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QUANTUM (Q)-KIT

# Quantum Chemistry:

Laboratory for Secondary Level Students

*Student Manual*



WOMEN SUPPORTING  
WOMEN IN THE SCIENCES

# Meet a Scientist

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## About me:

I started teaching while having a Bachelor's degree in Secondary Education and then I completed a Bachelor of Science in Physics and Mathematics. It still wasn't enough for me,

so I decided to study for a Master's degree in Physics at the University of Dodoma. My Master's thesis project focused on first principles studies of electronic, optical, and elastic properties of corundum from different mining sites in Tanzania. I am interested in physics research, especially as it relates to quantum computing.

## My advice for students interested in science:

- Don't worry if you don't understand everything at first.
- Don't be afraid to question things.
- Keep learning, stay patient, and enjoy the journey.

# Mission Statement

The mission of this laboratory is to teach secondary level students (ages ~12-18) about atoms and matter with hands-on experiments and activities.

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# 1. Introduction to WS2 Laboratory Kits

## 1.1. Information about WS2

Women Supporting Women in the Sciences (WS2), an international organization unifying and supporting graduate and professional-level women and allies in science, technology, engineering, and mathematics (STEM), was awarded an American Physical Society (APS) Innovation Fund in 2020 to form international teams to design and distribute low-cost physics and materials science lab kits to primary and secondary school students, predominantly in eastern Africa. The lab kits utilized local resources and included topics that are especially relevant to young girls in order to spur their interest in STEM subjects. From 2020-2023, over 5100 students from eastern Africa at over 40 school sites engaged with our lab kits, with 62% being girls.

WS2 was awarded their second APS Innovation Fund in 2025 to support another Lab Kit Initiative, though this time with a focus on quantum topics. For more information about WS2, please visit our website at [ws2global.org](https://ws2global.org).

WS2 is sponsored by the APS Innovation Fund, APS Forum on Education, Northwestern University Materials Research Science and Engineering Center, and Northwestern University Multicultural Student Affairs. WS2 is extremely grateful to the lab kit design volunteers for their hard work and external consultants (SciBridge and Projekt Inspire) for their advising. WS2 also thanks and acknowledges PhysicsQuest (<https://www.aps.org/initiatives/physics-education/physicsquest>) and Quantum Explorations Student Toolbox (QuEST) for example experiments that were used as foundation for the lab kit content.

## 1.2. Key Vocabulary

- Atom: the smallest unit of an element that retains the element's properties
- Electron: charged subatomic particle that forms "cloud" around atom's nucleus
- Nucleus: dense center of atom consisting of neutrons and protons
- Nanoparticle: a material with a diameter between 2-100 nanometers (nanometer is  $1 \times 10^{-9}$  m)
- Quantum dot: a nanoparticle typically between 2-10 nm in size with unique properties that arise from being so small (like light emission)
- Fluorescence: light emitted by an excited state particle that lasts on the order of nano- to microseconds

## 1.3. Key Questions

- What are the key features of the Rutherford, Bohr, and quantum mechanical models of the atom?

- What is a carbon quantum dot and what does it mean to have fluorescence?

## 1.4. Purpose

The purpose of this lab kit manual is to enable students to understand atoms and nanosized matter through theory, demonstration, and experiments. The manual introduces the students to atomic models before discussing quantum dots and the unique ways in which light interacts with them.

# 2. Background on Main Topics

## 2.1. The Atom

The atom is the basic building block of matter, making up everything around us. Atoms essentially are the smallest unit of an element (think of elements on the periodic table, like carbon, nickel, aluminum, and hydrogen) that still retain the element's properties. Atoms are incredibly small and cannot be seen with our naked eyes, but they are extremely powerful in that they determine the properties of everything around us from

metal chairs to the air we breathe. Beginning in the 1800s, scientists attempted to describe the atom. In 1808, John Dalton proposed the atomic model theory which described atoms as solid spheres that are small and indivisible. J. J. Thomson built on this model and in 1904 proposed the “plum pudding” model which described an atom as electrically neutral. He said that the atom itself was a sphere of positive charge with negatively embedded electrons, like plums found inside pudding (similar to blueberries or other fruit pieces inside of a cake or muffin), and these opposing charges equal each other. Electrons, which are extremely light, play a key role in how chemical reactions occur and also are the carriers that flow in electricity.

The concept of the atomic nucleus came about in 1911, when Ernest Rutherford described atoms with a dense concentration of positive charge at the center of the atom, the so-called nucleus. Electrons then move about the nucleus and the atom consists of a lot of empty space (Figure 1). Rutherford came up with this description after performing what became famously known as the “gold foil experiment” (see Figure 2). Rutherford and his team aimed alpha particles at a thin gold sheet. Based on the Thomson model, it was hypothesized that these alpha particles would pass directly through the sheet. Mostly these particles passed through the sheet, but occasionally, some bounced back. This was a remarkable finding, and led to Rutherford’s famous quote, “It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.” This finding led Rutherford to conclude that atoms have a dense nucleus where most of their mass is concentrated. We now describe the nucleus as containing both protons, which are positively-charged particles that define the identity of an element, and neutrons, which are particles with no charge and have similar mass to protons. For comparison, protons and neutrons are about 2000 times heavier than electrons.

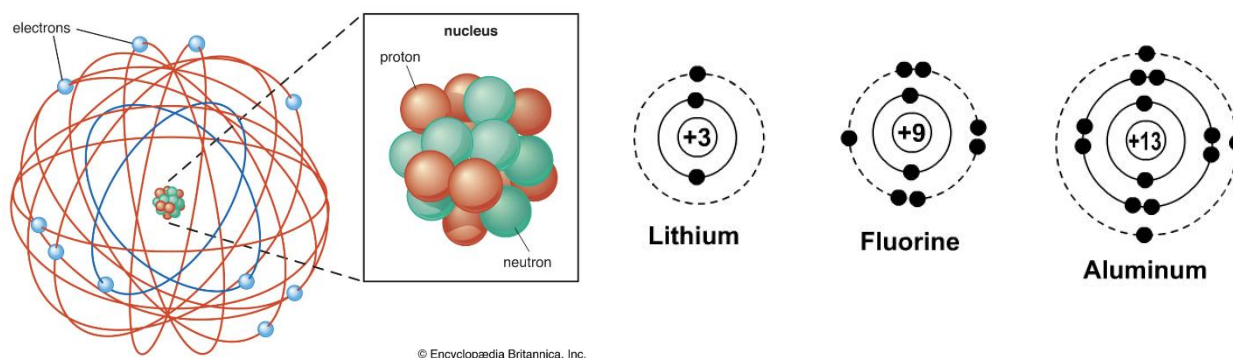


Figure 1. In the Rutherford model of the atom (left), the nucleus is a dense concentration of mass at the center of the atom and there is a lot of empty space. In Bohr model of the atom (right), the electrons orbit the nucleus with orbits that are well-defined sizes and energies. [This Photo](#) by Unknown Author is licensed under [CC BY-SA-NC](#).

Additional refinements to the atomic model concerned electrons. In 1913, Niels Bohr said that electrons orbit the nucleus, and the well-defined orbits have specific sizes and energies (see Figure 1), but this was later improved upon by Erwin Schrodinger in 1926 who said that electrons are really found in clouds, or orbitals, around the nucleus which contains protons and neutrons. The electron orbitals are areas that have a high probability of containing electrons. This model of the atom, known as the quantum mechanical model, is how we still describe atoms today.

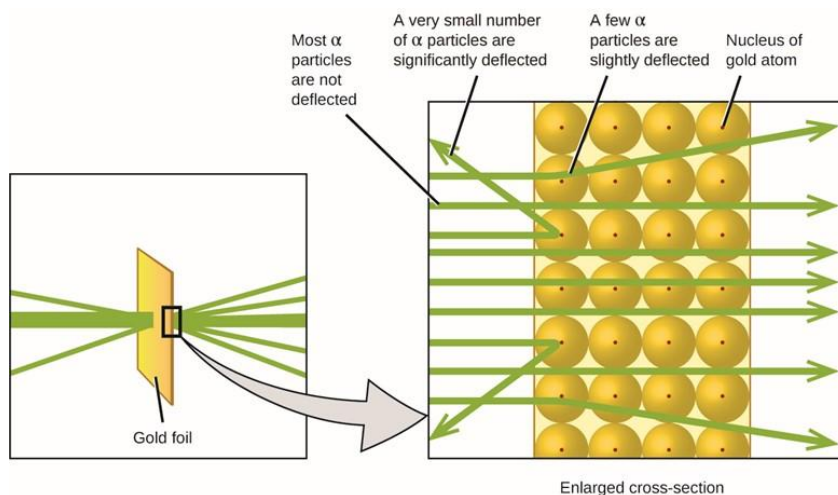


Figure 2. Gold foil experimental schematic. Most alpha particles passed through the gold foil, but a very small number are deflected when they hit the dense nucleus. [This Photo](#) by Unknown Author is licensed under [CC BY-SA-NC](#).

## 2.2. Quantum dots

Atoms can bond together to form much bigger entities. Consider water ( $H_2O$ ), which is a molecule that contains three atoms: two hydrogen and one oxygen. More than any other element, carbon has the capability of forming bonds to itself, which can lead to very large molecules that are predominantly carbon and hydrogen, like carbohydrates, proteins, and nucleic acids. Carbon can also bond with itself in an ordered way to make carbon crystals. Examples of carbon crystals are graphite and diamond which are both pure carbon materials. Interesting behaviors can emerge when carbon crystals become very small and are classified as nanoparticles, which are materials with diameters between 2-100 nanometers (nanometer is  $1 \times 10^{-9}$  m). Nanoparticles can be billions of times smaller than the diameter of a hair! Specifically, small nanocrystals of carbon that typically have sizes below 10 nanometers are called carbon quantum dots. Carbon quantum dots (Cdots) were discovered in the early 2000s as a reaction byproduct, and, interestingly, it was soon found Cdots can be produced from various carbon

sources (even plant leaves!). Cdots have fluorescence, which means that they emit light by absorbing light, and this emission lasts on the order of nano- to microseconds.

A unique aspect of quantum dots is that their fluorescent emission can be “tuned” simply by changing the size of the particle or its chemical composition. Larger particles emit at longer (redder) wavelengths, while smaller particles emit at shorter (bluer) wavelengths (see Figure 3). The system behaves analogously to the introductory quantum mechanics “particle-in-a-box” model. A crude picture of this is that because the particle size is roughly comparable to the size of the wavelength of light, the particle becomes the “box”, and the system becomes “quantized”, that is, has specific allowed energy levels (this is not exactly true for Cdots, which have broad energy “bands” rather than sharp allowed levels, but the basic ideas still follow). Providing energy to the particle can “excite” an electron from the ground state to an excited state, much as providing electricity to a neon light can excite the neon atoms in the tube. Once excited, the Cdots can glow. Nature in general dictates that systems prefer to be at their lowest energy level (think water running downhill), and one way neon atoms or Cdots can de-

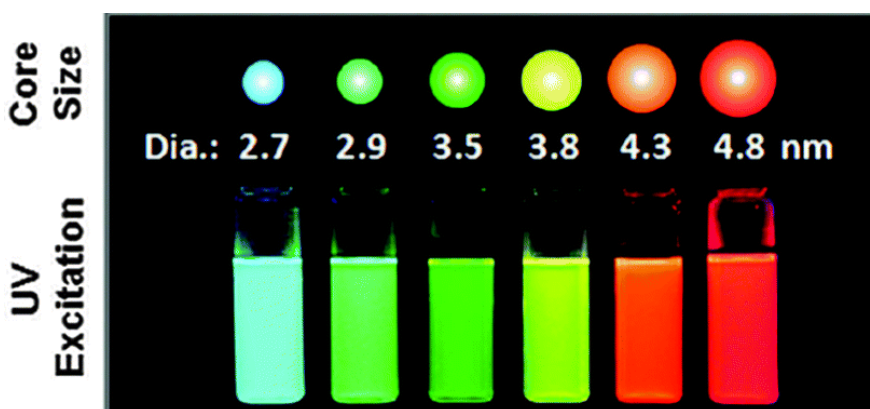


Figure 3. The size of quantum dots is related to the color they emit. Larger quantum dots emit at longer (redder) wavelengths. [This Photo](#) by Unknown Author is licensed under [CC BY-NC](#)

energize is to emit their excess energy as light. Neon tubes glow red because the energy of red light corresponds to the energy difference between the excited state energy level and the lower (ground) state level. Just as changing gases in “neon” lamps alters the emitted colors, incorporating other atoms in the Cdots can change the absorption and emission characteristics. It is worth noting that the energy of the light emitted will always be equal to or less than the energy of excitation – that is, the emission will be at longer wavelengths (blue, green or red) than the higher energy light (like ultraviolet) originally absorbed.

Interestingly, some excited molecules or nanoparticles may not emit visible light at all or emit light for a very long time after the excitation is turned off. In the former case, energy could be emitted as heat (i.e., infrared light which we cannot see). The latter

case will be familiar to children that have played with “glow-in-the-dark” toys. Neon lamps stop glowing almost immediately after we turn off the power (i.e., fluorescence), but glow-in-the-dark toys work by phosphorescence, where the energy gets trapped in the molecule, and only “leaks” out slowly, meaning the emission is a lot longer lived than in the fluorescence case.

## 2.3. Supplies List

- Sugar
- Water
- Source of heat (microwave oven, hot plate, stove top, flame)
- Pyrex conical flask
- Clear jar
- Test tubes (or small clear sample holders)
- Parafilm (or plastic wrap)
- Light sources (UV flashlight, green laser, red laser)
- Cotton swabs
- Paper
- Lemon juice
- Spherical-like candies of three colors (or compressed foil balls of three colors)
- Toothpicks
- Dark string (or pipe cleaners)
- Marker

## 2.4. Safety Information

Before the students begin the laboratory, please take into consideration the following safety concerns:

- Students should never look directly at a UV flashlight or laser point, as this can permanently damage their eyes due to the laser intensity and emission as a tight beam.
- Students should be careful handling hot glassware and should use potholders or protective gloves to move hot glassware.
- Students should not eat or taste items during experiments.

## 3. Experiments

### 3.1. Part I. Candy Atomic Models

#### 3.1.1. Pre-Activity Questions

1. What subatomic particles are found at the center of the atom (nucleus)?
2. What subatomic particles surround the nucleus?
3. What are the key features of the Rutherford model of the atom?

#### 3.1.2. Materials

- Spherical-like candies of three colors (or compressed foil/paper balls of three colors) (at least 8 of each per group)
- Toothpicks
- Dark string (or pipe cleaners)
- Paper
- Marker

#### 3.1.3. Procedure & Analysis (work in groups of 2-4)

1. Sort out candies of different colors (or create balls of paper/foil that are three different colors).
2. Select 8 candies each of two colors and use toothpicks to join them together in a densely packed nucleus. Set this nucleus on a piece of paper.

- a. What do these two types of candies represent? Label this on the paper.
  
3. Use two lengths of dark string (or pipe cleaners) and make concentric circles around the nucleus.
  - a. What do these circles represent? Label this on the paper.
  
4. Select 8 candies of the remaining color and place them on the concentric circles.
  - a. What do these candies represent? Label this on the paper.
  
5. Now, place 2 candies on the inner circle and 6 on the outer circle. This represents how electrons fill the outermost orbitals in this element (the first level contains 2 electrons and the second level contains 6 electrons, though it could contain up to 8 electrons total). See Figure 4 for an example of the candy atom model.



Figure 4. Example of the candy atom model with the densely packed nucleus and the electron orbits.

### 3.1.4. Post-Activity Questions

1. What element did you model in this activity? How do you know? (Hint: you may need to consult a periodic table – see Appendix)
  
  
  
  
  
  
  
  
  
  
2. Was this atom charged in this activity? How do you know?

- a. Extension question: How could you imagine making this atom charged?
- 
3. What are additional improvements that you could make to your model to more realistically represent an atom? Consider the other atomic models that followed Rutherford. Try these improvements out and record your observations.

## 3.2. Part II. Carbon Quantum Dots in the Kitchen

This section is based on the Secret Nanobits from the Kitchen activity from PhysicsQuest (American Physical Society).

### 3.2.1. Additional Background

Chemical reactions can convert everyday food items into carbon quantum dots (Cdots). Basically, heating carbon-based samples can cause them to break down and re-form as tiny carbon nanoparticles, in this case Cdots. These materials are fluorescent under certain light with high enough energy, like UV light and some lasers. Once Cdots are formed, they can be used in some simple applications, like “secret” writing.



- Cotton swabs
- Paper

### 3.2.4. Procedure (work in groups of 2-4)

The following steps can be completed as a class and then the resultant materials split up and used by smaller groups:

1. Measure 1 g (~1/4 tsp) of table sugar and place in Pyrex conical flask.
2. Add 10 g (10 mL or 2 tsp) water to the container. Stir until sugar is dissolved.
3. Place flask in/on the heat source for about 10 min.
  - a. The time may vary depending on the heat source. In a microwave at 40% power, 10 min is the approximate time.
  - b. The product should be dark orange in color and have a “sap” like consistency. The mixture will smell like burnt sugar.
4. Add about 50 g (50 mL or ¼ cup) water to the flask and swirl until the material is fully dissolved.
  - a. The solution should be dark orange (lighter than iced tea). If it is darker than iced tea, add a bit more water. See an example of what this solution will look like in Figure 5.
5. In a separate glass jar, add 1 g (~1/4 tsp) of table sugar and 10 g (10 mL or 2 tsp) of water. Stir until sugar is dissolved.
6. (if supplies allow) Repeat steps 1-4 using fresh lemon juice (10 g or 3 tsp) instead of sugar. Stop heating when the solution gets syrupy and dark (it may take less time than the sugar).



Figure 5. Example of sugar+water solution that has been heated.

The following steps can be completed by smaller groups:

7. Collect three samples in test tubes: sugar+water (heated), sugar+water (unheated), and lemon juice+water (heated).
8. Place parafilm or plastic wrap over the top of the solutions to keep them from being contaminated.
9. In the dark, shine the UV light on the three solutions, one at a time. Record your observations.
10. Repeat step 9 with your other light sources.
11. Saturate cotton swab with the different solutions.

12. On a piece of white paper, use the swab to write letters or draw a shape. You may have to re-wet the swabs. If the writing is wet enough to look dark on the paper, you probably have used enough solution.
13. Allow writing to dry.
14. In the dark, shine the UV light on the three marks. Record your observations.
15. Repeat step 14 with your other light sources.

### 3.2.5. Results

Solution	What did you observe in the room light?	What did you observe with the UV light?	What did you observe with the green laser pointer?	What did you observe with the red laser pointer?
<u>Sugar+water (heated)</u>  Test tube:  Marking on paper:				
<u>Sugar+water (unheated)</u>  Test tube:  Marking on paper:				

<u>Lemon juice+water (heated)</u>  Test tube:          Marking on paper:				
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### 3.2.6. Post-Experiment Questions

1. What did you observe in the room light with your solutions and markings?

2. With the light sources you used in the dark, what did you observe?



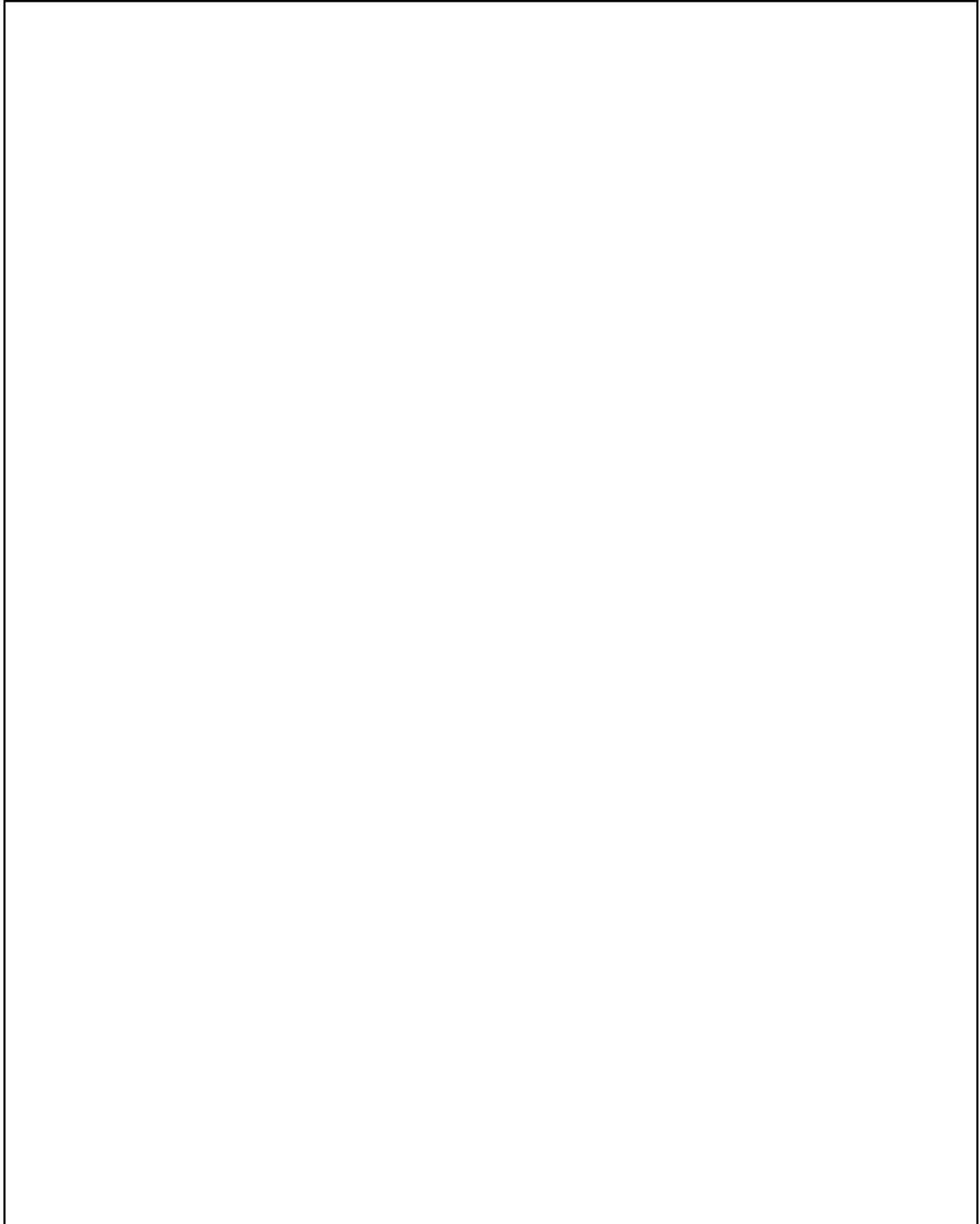


3. What role does the energy of the absorbed light play in fluorescence?

4. How could the properties of fluorescence be used in applications? Brainstorm many ideas and share and discuss with your classmates.

## 4.2 Design Sketch

Sketch the design of quantum dot fluorescence application below.



## 5. Sources

Atoms and atomic models:

<https://medium.com/@Intlink.edu/a-timeline-of-atomic-models-cb2607b1da85>

Quantum dots:

PhysicsQuest (2025): The Secret Glow of Nanobit from the Kitchen

United States Naval Academy Chemistry Department, Experiment #490: Synthesis and Properties of Quantum Dots. 2024.

[https://intranet.usna.edu/ChemDept/\\_files/documents/integrated-labs/SC364/2024\\_Documents/S24\\_SC364\\_EXP\\_490\\_Quantum\\_Dots\\_FV9.pdf](https://intranet.usna.edu/ChemDept/_files/documents/integrated-labs/SC364/2024_Documents/S24_SC364_EXP_490_Quantum_Dots_FV9.pdf)  
(accessed September 20, 2024).

# 6. Appendix

**PERIODIC TABLE**  
**Atomic Properties of the Elements**

NIST  
National Institute of Standards and Technology  
U.S. Department of Commerce

**Frequently used fundamental physical constants**

For the most accurate values of these and other constants, visit [physics.nist.gov/constants](http://physics.nist.gov/constants)

1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of <sup>133</sup>Cs

speed of light in vacuum  $c$  299 792 458 m s<sup>-1</sup> (exact)

Planck constant  $h$  6.626 07 x 10<sup>-34</sup> J s ( $h = h/2\pi$ )

elementary charge  $e$  1.602 177 x 10<sup>-19</sup> C

electron mass  $m_e$  9.109 38 x 10<sup>-31</sup> kg

$m_e c^2$  0.510 999 MeV

proton mass  $m_p$  1.672 622 x 10<sup>-27</sup> kg

fine-structure constant  $\alpha$  1/137.035 999

Rydberg constant  $R_\infty$  10 973 731.569 m<sup>-1</sup>

$R_\infty c$  3.289 841 960 x 10<sup>15</sup> Hz

$R_\infty hc$  13.605 69 eV

Boltzmann constant  $k$  1.380 6 x 10<sup>-23</sup> J K<sup>-1</sup>

**Physical Measurement Laboratory**  
[www.nist.gov/pml](http://www.nist.gov/pml)

**Standard Reference Data**  
[www.nist.gov/srd](http://www.nist.gov/srd)

■ Solids  
■ Liquids  
■ Gases  
■ Artificially Prepared

Group	PERIODIC TABLE																Physical Measurement Laboratory				Standard Reference Data				Group			
	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	13	14	15	16	17		18	18	
IA	IIA		IIIB	IVB	VB	VIB	VII B	VIII			IX		X	XI	XII	IIIA	IVA	VA	VIA	VIIA	VIIIA	IIIA	IVA	VA	VIA	VIIA	VIIIA	IIIA
1	<b>H</b> Hydrogen 1.008 1s																										<b>He</b> Helium 4.002602 1s	
2	<b>Li</b> Lithium 6.94 1s <sup>2</sup> 2s	<b>Be</b> Beryllium 9.0121831 1s <sup>2</sup> 2s <sup>2</sup>																									<b>Ne</b> Neon 20.1797 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup>	
3	<b>Na</b> Sodium 22.98976928 [Ne]3s	<b>Mg</b> Magnesium 24.305 7.6462 [Ne]3s <sup>2</sup>																									<b>Ar</b> Argon 39.948 [Ne]3s <sup>2</sup> 3p <sup>6</sup>	
4	<b>K</b> Potassium 39.0983 [Ar]4s	<b>Ca</b> Calcium 40.078 [Ar]4s <sup>2</sup>	<b>Sc</b> Scandium 44.955908 [Ar]3d <sup>1</sup> 4s <sup>2</sup>	<b>Ti</b> Titanium 47.867 [Ar]3d <sup>2</sup> 4s <sup>2</sup>	<b>V</b> Vanadium 50.9415 [Ar]3d <sup>3</sup> 4s <sup>2</sup>	<b>Cr</b> Chromium 51.9961 [Ar]3d <sup>5</sup> 4s <sup>1</sup>	<b>Mn</b> Manganese 54.938044 [Ar]3d <sup>5</sup> 4s <sup>2</sup>	<b>Fe</b> Iron 55.845 [Ar]3d <sup>6</sup> 4s <sup>2</sup>	<b>Co</b> Cobalt 58.933194 [Ar]3d <sup>7</sup> 4s <sup>2</sup>	<b>Ni</b> Nickel 58.6934 [Ar]3d <sup>8</sup> 4s <sup>2</sup>	<b>Cu</b> Copper 63.546 [Ar]3d <sup>10</sup> 4s <sup>1</sup>	<b>Zn</b> Zinc 65.38 [Ar]3d <sup>10</sup> 4s <sup>2</sup>	<b>Ga</b> Gallium 69.723 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>1</sup>	<b>Ge</b> Germanium 72.630 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>2</sup>	<b>As</b> Arsenic 74.921595 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>3</sup>	<b>Se</b> Selenium 78.971 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>4</sup>	<b>Br</b> Bromine 79.904 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>5</sup>	<b>Kr</b> Krypton 83.798 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>6</sup>										
5	<b>Rb</b> Rubidium 85.4678 [Kr]5s	<b>Sr</b> Strontium 87.62 [Kr]5s <sup>2</sup>	<b>Y</b> Yttrium 88.90584 [Kr]4d <sup>1</sup> 5s <sup>2</sup>	<b>Zr</b> Zirconium 91.224 [Kr]4d <sup>2</sup> 5s <sup>2</sup>	<b>Nb</b> Niobium 92.90637 [Kr]4d <sup>4</sup> 5s <sup>1</sup>	<b>Mo</b> Molybdenum 95.95 [Kr]4d <sup>5</sup> 5s <sup>1</sup>	<b>Tc</b> Technetium (98) [Kr]4d <sup>5</sup> 5s <sup>2</sup>	<b>Ru</b> Ruthenium 101.07 [Kr]4d <sup>7</sup> 5s <sup>1</sup>	<b>Rh</b> Rhodium 102.90550 [Kr]4d <sup>8</sup> 5s <sup>1</sup>	<b>Pd</b> Palladium 106.42 [Kr]4d <sup>10</sup>	<b>Ag</b> Silver 107.8682 [Kr]4d <sup>10</sup> 5s <sup>1</sup>	<b>Cd</b> Cadmium 112.414 [Kr]4d <sup>10</sup> 5s <sup>2</sup>	<b>In</b> Indium 114.818 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>1</sup>	<b>Sn</b> Tin 118.710 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>2</sup>	<b>Sb</b> Antimony 121.760 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>3</sup>	<b>Te</b> Tellurium 127.60 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>4</sup>	<b>I</b> Iodine 126.90447 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>5</sup>	<b>Xe</b> Xenon 131.293 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>6</sup>										
6	<b>Cs</b> Cesium 132.9054520 [Xe]6s	<b>Ba</b> Barium 137.327 [Xe]6s <sup>2</sup>	<b>La</b> Lanthanum 138.90547 [Xe]5d <sup>1</sup> 6s <sup>2</sup>	<b>Ce</b> Cerium 140.116 [Xe]4f <sup>1</sup> 5d <sup>1</sup> 6s <sup>2</sup>	<b>Pr</b> Praseodymium 140.907 [Xe]4f <sup>3</sup> 6s <sup>2</sup>	<b>Nd</b> Neodymium 144.242 [Xe]4f <sup>4</sup> 6s <sup>2</sup>	<b>Pm</b> Promethium (145) [Xe]4f <sup>5</sup> 6s <sup>2</sup>	<b>Sm</b> Samarium 150.36 [Xe]4f <sup>6</sup> 6s <sup>2</sup>	<b>Eu</b> Europium 151.964 [Xe]4f <sup>7</sup> 6s <sup>2</sup>	<b>Gd</b> Gadolinium 157.25 [Xe]4f <sup>7</sup> 5d <sup>1</sup> 6s <sup>2</sup>	<b>Tb</b> Terbium 158.92535 [Xe]4f <sup>9</sup> 6s <sup>2</sup>	<b>Dy</b> Dysprosium 162.500 [Xe]4f <sup>10</sup> 6s <sup>2</sup>	<b>Ho</b> Holmium 164.93033 [Xe]4f <sup>11</sup> 6s <sup>2</sup>	<b>Er</b> Erbium 167.259 [Xe]4f <sup>12</sup> 6s <sup>2</sup>	<b>Tm</b> Thulium 168.93422 [Xe]4f <sup>13</sup> 6s <sup>2</sup>	<b>Yb</b> Ytterbium 173.054 [Xe]4f <sup>14</sup> 6s <sup>2</sup>	<b>Lu</b> Lutetium 174.9668 [Xe]4f <sup>14</sup> 5d <sup>1</sup> 6s <sup>2</sup>											
7	<b>Fr</b> Francium (223) [Rn]7s	<b>Ra</b> Radium (226) [Rn]7s <sup>2</sup>	<b>Ac</b> Actinium (227) [Rn]5f <sup>1</sup> 7s <sup>2</sup>	<b>Th</b> Thorium 232.0377 [Rn]6s <sup>2</sup> 7s <sup>2</sup>	<b>Pa</b> Protactinium 231.03688 [Rn]5f <sup>2</sup> 7s <sup>2</sup>	<b>U</b> Uranium 238.02891 [Rn]5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup>	<b>Np</b> Neptunium (237) [Rn]5f <sup>4</sup> 6d <sup>1</sup> 7s <sup>2</sup>	<b>Pu</b> Plutonium (244) [Rn]5f <sup>6</sup> 7s <sup>2</sup>	<b>Am</b> Americium (243) [Rn]5f <sup>7</sup> 7s <sup>2</sup>	<b>Cm</b> Curium (247) [Rn]5f <sup>8</sup> 7s <sup>2</sup>	<b>Bk</b> Berkelium (247) [Rn]5f <sup>9</sup> 7s <sup>2</sup>	<b>Cf</b> Californium (251) [Rn]5f <sup>10</sup> 7s <sup>2</sup>	<b>Es</b> Einsteinium (252) [Rn]5f <sup>11</sup> 7s <sup>2</sup>	<b>Fm</b> Fermium (257) [Rn]5f <sup>12</sup> 7s <sup>2</sup>	<b>Md</b> Mendelevium (258) [Rn]5f <sup>13</sup> 7s <sup>2</sup>	<b>No</b> Nobelium (259) [Rn]5f <sup>14</sup> 7s <sup>2</sup>	<b>Lr</b> Lawrencium (262) [Rn]5f <sup>14</sup> 7p <sup>1</sup> 7d <sup>1</sup>											

\*Based upon <sup>12</sup>C, ( ) indicates the mass number of the longest-lived isotope. <sup>†</sup>LUPAC conventional atomic weights; standard atomic weights for these elements are expressed in intervals; see IUPAC for an explanation and values. For a description of the data, visit [physics.nist.gov/data](http://physics.nist.gov/data) NIST SP 966 (September 2014)

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