STEM Lesson Plan:

Condensed Matter? Nanoscale Marvel! (High School)

Lesson Overview:
Student will be able to…
- Describe how scientific inferences are drawn from scientific observations and provide examples from the content being studied.
- Understand what the study of condensed matter is and how it relates to real life applications.
- Describe the structure and properties of allotropes of carbon, including graphene.
- Observe the Moiré pattern effect and understand how it can lead to materials with customizable properties.
- Create and observe single layer graphene.
- Synthesize citric acid derived carbon quantum dots in order to observe their fluorescent properties.
- Research applications of nanotechnology.

Next Generation Science Standards:
- HS-PS1-3. 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-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- HS-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

Florida Sunshine State Standards:
- SC.912.N.1.6 Describe how scientific inferences are drawn from scientific observations and provide examples from the content being studied.
- SC.912.P.8.6 Distinguish between bonding forces holding compounds together and other attractive forces, including hydrogen bonding and van der Waals forces.
- SC.912.P.8.12 Describe the properties of the carbon atom that make the diversity of carbon compounds possible.

Time: Two Class Periods

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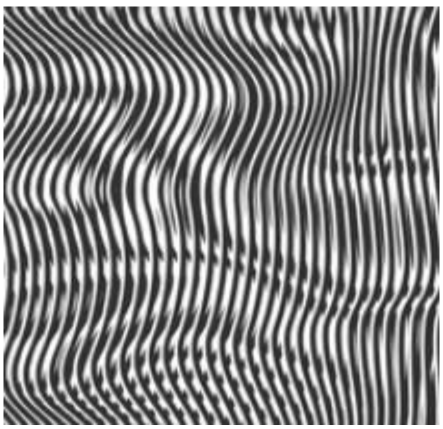
STEM Rationale for Lesson:

Condensed matter science? Most of the general public and even scientists outside of physics, have never heard of it! Quantum materials and nanotechnology? Most would struggle to describe it beyond mentioning nanobots or the "Quantum Realm" from Marvel's Ant Man. This is the heart of the issue: Condensed Matter has a PR problem!

It is one of the biggest sub-fields in physics; about one third of American physicists study or work in condensed matter physics, and it is an emerging sub-field in chemistry, with more emphasis on synthesis and reactivity of these materials.



One of the main goals of this lesson plan is to introduce this extremely interesting field to students and explore approachable concepts, which underpin a lot of current research and discoveries.

Moiré patterns are interference patterns that emerge when two periodic structures overlap with a slight misalignment or difference in pattern. In the context of materials like graphene, Moiré patterns can significantly influence their electronic properties. **Formation:** When two layers of a material, like graphene, are stacked with a slight twist angle between them, their individual atomic lattices interfere, creating a larger periodic pattern known as a Moiré pattern.

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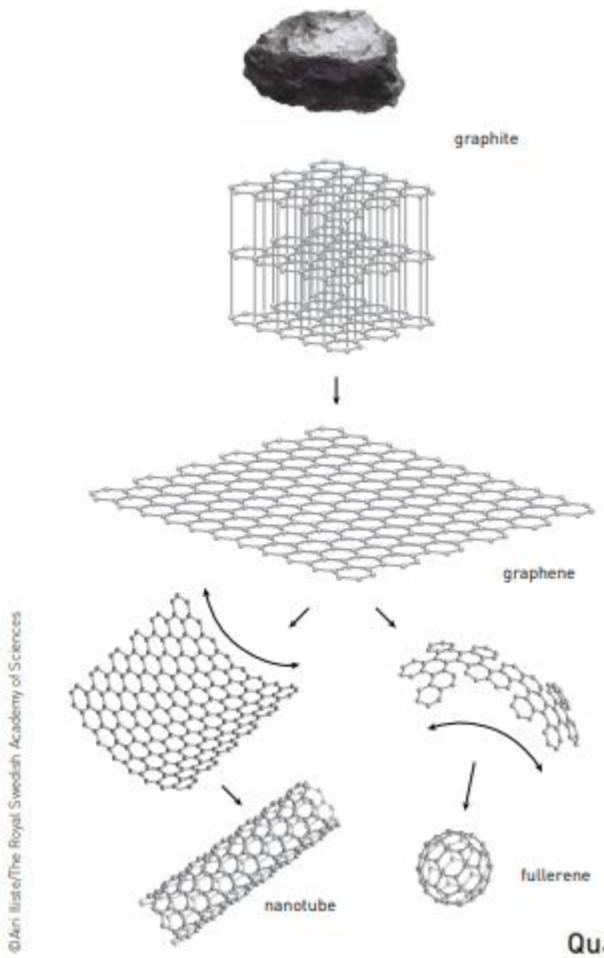

Emergence:
The resulting Moiré pattern can alter the electronic interactions between the layers, leading to unique phenomena that was not present in the individual layers. Emergent phenomena in condensed matter physics arise from the collective interactions of simple components within a material, leading to complex behaviors and properties. These phenomena cannot be understood by examining individual components alone; instead, they result from the system's overall behavior. This collective behavior often gives rise to new and unexpected physical properties. A notable example is the twisted bilayers graphene, where two graphene sheets are overlaid with a small twist angle. At a specific "magic angle" (~1.1 degrees), the Moiré pattern leads to flat electronic bands, which can result in superconductivity and other electronic states of high scientific interest.

Quantum Dots are 0D nanosized particles, (<10nm). Due to their super small size, they experience quantum effects, which modify the properties the element exhibits. Carbon quantum dots (CQD) exhibit strong luminescent properties and are very soluble in water, unlike elemental carbon, which is a black, insoluble in water and generally not fluorescent.

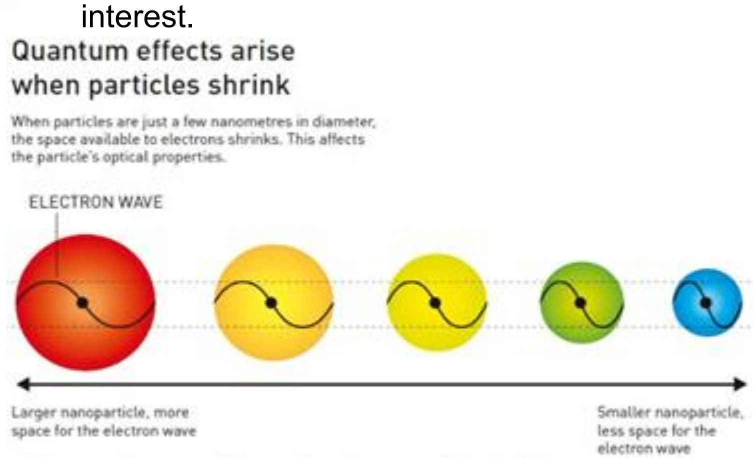

Figure 3. Quantum effects arise when particles shrink.

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"Moungi G. Bawendi*,* Louis E. Brus ***and*** **Aleksey Yekimov** ***are awarded the Nobel Prize in Chemistry 2023 for the discovery and development of quantum dots. These tiny particles have unique properties and now spread their light from television screens and LED lamps. They catalyse chemical reactions, and their clear light can illuminate tumor tissue for a surgeon."***

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Activate Prior Knowledge:

- States of matter- solid, liquid, gas, as well as the transitions between the states.
- Units of measurement and perception of scale and magnitude.
- Basic atomic theory- structure of atoms and subatomic particles.
- An awareness of different types of bonding: metallic, ionic, and covalent bonding.
- Ionic compounds vs. covalent compounds and their typical properties.
- Inter and intramolecular forces.
- Knowledge of the electromagnetic spectrum and how light is emitted (this can be part of the aims of this lesson if desired in your lesson planning)

Materials:

Intro Activity:

- Post-it notes, small whiteboards, or printer paper (whatever material you have available)

Activity #1: Moiré Patterns

- 2x Window screen mesh squares, A4 size (any mesh fabric will work)

Activity #2: Graphene Examination

- Pencil led, or graphite (woodless pencil/crayon or ingot)
- Scotch tape
- Optic microscope, x40 or more
- Microscope glass slides

Activity #3: Carbon Quantum Dots Synthesis

- Basic PPE- apron, safety glasses
- Smooth lemon juice (or any citrus juice, variations for further testing are optional)
- Dilute ammonia hydroxide (store bought Ammonia) or sodium bicarbonate solution
- Distilled water
- 10 mL graduated cylinder
- Funnel
- 1x 125ml Erlenmeyer Flask
- 1x 500ml glass beaker
- Tongs or heatproof gloves
- Plastic or glass pipettes
- Filter paper (coffee filters work well)
- Black light/UV light
- Hot plate or microwave

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Lesson Activity Steps:

Introduction-Condensed Matter? (2-3 x 50min class periods)

1. Instruct students to complete the preassessment questionnaire, answering all the questions to the best of their knowledge. At this stage, correct answers are not expected, and student participation/inquiry is the goal. This should not be graded for accuracy as this questionnaire will be for assessing understanding, before and after the lesson. Assure students that it is ok not to know the correct answer, but they should provide a response to ALL the questions, and feel free to:
   a. make educated guesses
   b. draw images/diagrams
   c. use previously acquired knowledge
   d. personal experiences, etc.

2. **Think-pair-share:** Ask students to 'think' and write down what they think about the following questions:
   a. "What do you consider condensed matter?"
   b. "What do you think is the study of condensed matter?"

   Students should then 'pair' with a partner or small group and 'share' ideas. Ask them to write their shared response on Post-it notes/individual whiteboard/blank paper and post them on a display board at the front of the class. Teacher should then go over all the ideas presented and guide discussion to uncover any gaps in knowledge, relevant experiences, and misconceptions the students may have. Allow students to lead the direction of the discussion and avoid correcting students at this point.

3. **Watch:** the video linked in https://physicsworld.com/a/whats-the-matter-with-condensed-matter-getting-past-solid-state-physics-relative-obscurity-in-the-public-eye/

4. **Active reading:** Source materials: #1 "What's the Matter with Condensed Matter?" and source material #2 "Commentary: Condensed matter's image problem"

5. **Group** students in small groups to complete the card sorting activity, found in the lesson assessment section below.

6. **Assess:** by instructing students to complete the accompanying worksheet **"Understanding Condensed Matter Physics."**

Teacher notes: Important takeaways for students throughout this section include:

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- Condensed matter science is everywhere, from smartphones in their pockets, to cutting-edge medical devices.
- The field is constantly evolving, in the areas of physics and chemistry, with new discoveries that might shape the future of technology.
- Public awareness and interest are essential for continued funding and advancements, making communication a crucial skill for future scientists.

Moiré Pattern Phenomena (~2x 50min class periods)

1. Mini anchoring phenomenon- Moiré clock: Watch the following video and have student write down observations, thoughts, and any questions that may arise: https://www.youtube.com/watch?v=TQRd3D4xX6M
    1. After the video, ask students to:
        1. Share their thoughts on the observed phenomenon.
        2. Have they seen this phenomenon before and where?
        3. Suggest possible reasons why the patterns are moving/shifting.

2. Discuss how the moiré pattern phenomena occurs.

3. **Hands-on Activity #1:** Creating Moiré patterns. Look at the next section for instructions. Instruct students to write down their observations in their notebooks as they complete the activity. Afterwards, write a description of what is occurring using the content they just learned though the lecture.

4. **Watch:** the following video displaying different types of patterns: https://www.youtube.com/watch?v=QAja2jp1VjE . Remind students to make comparisons between the video and what they observed in their patterns, as well as foster any student lead discussion that arises.

5. **Note Taking:** Instruct students to explore, read and make notes on the MagLab's article on "Twisted Physics". This will be the student's introduction to the nanomaterials and graphene.
    1. Optional: watch the video linked in the article "That's a Moiré!" https://www.youtube.com/watch?v=fPaEik0CBSQ&feature=youtu.be , which explains the Moiré effect in song format.
6. **Research:** Ask students to research real life examples of where Moiré patterns occur in our everyday environment. Students can produce a mini poster on their findings, which they can present, if formal assessment is required.

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Graphene Discovery (~1-2 x 50min class periods)

1. **Teach**- the importance of the discovery of graphene and how this applies to condensed matter, Moiré patterns and nanoscale research. Use the article about graphene in issue 14 and issue 13 of Nanooze, an online science magazine by NNCI. Alternative reading source can be found on the Nobel Prize website https://www.nobelprize.org/uploads/2018/06/popular-physicsprize2010.pdf .

Hands-on Activity #2: Creating graphene.

2. This is a modified procedure to the Sticky Tape method, that can be found in this video: www.youtube.com/watch?v=rphiCdR68TE

3. Group students in small groups of 2 or 3. Each group will get scotch tape and a piece of graphite. The graphite can be in the form of a woodless pencil/crayon or an ingot. If that supply is not available, instruct students to darkly shade in a small square on a blank piece of paper with a normal pencil; that will be their source of graphite.

4. Cut a piece of scotch tape about 8cm long and place it onto the surface of the graphite source. Carefully peel off the tape and make observations of the layer stuck on the tape.

5. **Observe:** instruct students to observe the graphite layer on the tape under the microscope. Place the tape onto a glass slide for easier viewing. Alternatively, you can project the image of the sample onto the classroom board, if you have a microscope camera. You can expect to see dark clusters or streaks of graphite (*figure 1*, 1st tape strip).

6. Take a second piece of tape of similar length and place the sticky sides of both strips together. Carefully peel off the second strip, which should hold thinner layers of graphene. The first strip can then be taped into the student's lab book and labeled.

7. Continue to make thinner layers of graphene by sticking a new strip of tape on top of the previous strip and peeling it off. Observe each strip under the microscope to take note of any differences in the graphene layers. (Figure 1.) It should take about 4-5 strips of tape to observe transparent layers of graphene if original source was a woodless pencil/crayon or ingot. (Figure 2.)

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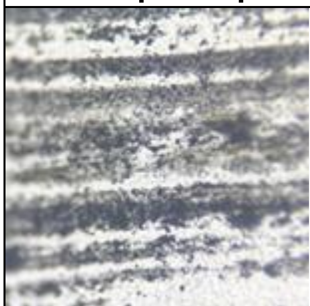
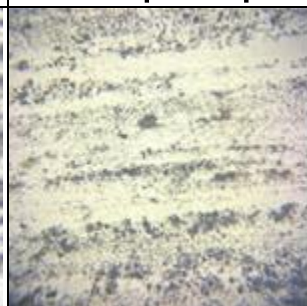
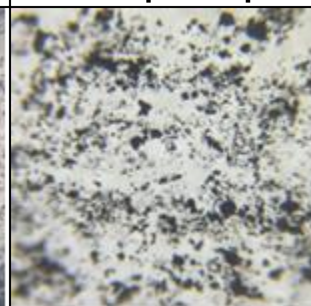
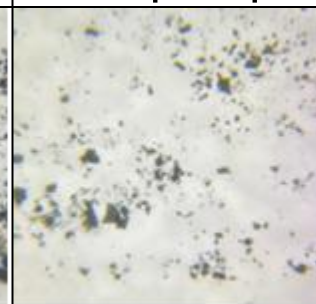
1st Tape Strip	2nd Tape Strip	3rd Tape Strip	4th Tape Strip
			
(x20)	**(x20)**	**(x40)**	**(x40)**
Figure 1. consecutive tape strips showing thinner layers of graphene. 2nd applied to 1st, 3rd applied to 2nd, 4th applied to 3rd.			

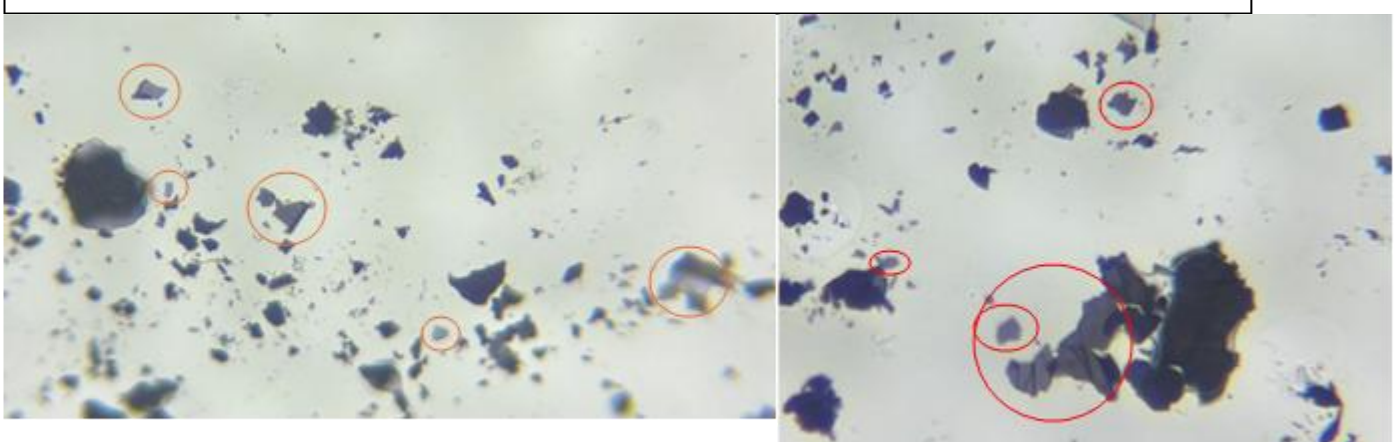


Figure 2. Fifth strip of tape under the microscope at x40 magnification. Transparent layers of graphene are circled in red, indicating the creation of thin graphene layers.

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Quantum Dot Synthesis Lab (~1-2x 50min class periods)

This is a modified procedure taken from the NNCI teacher resources.
Lab Procedure:

1. Using a graduated cylinder and funnel, measure 5ml of non-pulp lemon juice and pour into a 125ml Erlenmeyer flask.
2. *Hot plate:* heat the lemon juice on the hot plate until all the water has evaporated and a deep brown/black residue is left behind. (quantum dots synthesized)
3. Using tongs or heat-resistant gloves, remove the Erlenmeyer flask from the hot plate and let it cool for 1-2 mins.
4. *Microwave:* alternatively, the lemon juice can be heated until the dark residue forms and there is no visible liquid.
5. Measure 5ml of Ammonia (alternatively dilute sodium bicarb solution) and slowly pour into the beaker with the lemon juice residue and mix.
6. Measure 250-300ml of distilled water and pour into 400ml beaker.
7. Darken the room and turn on the UV/black light. Shine the UV light onto the Erlenmeyer flask containing the residue/ammonia mixture and observe any fluorescence. Shine the light on the beaker containing the water.
8. Using a pipet, pipet some of the residue/ammonia mixture.
9. Slowly and dropwise, add the mixture into the beaker containing the water, and observe the fluorescence of the drops as they disperse through the water.

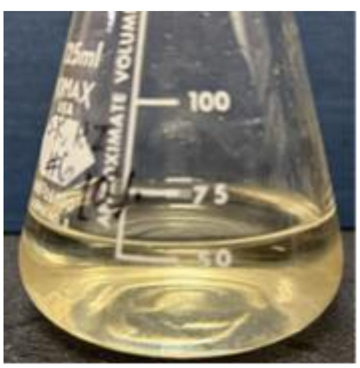

Image 1: left over residue dissolved in water, under ambient

Image 2: left over residue dissolved in water, under UV light. Fluoresces with as light green

You can instruct students to test different types of citrus juices, e.g., orange, grapefruit, lime, pineapple etc. If you have trouble with fluorescence, make sure that the water from the juice has fully evaporated and the residue is very dark. The darker the residue, the more carbon quantum dots are produced. Increased fluorescence is also observed when drops of the residue mixture is dissolved in an excess of water. The more dilute the quantum dots are in aqueous solution, the easier it is to observe fluorescence (image 1&2)

Analysis and Reflection questions:

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1. What are carbon quantum dots (CQD), and what makes them unique compared to bulk carbon materials?
2. What method did you use to synthesize the carbon quantum dots, and what were the key steps in the process?
3. Why do carbon quantum dots exhibit fluorescence, and how does this relate to their quantum confinement properties?
4. What factors could influence the fluorescence color of the CQDs you synthesized?
5. What are some potential real-world applications of carbon quantum dots, and how do their properties make them useful?
6. What challenges or sources of error did you encounter during the synthesis, and how could they be reduced in future experiments?
7. How do citric acid derived CQD’s compare to traditional semiconductor quantum dots in terms of composition, environmental impact, and cost?
8. Based on your observations and results, what further experiments would you design to explore CQD properties or improve their synthesis?

Individual Student Research Presentation:

This can be an individual or paired student presentation. Instruct students to research a current event/finding in scientific research about nanomaterials and create a slide show to present their findings. A great website they can use to find current events is: https://www.acs.org/pressroom/presspacs/2025.html, which has links to scientific news articles dating as far back as 2009. Another possible source of nanotechnology news are: https://www.acs.org/policy/nanotechnology.html and https://www.nature.com/nnano/ These websites can be a good starting point for students.
Rubic for presentation is in Assessment section below.
Examples of topics: Antibacterial nanoflowers, cooling sunscreen with TiO_2 nanoparticles

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Assessment

Pre/Post Assessment Questionnaire & Suggested Answer Key: Condensed Matter & Nanomaterials

1. **What is condensed matter science in chemistry and physics?**
   Answer: *Condensed matter refers to substances in solid and liquid states where atoms or molecules are closely packed together. The study of condensed matter in physics or chemistry involves understanding physical properties of solids and liquids (soft matter), including electrical, magnetic, and optical behaviors. It is the largest subfield of physics and plays a crucial role in technological advancements. It is an emerging sub-field in chemistry, focusing on the synthesis and chemical activities of nanotechnology with desired functions at a low cost.*
2. **What are the two main types of condensed matter?**
   Answer: *Solids and liquids.*
3. **What is graphene made of?**
   Answer: *Carbon atoms arranged in a flat single (mono) layer in a hexagonal lattice resembling a 2D honeycomb lattice.*
4. **How thick is a single layer of graphene?**
   Answer: *One atom thick (about 0.345 nanometers).*
5. **Why is graphene and its properties considered special compared to other forms of carbon?**
   Answer: *It is extremely strong, lightweight, flexible, and highly conductive (both electrically and thermally). They have high carrier mobility, high thermal conductivity, ultrahigh optical transparency, and high mechanical strength.*
6. **What is a moiré pattern, and how does it relate to moiré superlattices?**
   Answer: *A moiré pattern is an interference pattern that forms when two grids or repetitive structures overlap at a slight angle.*
7. **Where can you observe moiré patterns in everyday life?**
   Answer: *On digital screens, mesh fences, or when viewing two layers of fine fabric overlapping.*
8. **What are carbon quantum dots, and how are they different from regular carbon?**
   Answer: *Carbon quantum dots are tiny carbon-based nanoparticles (<10 nm) that can emit light (fluorescence) and have unique quantum properties.*
9. **What are the possible uses of carbon quantum dots in technology or medicine?**
   Answer: *They can be used for bioimaging, biosensors, drug delivery, as fluorescent markers in medical diagnostics and solar cell research.*
10. **Why do scientists and engineers study materials like graphene and carbon quantum dots?**
    Answer: *To develop advanced technologies in electronics, medicine, energy storage, and materials science. E.g. batteries, sensors, superconductors*

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Card Sorting Activity: Condensed Matter Physics

Instructions:

- Cut out the cards below.
- Work in small groups to sort them into the correct categories.
- Discuss your reasoning with your group members.
- After sorting, your teacher will lead a discussion on your choices.

Categories:

- Types of Materials, - Applications, -Challenges in Public Perception,
- Misconceptions vs. Reality, -Scientific Concepts (Match with descriptions)

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0D Quantum Dots	Lack of media representation	Biosensors	Magnetic Skyrmions	
Outdated terminology (e.g. Solid-State Physics)	Quantum Computing	Less public funding compared to astrophysics	"Condensed matter physics has no real-world impact."	
Energy Storage	Superconductors	3D Nanocomposites	"Condensed matter physics only studies solids."	"It also includes liquids, soft materials, and emerging phenomena."
2D Nanosheets	Medical Imaging	Smartphones	Complicated scientific language	
Graphene	Limited public awarness	1D Nanowires	"It's responsible for most modern technologies, from transistors to quantum computing."	

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Scientific Concepts (Match with descriptions)

- Spintronics
- Plasmonics
- Superconductivity
- Excitons
- Topological Insulators

"A field studying electron spin for data storage and computing."

"Materials that conduct electricity with zero resistance at low temperatures."

"Materials that conduct on the surface but insulate in the bulk."

"The study of electron oscillations in nanomaterials for advanced optics."

"Electron-hole pairs in semiconductors that influence optical properties."

Discussion Questions After Sorting:

- What was the most surprising thing you learned?
- Which materials or applications seemed the most interesting to you?
- How could scientists improve public awareness of condensed matter physics?

Teacher's Notes: Encourage students to discuss how condensed matter physics connects to everyday technology. Use examples to help clarify complex concepts.

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STEM Lesson Plan:

Key:

Types of Materials (Sort into this category)

- Graphene
- 1D Nanowires
- 2D Materials
- 0D Quantum Dots
- Superconductors
- Magnetic Skyrmions

Applications (Sort into this category)

- Smartphones
- Quantum Computing
- Medical Imaging
- Biosensor
- Energy Storage

Challenges in Public Perception (Sort into this category)

- Outdated terminology (e.g., "Solid-State Physics")
- Limited public awareness
- Lack of media representation
- Complicated scientific language
- Less public funding compared to astrophysics

Scientific Concepts (Match these with descriptions)

- Spintronics: "A field studying electron spin for data storage and computing."
- Plasmonics: "The study of electron oscillations in nanomaterials for advanced optics."
- Superconductivity: "Materials that conduct electricity with zero resistance at low temperatures."
- Excitons: "Electron-hole pairs in semiconductors that influence optical properties."
- Topological Insulators: "Materials that conduct on the surface but insulate in the bulk."

Misconceptions vs. Reality

- Misconception: "Condensed matter physics only studies solids."
- Reality: "It also includes liquids, soft materials, and emerging phenomena."
- Misconception: "Condensed matter physics has no real-world impact."
- Reality: "It's responsible for most modern technologies, from transistors to quantum computing."

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Worksheet: Understanding Condensed Matter Physics

<u>Multiple-Choice Questions:</u>

1. What is the primary focus of condensed matter physics?
    A) Studying celestial bodies like stars and planets
    B) Investigating the physical properties of solid matter
    C) Exploring chemical reactions
    D) Analyzing subatomic particles

2. Which of the following is a common application of condensed matter physics?
    A) Designing spacecraft
    B) Developing new electronic devices
    C) Studying ocean currents
    D) Predicting weather patterns

3. Why does condensed matter physics often remain less recognized by the general public compared to fields like astronomy?
    A) It lacks practical applications
    B) Its concepts are less visible and harder to visualize
    C) It is a relatively new field
    D) It doesn't involve advanced mathematics

4. Which material is commonly studied in condensed matter physics due to its unique properties?
    A) Graphene
    B) Helium gas
    C) Liquid nitrogen
    D) Carbon dioxide

5. What is one reason for the "image problem" of condensed matter physics mentioned in the article?
    A) Lack of funding for research
    B) Its contributions are often integrated into everyday technology without public awareness
    C) It is not taught in schools
    D) It has no real-world applications

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Free-Response Questions:

6. Explain in your own words what condensed matter physics studies and why it is important.

7. Describe one technological advancement that has resulted from research in condensed matter physics.

8. Discuss a challenge that scientists in condensed matter physics face when communicating their work to the public.

9. How does the study of materials like graphene contribute to advancements in technology?

10. Reflect on why it's important for the public to have an understanding of fields like condensed matter physics, even if they are not as visible as other sciences.

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Answer Key:

Multiple-Choice Questions:

1. B) Investigating the physical properties of solid and liquid matter
2. B) Developing new electronic devices
3. B) Its concepts are less visible and harder to visualize
4. A) Graphene
5. B) Its contributions are often integrated into everyday technology without public awareness

Free-Response Questions:

6. Condensed matter physics studies the physical properties of solid and, in some cases, liquid materials, focusing on understanding behaviors such as conductivity, magnetism, and superconductivity. It is important because it leads to the development of new materials and technologies that are integral to modern life.
7. One technological advancement from condensed matter physics research is the development of semiconductors, which are essential components in electronic devices like smartphones and computers.
8. A challenge in communicating condensed matter physics is that its concepts are often abstract and not easily visualized, making it difficult for the public to grasp their significance and impact.
9. Studying materials like graphene, which has exceptional strength and electrical conductivity, contributes to advancements in technology by enabling the creation of faster, smaller, and more efficient electronic devices.
10. It's important for the public to understand fields like condensed matter physics because they underpin many technologies we rely on daily. Awareness can lead to greater appreciation and support for scientific research, fostering innovation and informed decision-making. It can also foster an interest for young people wanting to become condensed scientists, bringing greater diversity to the field.

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Nanotechnology Research Presentation Rubric:

Category	Excellent (4 pts)	Good (3 pts)	Fair (2 pts)	Needs Improvement (1 pt)
Content Accuracy & Understanding	Topic is clearly explained with accurate and well-researched information. Demonstrates strong understanding of nanotechnology concepts.	Topic is mostly accurate with good research. Shows understanding but lacks depth in some areas.	Some inaccuracies or missing details. Basic understanding but lacks depth.	Many inaccuracies or misconceptions. Shows little understanding of the topic.
Relevance to Nanotechnology	Research is directly related to nanotechnology, and connections to real-world applications are clearly explained.	Research is mostly relevant, with some connections to real-world applications.	Research is relevant but lacks clear connections to nanotechnology.	Research is unrelated or does not connect to nanotechnology effectively.
Organization & Clarity	Information is logically organized and easy to follow. Slides are well-structured without excessive white space.	Mostly organized, but some parts are unclear or difficult to follow.	Some organization, but information is scattered or lacks a clear flow.	Lacks organization; difficult to follow. Presentation feels disjointed.
Visual Aids & Engagement	Slides are visually appealing, with relevant images, graphs, or diagrams. Engages the audience effectively.	Slides are clear with some visuals but may lack strong engagement.	Some visuals included, but they may not enhance understanding.	Poor visuals or excessive text. Little effort to engage the audience.
Presentation Delivery	Speaker is confident, clear, and maintains eye contact. Engages with the audience well.	Speaker is clear but may lack confidence or engagement at times.	Speaker is difficult to hear or understand. Minimal audience engagement.	Speaker is difficult to hear, monotone, or unprepared. Lacks engagement.
Sources & Citations	Uses multiple reliable sources and properly cites them. Shows strong research effort.	Uses reliable sources, but citations may be incomplete.	Few sources used or not all are credible. Citations may be missing.	Little to no sources cited. Research is weak or unreliable.

Sources:
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https://physicsworld.com/a/whats-the-matter-with-condensed-matter-getting-past-solid-state-physics-relative-obscurity-in-the-public-eye/

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