

Quantum Mechanics Lesson 2: Particle Properties of Light

The Photoelectric Effect

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Grade Level	11th – 12th Grade	**Duration**	3 days
Subject	Science		
Course	Physics		

Essential Question

Is light a wave or a particle?

Summary

Students investigate the particle properties of waves by discharging electroscopes and take notes using the Cornell Note System. The teacher performs a demonstration of discharging an electroscope with light. The students investigate the photoelectric effect using a simulation. Then using the Cornell Note System students explore Rogentgen's and Compton's experiments. Students use the 3-2-1 strategy to share what they have learned about the particle properties of light.

Snapshot

Engage

Students participate in two questions where they process different scenarios and discuss the difference between classical physics and quantum physics.

Explore

Students take notes using the Cornell Note System and focus on Max Planck's work, colors emitted by iron rods, and ultraviolet catastrophe.

Explain

The students observe a teacher demonstration for discharging an electroscope with UV light. They also participate in a PhET Photoelectric Effect simulation.

Extend

Students use the Cornell Note System to take notes about Roentgen's and Compton's experiment.

Evaluate

Students answer 3-2-1 prompts to show what they know about light having particle properties.

Standards

Next Generation Science Standards (Grade 3)

3-PS2-3: Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other.

Next Generation Science Standards (Grade 3)

HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
HS-PS4-3: Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

Oklahoma Academic Standards (Physical Science)

PS.PS3.3 : Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*

Attachments

- Electroscope Investigation - Spanish.docx
- Electroscope Investigation - Spanish.pdf
- Electroscope Investigation.docx
- Electroscope Investigation.pdf
- Lesson Slides-Particle Properties of Light.pptx
- PhET Simulation Photoelectric Effect Teacher's Guide.docx
- PhET Simulation Photoelectric Effect Teacher's Guide.pdf
- PhET Simulation_ The Photoelectric Effect Student Handout - Spanish.docx
- PhET Simulation_ The Photoelectric Effect Student Handout - Spanish.pdf
- PhET Simulation_ The Photoelectric Effect Student Handout.docx
- PhET Simulation_ The Photoelectric Effect Student Handout.pdf
- Teacher Demonstration_ Discharging an Electroscope with UV Light.docx
- Teacher Demonstration_ Discharging an Electroscope with UV Light.pdf

Materials

- Lesson Slides (attached)
- Electroscope Investigation handout (attached, optional)
- Teacher Demonstration Discharging an Electroscope with UV light handout (attached, optional)
- PhET Simulation Photoelectric Effect handout (attached, one per student)
- PhET Simulation Photoelectric Effect Teacher’s Guide handout (attached, optional)
- Class set of electroscopes with rods and clothes and static tubes (Optional)
- Teacher Demonstration:
  - Red laser
  - Green laser (optional)
  - UV light source 254 nm
  - Electroscope with zinc disk on top
  - Rubber rod
  - Wool cloth
- Access to computers or computer lab
- Science Notebooks
- Paper (optional, multiple pages per student)
- Optional Student Electroscopy Activity
  - Static tube
  - Electroscope

    - Ebony (or pvc) rod
    - Acrylic rod
    - Wool cloth
    - Silk cloth
- Balloon (one per group, optional)
- Cloth (one per group, optional)

15 minutes

Engage

Use the attached **Lesson slides** to present the lesson.

Display **slides 3-4** to introduce the essential question and learning objectives to the class.

Display **slide 5** and introduce the thought questions to the class. Inform them you will show them two different scenarios. They will take some time to think about the questions, discuss it with those sitting around them, and then discuss it as a whole class. Students can use their Science Notebooks or notebook paper to work out the questions or record their thoughts. Read over the thought questions on the slide. Provide students with time to think about the two questions and discuss it with their neighbors. Ask for volunteers to discuss their thoughts and answers.

Display **slide 6** and discuss with the class the difference between classical physics thinking and quantum physics thinking.

Display **slide 7** and present the second thought question to the class. Provide students with time to think about the question. Ask for volunteers to discuss their thoughts and answers. Display **slide 8** and provide students with a second question to consider.

Possible Student Responses:

Slide 5: The volumes that can be added with the ice cubes are 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 or ten volumes which can be found by dividing 100/10=10

Slide 6: Using the 0.01 ml drops: 100/0.01=10,000 different volumes.

Slide 7: Using 1 molecule at a time 100ml/(1g/ml)=100g; 100g/(18.02g/mol)=5.55 mol

5.5 mol x 6.022x10^23=3.34x10^24 molecules

Display **slide 9** and discuss with the class the difference between classical physics thinking and quantum physics thinking.

Teacher's Note

Students may use the same paper to record observations and answer questions through the Explore phase.

20 minutes

Explore

Display **slide 10** and introduce the class to the Cornell Notes System instructional strategy. Have students draw the image (an upside-down T) from the slide on a blank page in their Science Notebook. Let the students know that they will want to leave two-three blank pages after their first diagram for more Cornell Notes later in the lesson.

Display **slide 11** and have students fill in the right side of their Cornell Notes focusing on the big ideas from the information from the following slides. Introduce students to Max Planck's Quantum Theory.

Inform students that a description of Planck's work with blackbody radiation will be presented. Students should define a blackbody and give an example in their notes.

Display **slide 12** and discuss colors of light emitted by iron rod. Students should note that objects emit light of greater intensity as their temperature increases.

Embedded video
https://youtube.com/watch?v=1wMoR2y01Nw

Display **slide 13** and inform the students that as they watch the video pay attention to the colors of light emitted by iron rods in the video. Show the video, **Heating a Nail White Hot.**

Display **slides 14-15** and present the ultraviolet catastrophe. Students should note the meaning of the ultraviolet catastrophe and what caused it. Have students also note that energy is quantized and has a fundamental unit and may be calculated using the E=hf equation.

Embedded video
https://youtube.com/watch?v=tQSbms5MDvY

Display **slide 16** and show the video, **Planck's Constant and the Origin of Quantum Mechanics**. Start the video at the 3:04 mark and stop the video at 10:15 minutes.

Have students skip two-three pages in their Science Notebooks for further notes in the Extend section.

Display **slide 17** and have students look over their notes. Have students write down the key concepts they learned from the last few slides. Once they have recorded their key concepts, have them write 2-3 sentences summarizing what they have learned. Ask for a few volunteers to share their summaries.

55 minutes

Explain

Teacher's Note: Optional Electroscope Activity

Consider having the students complete the electroscope activity before your demonstration.

If you would like students to perform the electroscope charging part of the demonstration as a class activity unhide **slide 18**.

Follow the activity direction on the slide and here in the narrative.

Provide each pair of students with the following materials.

- Static tube
- Electroscope
- Ebony (or pvc) rod
- Lucite rod
- Wool cloth
- Silk cloth
- **Electroscope Investigation** handout

You can make static tubes by adding styrofoam filling into empty dry water bottles. You may have different types of rods and cloths. As long as they can produce both positive and negative charge, you may use any available. You can rub a balloon on cloth to create a negative charge.

Students will investigate electroscopes and how they work. They will charge an electroscope with negative charge. Then discharge the electroscope with their finger. Students will charge the electroscope with positive charge and discharge with their finger. Allow 15-20 minutes.

When students are finished, have them answer the post lab questions on a piece of paper or in their Science Notebooks.

Show the video, **Opposites Attract - Static Electricity**, of a homemade static tube. Have students complete the video questions.

Embedded video
https://youtube.com/watch?v=l5JjkoDyHlM

Display **slides 19-20** and on a clean page in their Science Notebooks (remind them to skip a few pages), have students record the definitions for conductors and insulators.

Display **slide 21** and, using the electroscope from the class demonstration, have students sketch a diagram of the electroscope and label the following parts.

- Conductor
- Insulator
- Top plate or ball
- Stationary stem
- Mobile rod
- Plastic/rubber stopper

In a separate window, navigate to the **Balloon and Static Electricity** PhET simulation. You will do this activity as a teacher demonstration. Start and complete the activity before moving to the next slide.

Teacher's Note: Balloon and Static Electricity Alternative Activity

If you are unable to complete the teacher demonstration, unhide slides **22** and **23** to discuss the simulation. Display **slide 22** and emphasize there are equal numbers of opposite charges. Display **slide 23** and emphasize that negative charges have been transferred to the balloon, creating a positively and negatively charged object.

Display **slide 24** and perform a teacher demonstration of charging and discharging an electroscope using the **Teacher Demonstration Discharging an Electroscope with UV Light** handout.

Teacher's Note: During Demonstration

You may consider demonstrating induction of the electroscope during the demonstration.

Display **slide 25** and show the **Electrostatic Induction** video.

Embedded video
https://youtube.com/watch?v=dwJ-MM7yu4E

This video is used to help students understand what they observed in the investigation.

Teacher's Note: Alternative to Demonstration

Embedded video
https://youtube.com/watch?v=oYnp0WZDhYQ

Unhide and use **slide 26** to show the **Knocking Electrons with Light** video, if you do not have the equipment for this demonstration. This can also be used as an example as well.

Teacher's Note: PhET Simulation Technology Requirements

Be sure that your computers will run the PhET simulation. You may need help from your IT department.

Day 2

Display **slide 27** and introduce the students to an investigation of the photoelectric effect using a Phet simulation. Pass out the **PhET Photoelectric Effect** handout to each student. Have students work in pairs and share laptops. Have students navigate to the link on the slide to access the simulation. Students will set up the simulation as instructed.

Teacher's Note: PhET Simulation Discussion

Use the teacher's guide discussion notes to explain the simulation to the class.

Show **slide 28** and use the following 11 slides to help guide the students through the simulation.

First, make sure students have properly adjusted settings.

Have students complete experiment steps 1-3 and show **slide 29.**

Emphasize that now photoelectrons are produced and there is no current.

Have students complete experiment steps 4 and 5 and then show **slides 30** and **31**.

Emphasize that photoelectrons are produced, there is a current and the increasing the intensity causes the current to increase.

Have students complete experiment step 6 and show **slide 32**.

Emphasize that a single photon can produce a photoelectron.

Have students complete experiment step 7 and show **slide 33**.

Emphasize that red photons cannot produce photoelectrons at any intensity.

Have students complete experiment step 8 and show **slide 34**.

Emphasize that higher frequency photons produce photoelectrons with higher kinetic energy.

Have students complete experiment step 9 and show **slide 35**.

Emphasize the maximum wavelength of the photons that produced photoelectrons.

Have students complete experiment step 10 and show **slide 36-39**.

Emphasize the maximum wavelengths of the photons that produced photoelectrons for each metal.

Once the simulation is complete, display **slide 40** and show the video **Photoelectric Effect**. Explain to the students that this is the experiment that goes with the simulation they just worked through.

Embedded video
https://youtube.com/watch?v=kcSYV8bJox8

15 minutes

Extend

Have students get their Science Notebooks back out and open to the extra pages by their Cornell notes. Show **slide 41** and remind students of the Cornell Note System. Have them draw a new diagram in their Science Notebook.

Display **slide 42** and present Einstein's experiment and ideas. Students should note that Einstein applied Planck's idea, the formula for photon energy and how the photoelectric effect demonstrates particle behavior, what a photon is and how classical wave theory was inconsistent with the observed effect.

Display **slide 43** and emphasize the points on the slide.

Day 3

Display **slide 44** and present Roentgen's experiment. Students should note the detail of the experiment and that it supported particle-like behavior.

Display **slide 45** and show the video **How Does an X-ray Tube Work**. Tell students this is similar to the device Roentgen used in his experiment.

Embedded video
https://youtube.com/watch?v=Bc0eOjWkxpU

Display **slide 46** and present Comptons' Experiment. Students should note the detail of the experiment and that it supports particle-like behavior.

Display **slide 47** and show the video of Compton Experiment Animation. Explain to the students that this will help them understand Comptons' Experiment.

Embedded video
https://youtube.com/watch?v=zTzJJ9lGP0U

Display **slide 48** and have students look over their notes. Have students write down the key concepts they learned from the last few slides. Once they have recorded their key concepts, have them write 2-3 sentences summarizing what they have learned. Ask for a few volunteers to share their summaries.

15 minutes

Evaluate

Display **slide 49** and introduce the students to the 3-2-1 instructional strategy. Inform the students that they will use this strategy to assess what they have learned throughout this lesson. Students will address the following concepts in their Science Notebooks or on a sheet of notebook paper.

3 -Statements showing what you learned about light having properties of particles.

2- Questions you have about light having properties of particles.

1- Thing you found most interesting about light having properties of particles.

Teacher's Note

You can use the 3-2-1 strategy as a way to assess what the students learned and what they might need to revisit.

Technology Alternative: 3-2-1

Consider using this strategy digital. Go to this link and follow the prompts to present in real time.

Resources

Bozeman Science. (2015, January 12). Electrostatic induction. YouTube. Video. https://www.youtube.com/watch?v=dwJ-MM7yu4E

Ionactive Consulting Limited. (2009, November 4). How does an X-ray tube work (radiation protection). YouTube. Video. https://www.youtube.com/watch?v=Bc0eOjWkxpU

Kids Fun Science. (2017d, October 6). Opposites attract static electricity experiment. YouTube. Video. https://www.youtube.com/watch?v=l5JjkoDyHlM

K20 Center. (n.d.). 3-2-1. Strategies. https://learn.k20center.ou.edu/strategy/117

K20 Center. (n.d.). Cornell notes system. Strategies. https://learn.k20center.ou.edu/strategy/56

PBS Space Time. (2016b, June 22). Planck's Constant and the origin of quantum mechanics. YouTube. Video. https://www.youtube.com/watch?v=tQSbms5MDvY

Rebiaz, Catatan Si. (2021c, December 6). Compton Experiment Animation | 12th class physics. YouTube. Video https://www.youtube.com/watch?v=zTzJJ9lGP0U

The Action Lab. (2021a, July 8). Knocking electrons with light-the photoelectric effect. YouTube. Video. https://www.youtube.com/watch?v=oYnp0WZDhYQ

University of California. Berkeley. College of Chemistry. (2012, August 15). Photoelectric effect. Video. YouTube. https://www.youtube.com/watch?v=kcSYV8bJox8

University of Colorado at Boulder. (n.d.). Balloons and static electricity. PhET. Interactive Simulations. https://phet.colorado.edu/en/simulations/balloons-and-static-electricity/about

University of Colorado at Boulder. (n.d.). Photoelectric effect. PhET. Interactive Simulations. https://phet.colorado.edu/en/simulation/legacy/photoelectric

Walding, Richard. (2019a, June 26). Heating a nail white hot (NCPQ). YouTube. Video. https://www.youtube.com/watch?v=1wMoR2y01Nw