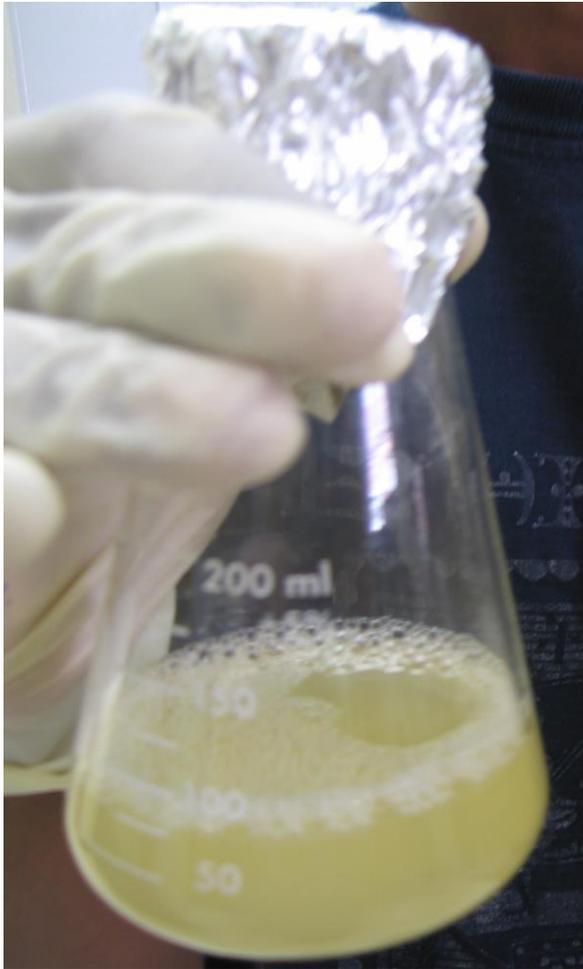
virus DNA makes stuff that
destroys bacteria DNA



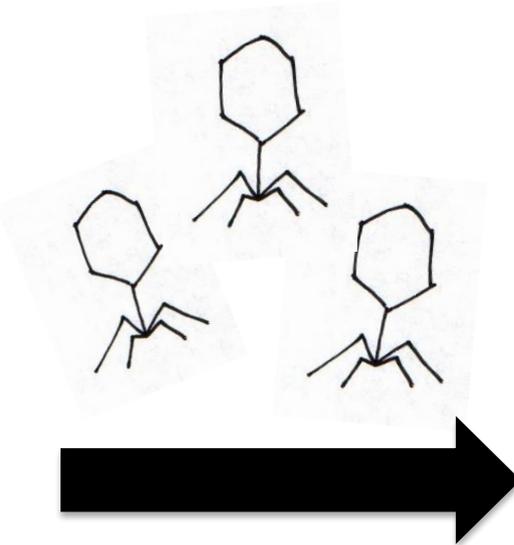
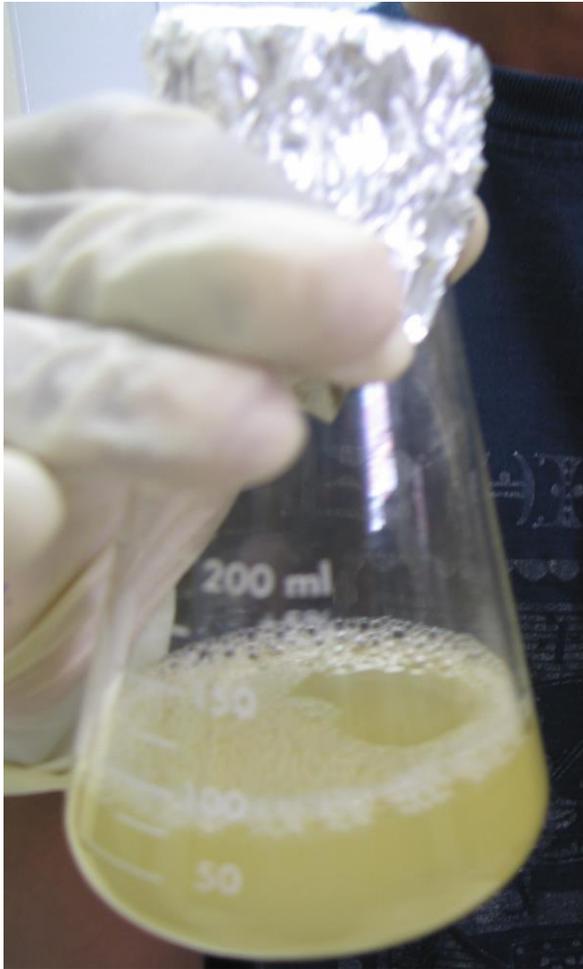
virus DNA tells the bacterium
to make more viruses



bacterium gets so filled with viruses
it breaks open and dies!

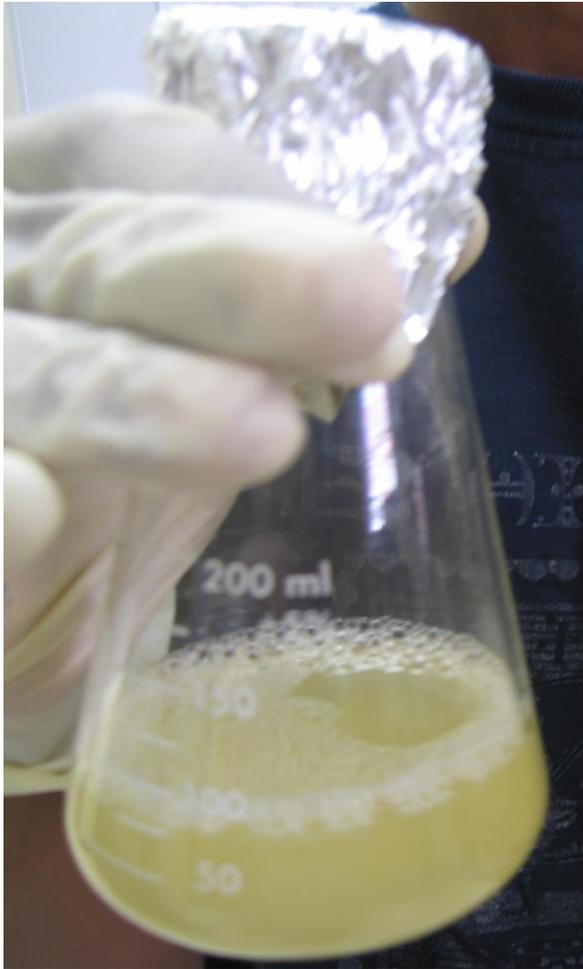


Cloudy with Bacteria

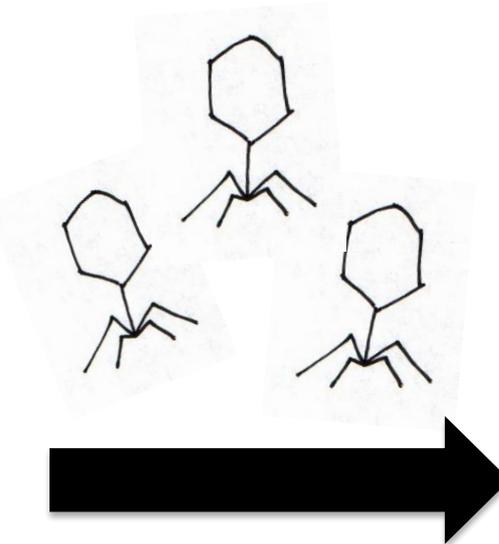


add some virus

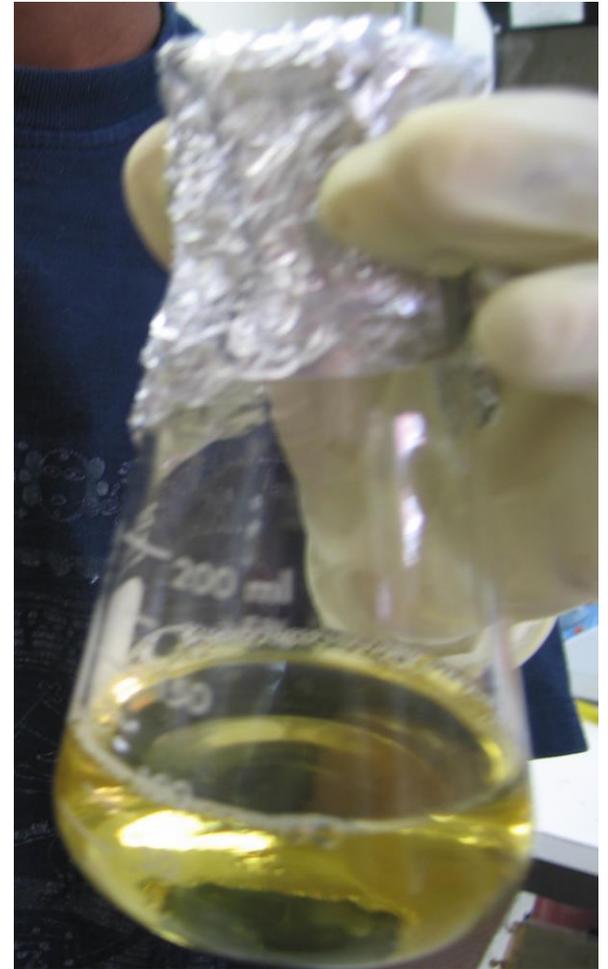
Cloudy with Bacteria



Cloudy with Bacteria



add some virus



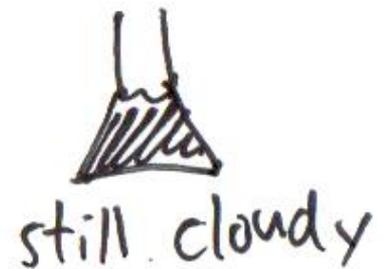
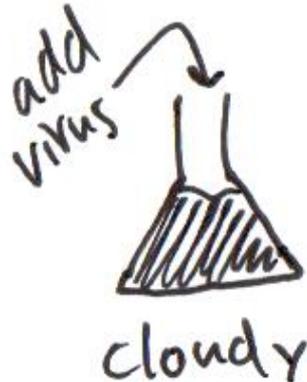
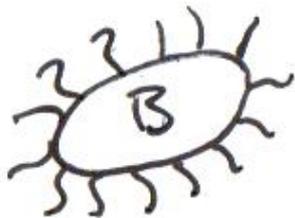
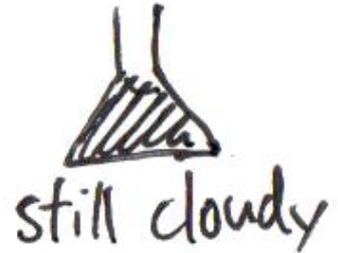
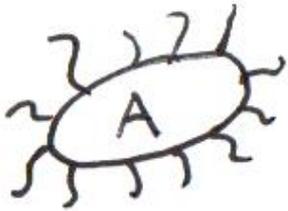
Clear, because Bacteria have all been killed

Process

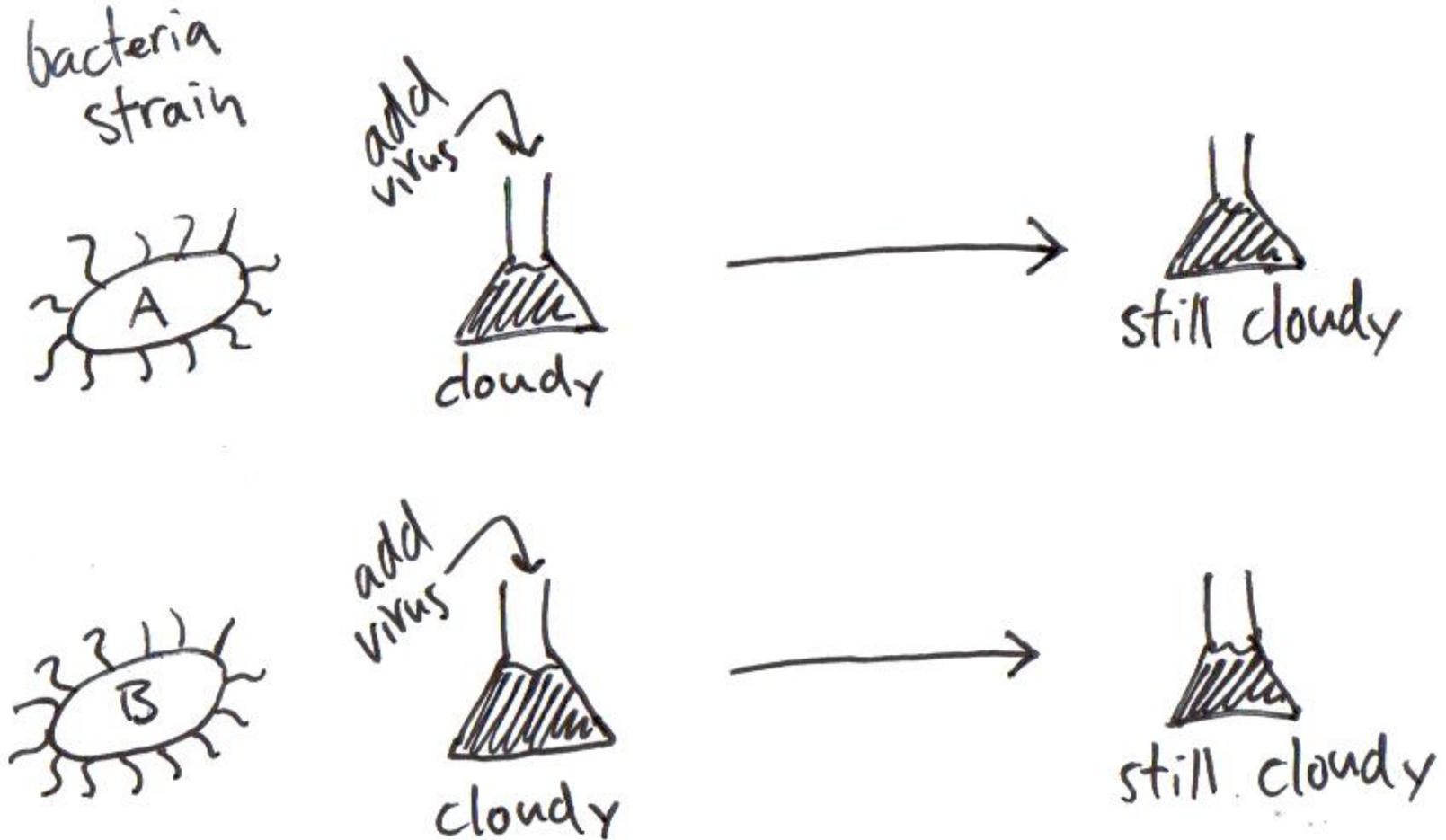
Now we figure out something new

One day, I try to infect some different types of bacteria with the virus:

bacteria strain



One day, I try to infect some different types of bacteria with the virus:

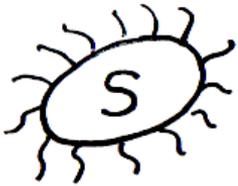


These two types of bacteria appear to be resistant to the virus.

Has something happened to the viruses? Are they still active and effective?

Use a type of bacteria that I know from previous experiment is sensitive to the virus, and try to infect it with the virus.

bacteria
strain



standard
sensitive



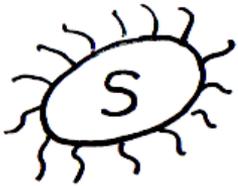
add
virus

cloudy



Use a type of bacteria that I know from previous experiment is sensitive to the virus, and try to infect it with the virus.

bacteria strain



standard
sensitive



add
virus

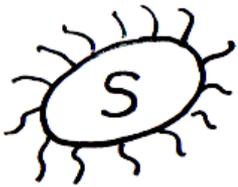
cloudy



still cloudy

Use a type of bacteria that I know from previous experiment is sensitive to the virus, and try to infect it with the virus.

bacteria strain



standard
sensitive



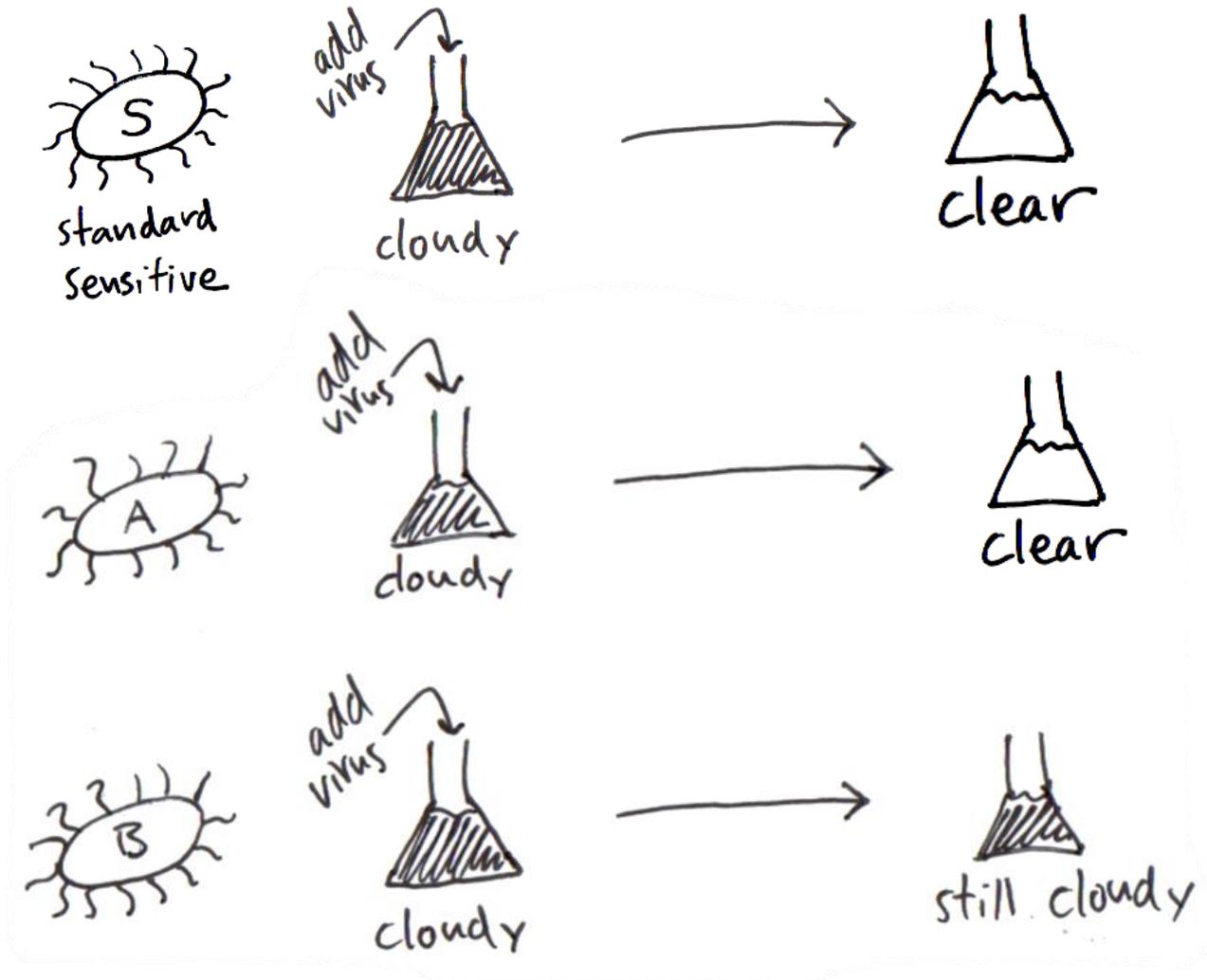
cloudy



still cloudy

The virus is no longer active!

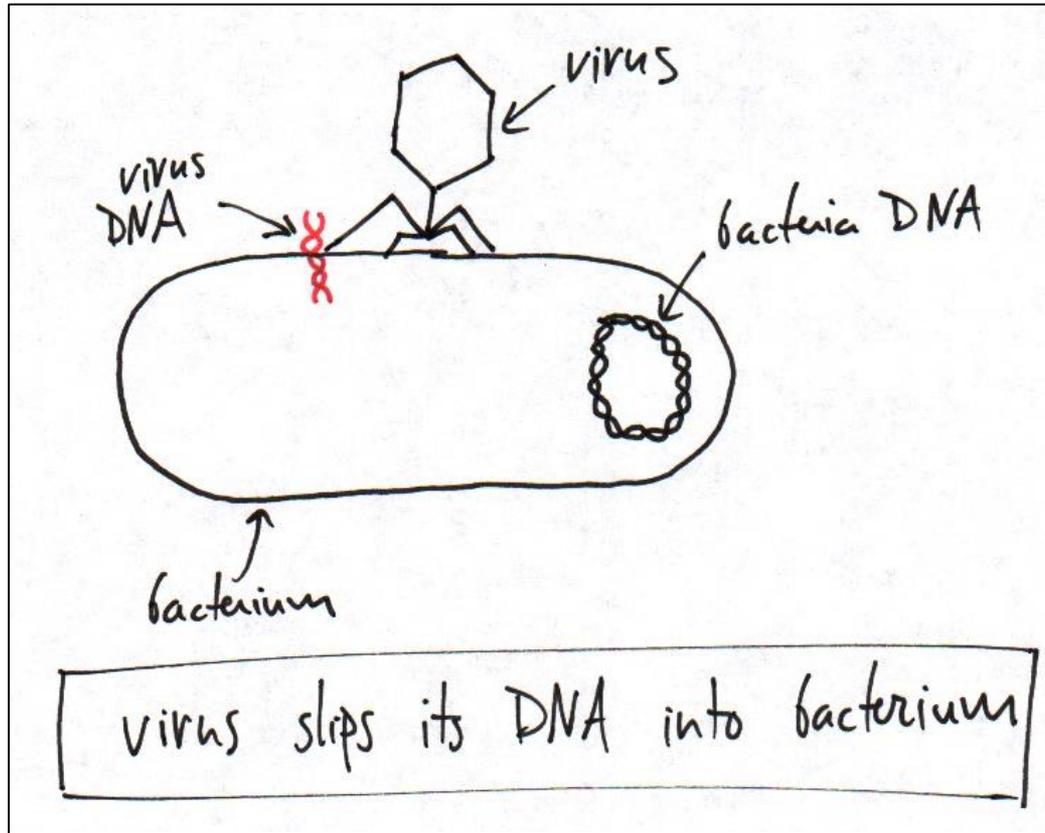
Repeat experiment with new, fresh virus:



Bacteria A is not resistant, but Bacteria B is resistant.

**Let's figure out why Bacteria B
is resistant to the virus.**

First step of infection:



I want to ask: Is the virus DNA getting into the bacteria?

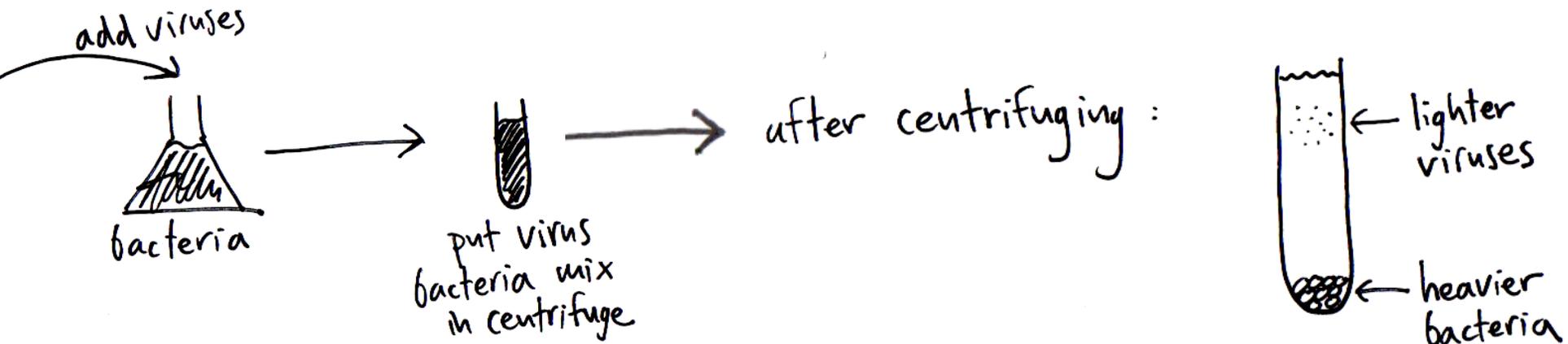
Is the virus DNA getting into the bacteria?

I will mix together the bacteria and virus, then wait for a while, and separate them, and ask, “Where is the virus DNA?”

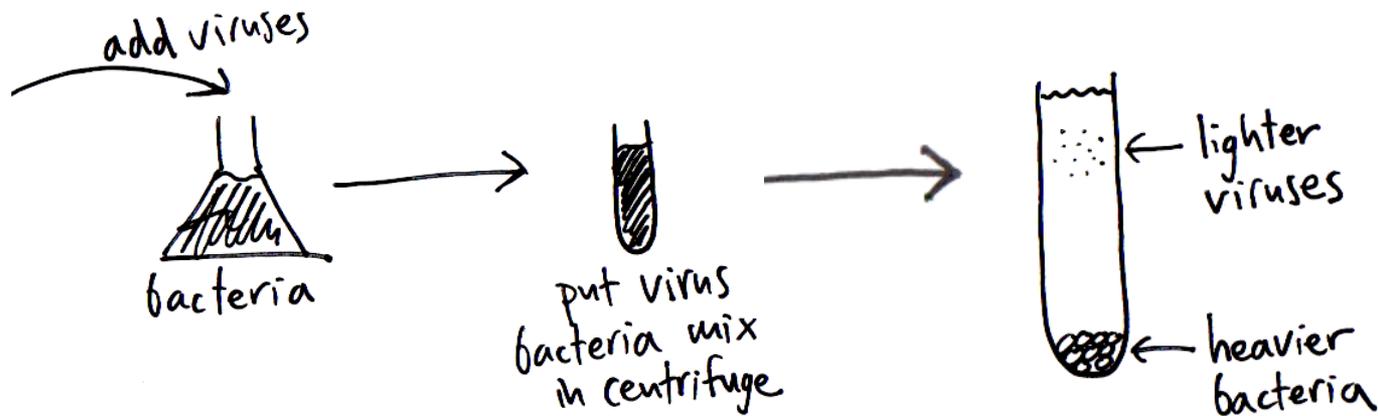
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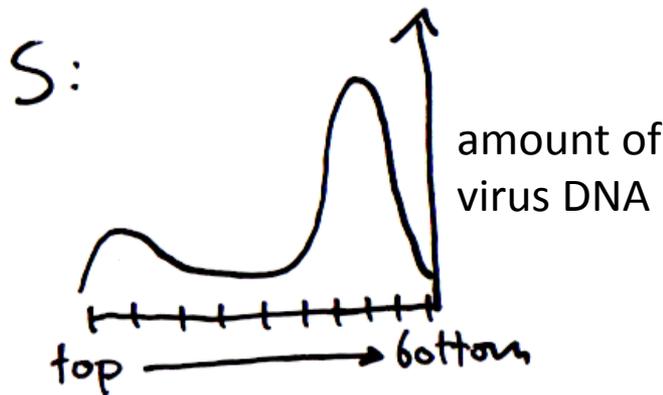
centrifuge



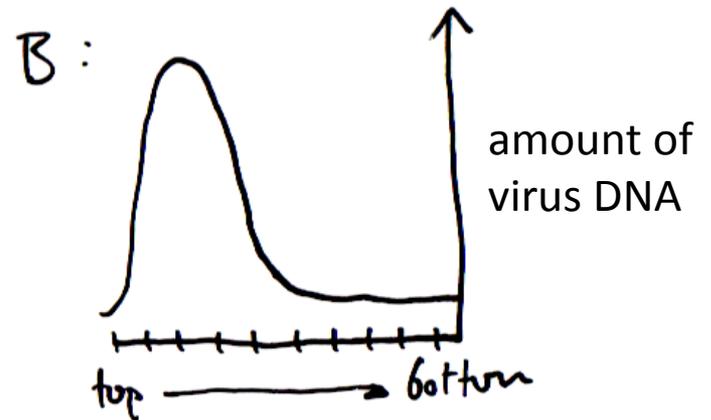
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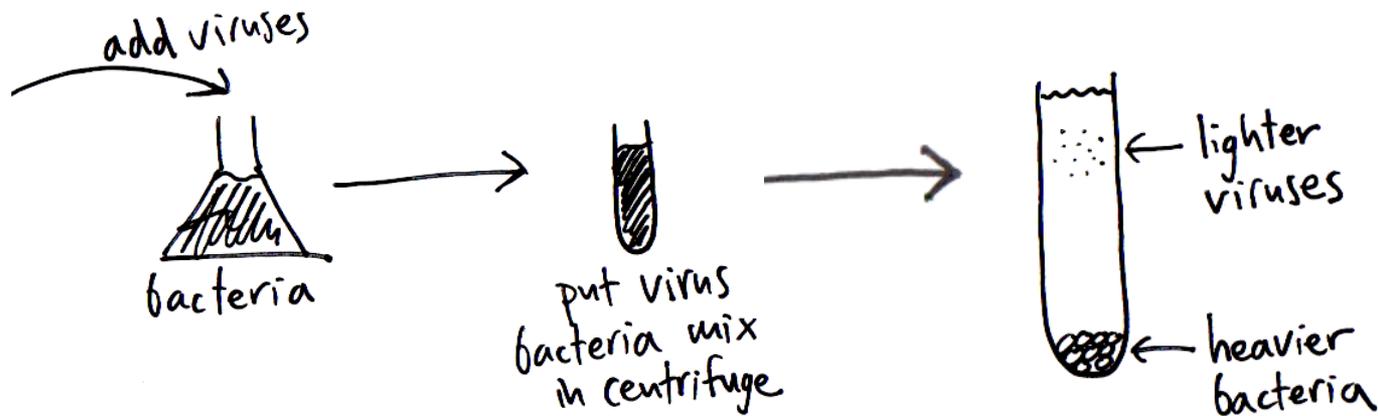
not resistant bacteria



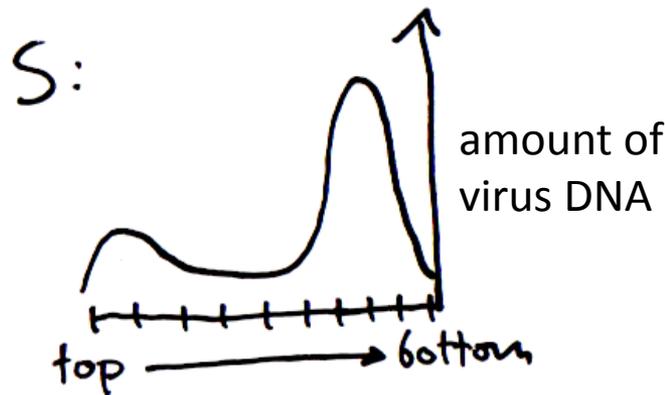
resistant bacteria



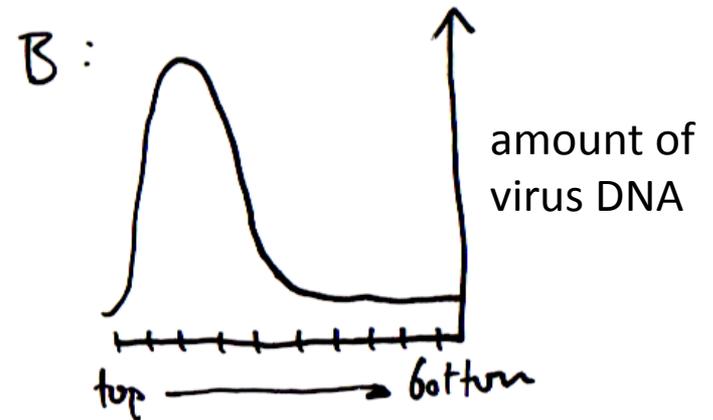
I will mix together the bacteria and virus, then wait for a while, and separate them, and ask, "Where is the virus DNA?"



not resistant bacteria



resistant bacteria



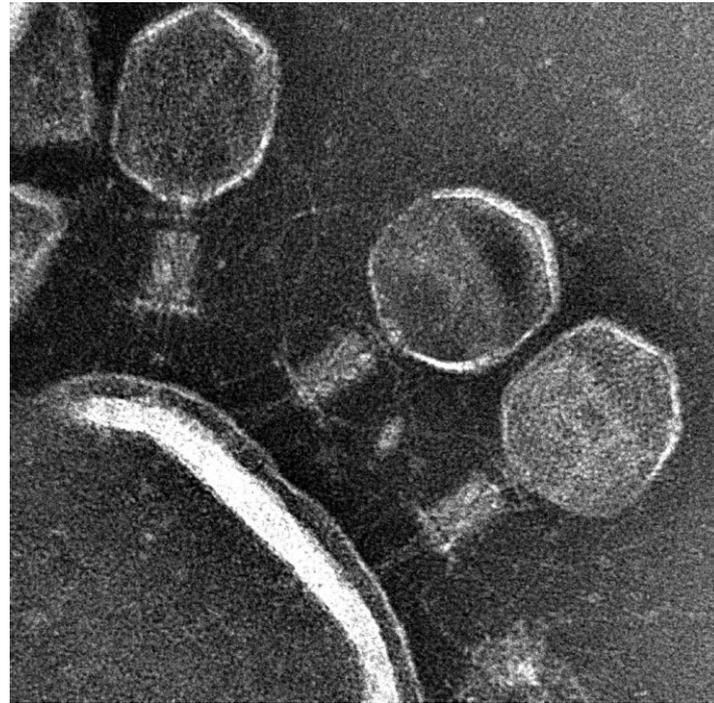
Virus DNA is getting into Bacteria S.

Virus DNA is not getting into Bacteria B.

Let's examine the bacteria and viruses with a microscope, to see what they look like.



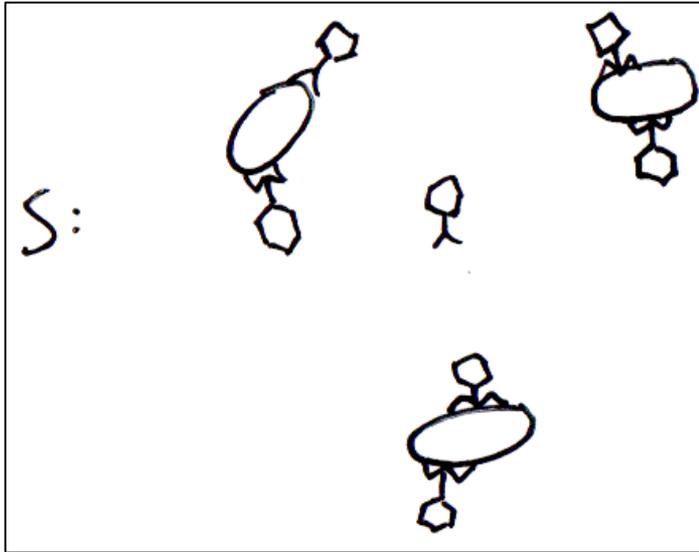
electron microscope



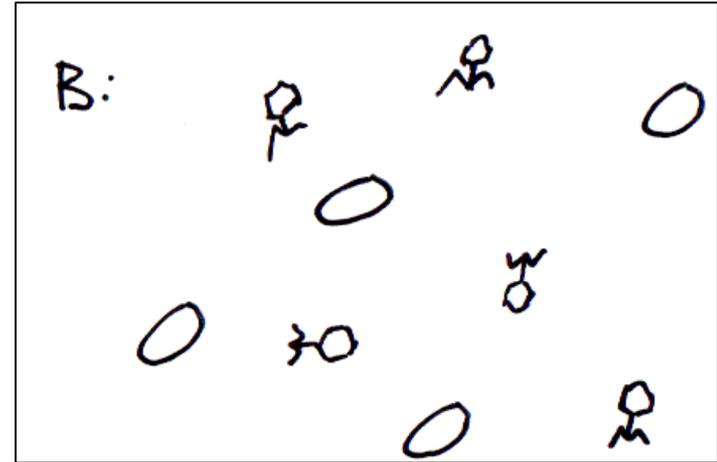
electron microscope image of viruses

Let's examine the bacteria and viruses with a microscope, to see what they look like.

not resistant bacteria

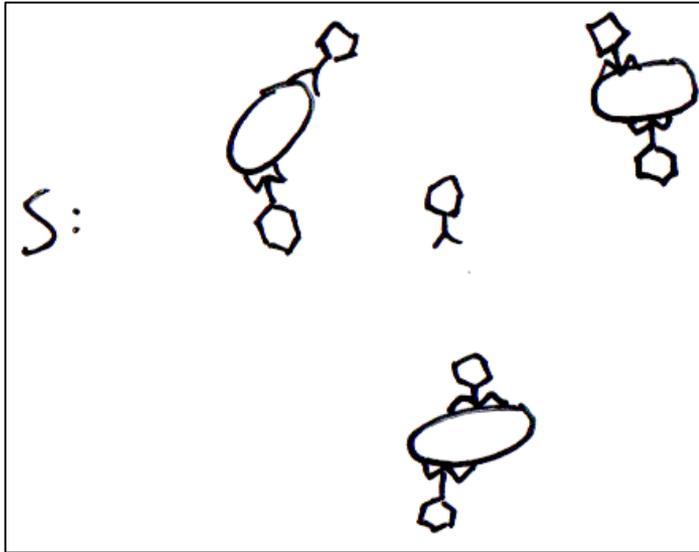


resistant bacteria

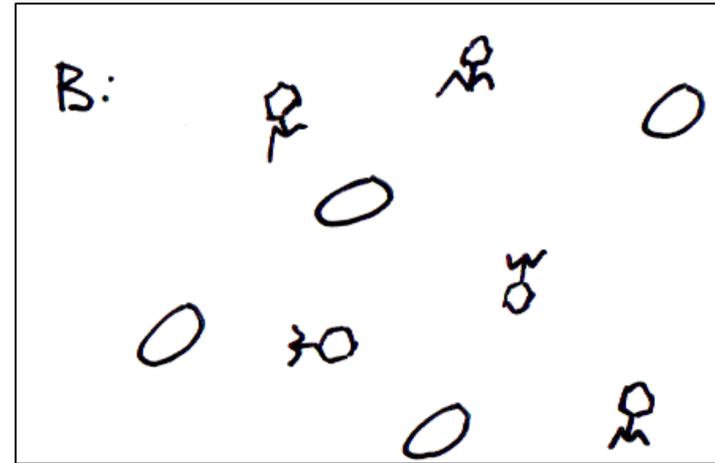


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not resistant bacteria

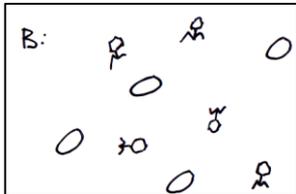
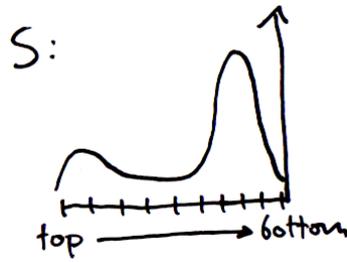
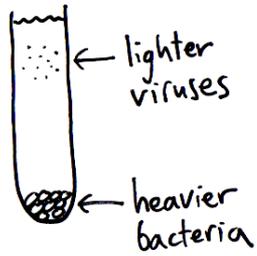
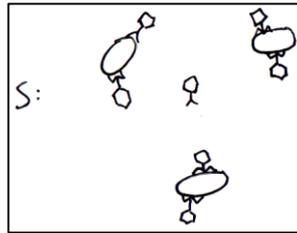
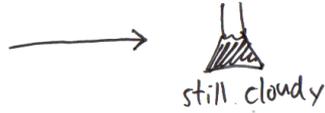


resistant bacteria

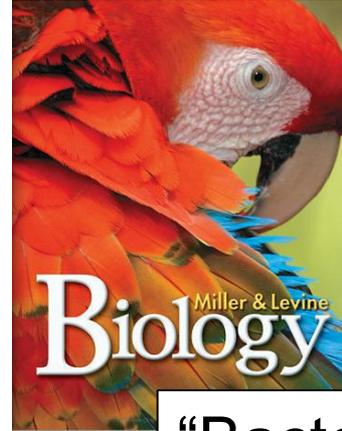


Viruses cannot stick to Bacteria B, which is why they cannot add their DNA to the bacteria, and why the bacteria are resistant to the virus.

Process



Products



“Bacteria can become resistant to a virus if their outer surface changes so that viruses cannot stick.”

April 6-12

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**JUST
KIDED**



The Real Housewives of New Jersey | BRAVO **Best Frenemies Forever**

A reluctant Teresa and Jacqueline have a meeting, but things quickly sour. Meanwhile, Caroline's husband makes a stunning demand; Melissa and Joe receive an interesting offer; and Kathy adds spark to her sister's love life.



True Blood | HBOe **Dead Meat**

Jason gets to know Violet in vampire camp; Sarah is desperate to keep Tru Blood flowing; Sookie mulls brokering a deal between Warlow and Bill; Sam's and Nicole's futures depend on Alcide's decision.



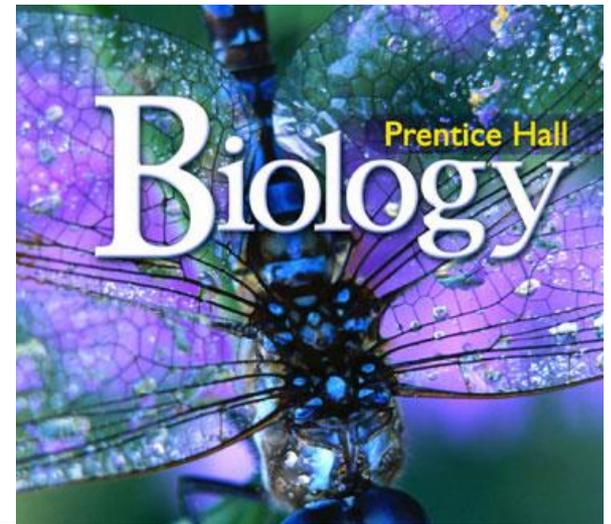
The Killing | AMC **From Up Here; The Road to Hamelin**

In the Season 3 finale, Sarah seeks peace in the case's aftermath, and the detectives pick up an unnerving new assignment. Then, Sarah risks her life when someone dear to her goes missing; and Holder's past is used against him.



The Real Housewives of New Jersey | BRAVO Best Frenemies Forever

A reluctant Teresa and Jacqueline have a meeting, but things quickly sour. Meanwhile, Caroline's husband makes a stunning demand; Melissa and Joe receive an interesting offer; and Kathy adds spark to her sister's love life.



BIOLOGY

Sixth Edition



CAMPBELL • REECE



True Blood | HBOe Dead Meat

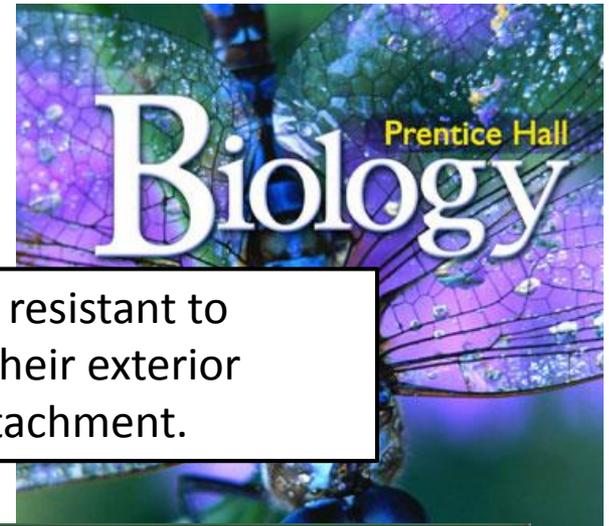
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The Real Housewives of New Jersey | BRAVO Best Frenemies Forever

A reluctant Teresa and Jacqueline have a meeting, but things quickly sour. Meanwhile, Caroline's husband makes a stunning demand; Melissa and Joe receive an interesting offer; and Kathy adds spark to her sister's love life.

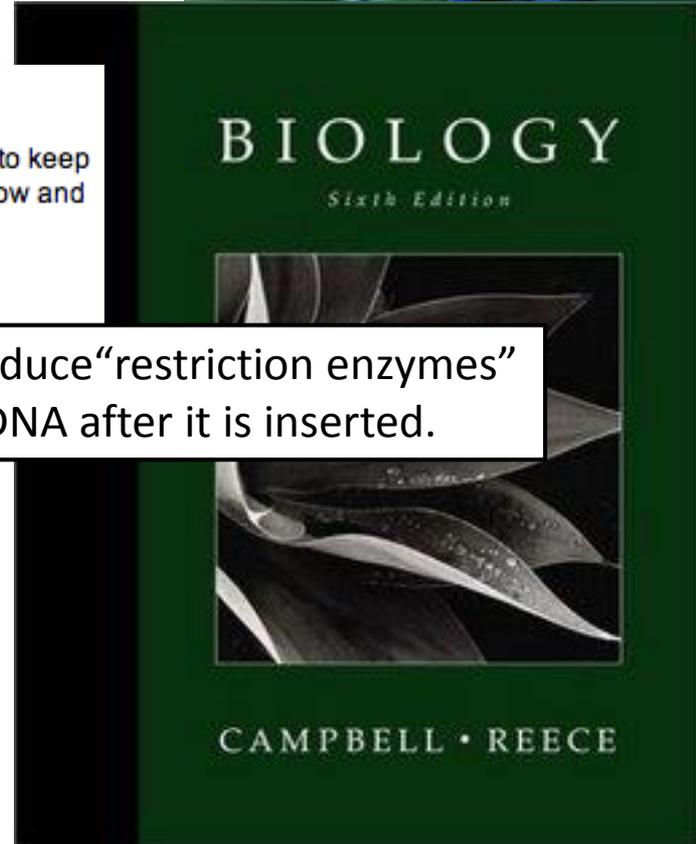


Some bacteria can become resistant to certain viruses by altering their exterior surfaces to prevent viral attachment.



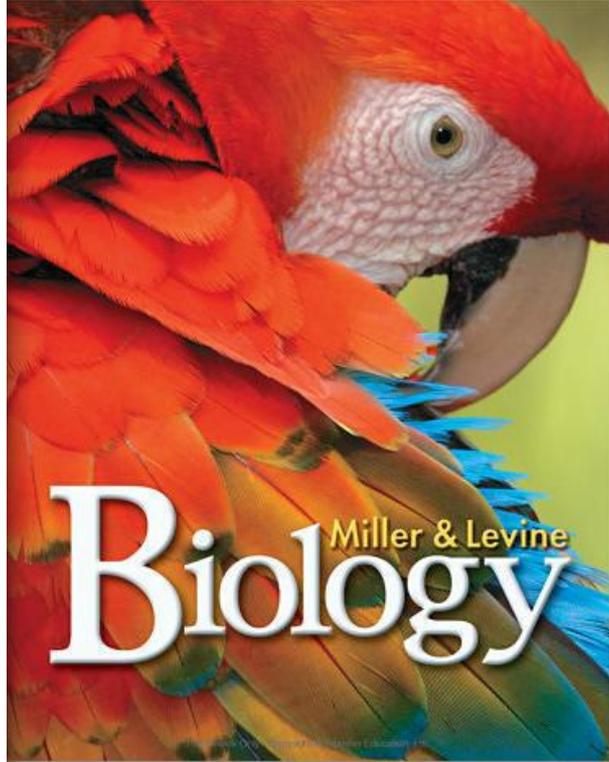
True Blood | HBOe Dead Meat

Jason gets to know Violet in vampire camp; Sarah is desperate to keep Tru Blood flowing; Sookie mulls brokering a deal between Warlow and Bill; Sam's and Nicole's futures depend on Alcide's decision.



Other bacteria produce "restriction enzymes" that destroy viral DNA after it is inserted.





Dear Student,

Biology is one of the subjects you're going to study this year, but I hope you'll realize from the very first pages of this book that biology is a lot more than just a "subject." Biology is what makes an eagle fly, a flower bloom, or a caterpillar turn into a butterfly. It's the study of ourselves—of how our bodies grow and change and respond to the outside world, and it's the study of our planet, a world transformed by the actions of living things. Of course, you might have known some of this already. But there's something more—you might call it a "secret" that makes biology unique.

That secret is that you've come along at just the right time. In all of human history, there has never been a moment like the present, a time when we stood so close to the threshold of answering the most fundamental questions about the nature of life. You belong to the first generation of students who can read the human genome almost as your parents might have read a book or a newspaper. You are the first students who will grow up in a world that has a chance to use that information for the benefit of humanity, and you are the very first to bear the burden of using that knowledge wisely.

If all of this seems like heavy stuff, it is. But there is another reason we wrote this book, and we hope that is not a secret at all. Science is fun! Biologists aren't a bunch of serious, grim-faced, middle-aged folks in lab coats who think of nothing but work. In fact, most of the people we know in science would tell you honestly, with broad grins on their faces, that they have the best jobs in the world. They would say there's nothing that compares to the excitement of doing scientific work, and that the beauty and variety of life make every day a new adventure.

We agree, and we hope that you'll keep something in mind as you begin the study of biology. You don't need a lab coat or a degree or a laboratory to be a scientist. What you do need is an inquiring mind, the patience to look at nature carefully, and the willingness to figure things out. We've filled this book with some of the latest and most important discoveries about living things, but we hope we've also filled it with something else: our wonder, our amazement, and our sheer delight in the variety of life itself. Come on in, and enjoy the journey!

Sincerely,

A handwritten signature in black ink that reads 'Ken Miller'. The signature is written in a cursive, slightly slanted style.



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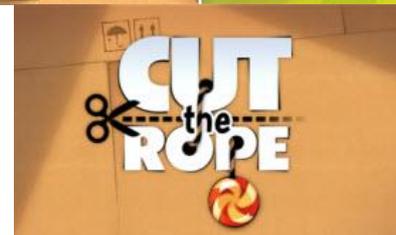
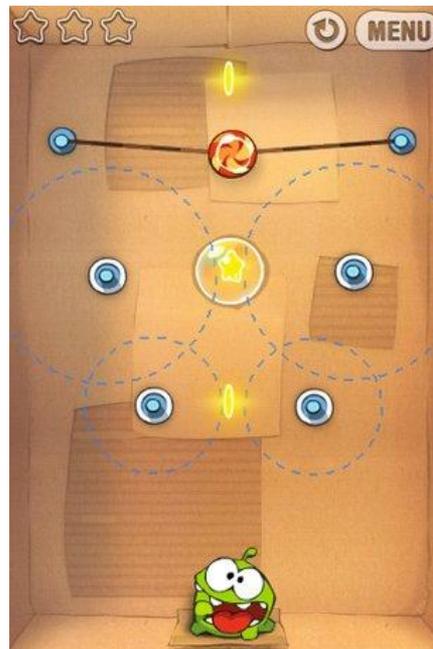
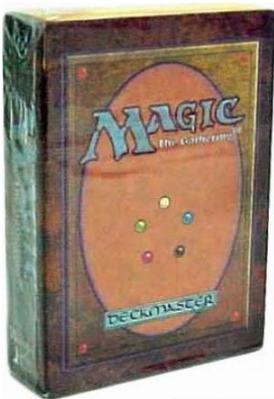
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Ken Miller

Students were engaged in “scientific” thinking and critical reasoning, just not in science class...



Automobile maintenance classes employ much more scientific thinking than most science classes.

The car won't start:

Is there enough gas in the car?

- How to test this?

Is there a charge in the battery?

-How to test this?

Is the starter motor running?

-How to test this?

Is the starter motor broken?

- How to test this?

Is the starter motor running properly, but electricity from the battery is not reaching the starter motor?

- How to test this?





Why should we focus more on teaching the process of science?

- Students will quickly forget most of the products they learn from textbooks or science courses.
- The critical thinking skills taught through scientific process are transferrable to a wide range of disciplines.
- Individuals generally enjoy critical thinking, puzzles, and problem solving more than memorization.
- Students who may want to be scientists should see what “real science thinking” looks like.
- Without knowledge of process, members of the public don't understand how scientific information is created, or how conclusions are reached.

How can we restructure instruction so that students can learn, enjoy, and engage with the process of science?

Textbooks and traditional instruction often ruin the fun and challenge of discovery by giving students the answers (the products) right away.