INTRODUCTION:

The tape contains two videos, you will watch both segments.

These videos introduce the materials covered in Sections 5.1 - 5.6 in your text (as well as reviewing Sections 2.1-2.4) which you should read before watching the video. The two segments cover two major topics: the development of the Bohr model of the atom and the concept of wave-particle duality. Both of these topics are precursors to the modern theory of the atom: quantum mechanics. The video series is written for a physics audience and are thus a little mathematical, but this is an area of chemistry that overlaps directly with physics.

The first segment traces the development of the Bohr model of the atom. Note that in the late 1800s the two major theories in physics were Newtonian mechanics (laws of motion) and Maxwell's theory of electromagnetic radiation (light, radio waves, etc.). Any thing that questioned these theories was scientific heresy, which is what makes Bohr's ideas so radical.

The second segment introduces one of the great paradoxes of modern physical theory: wave-particle duality. Light was believed to be a wave, characterized by a wavelength, $\lambda$ (units of cm$^{-1}$), and a frequency, $f$ (units of s$^{-1}$). Waves are continuous, having no beginning or end, and whose amplitude can have any value. Matter (such as electrons, protons, etc.) consists of particles, characterized by mass, momentum ($p = mass \times speed$), and kinetic energy. Particles are discrete units and can be counted, there are no such things as half an electron. Newtonian mechanics governed particles, Maxwell's electromagnetics governed waves. By the time Schrodinger was finished, particles had wave properties and waves had particle properties.

Below is a list of variables and constants used in the video to help you make sense of the many equations that are introduced. All of the important equations are reproduced in your book so you need not understand every equation introduced.

- $M$ - mass (usually of a single atom or electron)
- $G = 6.67 \times 10^{-11}$ N·m$^2$·kg$^{-2}$ - gravitational constant - force of gravity between two objects
- $K_e = 8.988 \times 10^9$ m$^3$·kg·s$^{-2}$·C$^{-2}$ - electron force constant - electrical force between two charges
- $e = 1.602 \times 10^{-19}$ C - charge on the electron
- $r$ - radius of orbit for electron
- $F = \text{force between two objects}$
- $L = mvr$ - angular momentum - momentum associated with rotating objects
- $U$ and $K$ - potential and kinetic energies of a system
- $\lambda$ - wavelength of wave (both light and matter)
- $n, m$ - integers to describe the various orbits (and energy levels) of electrons
- $R = 1.097 \times 10^7$ m$^{-1}$ - Rydberg constant for spectral lines of hydrogen
- $f = c/\lambda$ - frequency of radiation - also $\lambda = 2\pi f$ and is also called a frequency (your book uses $\nu$ for frequency)
- $h = 6.626 \times 10^{-34}$ J·s - Planck's constant - relates energy of light to frequency - also $h = hf/2\pi$
- $p = mv$ - momentum of an object
**THE ATOM**

1. What is the age-old question introduced at the end of the introduction (by Dr. Goodstein)?
   - What is the ultimate nature of matter?

2. What analogy is used for the model of the atom developed by Niels Bohr? What two concepts in Bohr's model conflicted with Newtonian mechanics and Maxwell's electromagnetic theory?
   - Analogy: solar system.
   - Conflicts:
     1) That e⁻ can travel in circular moments without radiating energy.
     - Violates Maxwell's laws
     2) That e⁻ could only exist in certain discrete orbits with certain energies.
     - Violates Newton's laws

3. Who was the first person to propose the concept of an atom?
   - Democritus of Greece, a contemporary of Aristotle.

   Which two chemists does the video credit with significant contributions to the development of atomic theory?
   - Dalton and Avogadro.

4. What was the new instrument that early scientists such as Maxwell, Balmer, and Rydberg used to investigate the hydrogen atom? What do you observe using this instrument?
   - Spectroscope, which allows you to see line spectra for gaseous atoms.

5. J. J. Thomson discovered the ____________ and proposed the _________ _________ model of the atom.
   - electron; plum-pudding model

   Ernst Rutherford discovered the ____________.
   - atomic nucleus

6. What is Rydberg's Equation? More importantly, write down the value of Rydberg's constant (including units).
   \[
   \frac{1}{\lambda} = R \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right) \quad R = 109,677.58 \text{ cm}^{-1}.
   \]

7. What is/are the problem(s) with the planetary model of the atom suggested by Rutherford? (See #2 above also.)
   - According to Maxwell's theory, an e⁻ should radiate energy as it orbits the nucleus, lose energy in the process, and gradually collapse into the nucleus.

8. What is Planck's equation? What does his theory of matter propose about emitted radiation?
   - \[ E = hf, \] Energy of a photon equals a constant (Planck's constant \( h \)) times the frequency.
   - Matter emits discrete amounts of energy (photons).
9. What is the significance of the theoretical calculation of the radius of the Bohr atom: \(0.529 \times 10^{-10}\) m?
   - It gave a real, tangible value to the atomic radius.

10. What is the value of Rydberg constant as calculated by Bohr theory? Is it in close agreement with the experimental value? (Note the comments made by Dr. Goodstein in his conclusion—following Question 7—about working out the consequences of a theory—how do they apply here?)
   - Agreement is very close (to four significant figures). "Nothing short of amazing."

11. Why was Bohr model accepted even though it violated conventional wisdom?
   - The fit between theory and experiment was too good (compelling and precise) to ignore, despite the assumptions which contradicted old theories.

12. What purpose does judgment serve in theory testing and formation?
   - There is never a perfect match between theory and experiment.
   - Need to judge if a theory's conclusions are convincing. Is the difference(s) a result of approximations (acceptable), experimental error, or a fatal flaw in the theory?

13. What four things cannot be taught to great scientists?
   - Imagination, creativity, judgment, relentless dedication to work.

**APARTICLES AND WAVES**

1. What is common to all glowing bodies?
   - The colors with which they glow are related only to their temperature.

2. What relationship between energy and frequency did Planck introduce? (Note that blue light has a higher frequency than red light and therefore more energy. Keep this idea in mind when the photoelectric effect is discussed.)
   \[ E = hf \] (energy is proportional to frequency)
   - \(E\): energy
   - \(f\): frequency
   - \(h\): Planck's constant

3. What is Einstein photoelectric effect equation? What does it imply about what light is made of (particles or waves)? What did Milliken verify using this equation?
   \[ E = hf - \phi \]
   - \(E\): kinetic energy of emitted electron
   - \(\phi\): work function: the energy needed to remove an electron from the metal

4. What are light particles called?
   - Photons

5. What is the paradox regarding the nature of light?
   - Light has both wave and particle (photon) properties.
6. What question did de Broglie (pronounced de-broy) ask about particles? What equation did he introduce? Was he right?
- If light sometimes behaves like particles, would particles (such as electrons) sometimes behave as waves? He was correct.

\[ \lambda = \frac{h}{mv} \]

7. How does the de Broglie theory and equation help to understand the orbits of fixed diameter in the Bohr atom?
- If electrons have wave properties (including a wavelength), than the circumference of their orbits around a nucleus must be an integer number of wavelengths.

8. Do waves have a beginning or end? What happens when you combine several waves with slightly different frequencies (wavelengths)?
- Waves do not have a beginning or end.
- If you combine several waves with slightly different frequencies, you can concentrate the wave into a small region of space. This entity is neither a true wave or a true particle—it is a photon.

9. "Light passing through 2 slits causes an obvious wave ______________, clearly revealing itself as a pattern [on the screen] of ________ and ________ _________."
   - interference; light; dark stripes

10. "If light is made up of photon particles...then each particle has to hit the screen __________."  
    "There is a higher __________ that more photons will land in certain regions."  
    "The result will be a definite _______-_________ __________ of particles."  
    - individually; probability; wave-like diffraction pattern

Max Born explains: "Photons might be particles, but the patterns they make are ruled by __________ that interfere like waves."
    - probabilities

11. What equation did Heisenberg introduce? Paraphrase the meaning of this equation.
    \[ \Delta x \Delta p \equiv h \]
    - The minimum errors associated with our knowledge of the position and momentum (effectively the speed) of a particle are limited by the above equation. Therefore, it is not possible to know both precisely at the same time.
    - Elevated uncertainty to a fundamental truth of nature.

12. What is the irony suggested by the narrator (in reference to Planck)?
    - Planck's quest for truth led to the uncertainty principle.
I would say that God's transcendence is critical to understanding this "dilemma". First, any understanding we have of how creation works is both descriptive and limited. There may very well be things about creation that God knows and we cannot. Second, God is not limited by the creation, except that he is faithful to it. His understanding is prescriptive—his word is law, and he is not limited by quantum mechanics.

14. Describe Goodstein's demo using Polaroid (polarizers). It is explained using wave ideas and particle ideas. Listen carefully to the differences and describe each explanation. (You can do the same demo at home if you have two or three polarizing lenses of the type found in sunglasses.)