PRESENTATION SUMMARY TEACHER GUIDE

Wakelet link: http://k20.ou.edu/quantumwakelet

Assignment: In pairs, students view videos assigned to them and take notes. Combine all groups that viewed the same videos and have them make slideshow presentations over the videos viewed, and then present to the class.

Slideshow Requirements:

6-8 slides

1 screenshot per slide

Follow the question prompts on each group of videos.

Presentation requirements:

3-4 minutes presentation – about 30 seconds of explanation on each slide

Each group member must present at least one slide.

Answer student's questions after the presentation while students add to their note catcher.

Students can use their notes on the exit ticket questions at the end of the lesson.

Descriptions below each video link explain the concepts that students should address in their presentations.

TOPIC 1: WAVE PARTICLE DUALITY (DOUBLE SLIT EXPERIMENT AND THE PHOTOELECTRIC EFFECT)
Presentations are focused on explaining the phenomenon from previous lessons in the unit.
Group One Videos
Video 1: How Do We KNOW Light is a Wave? (5:49) • Light is an electromagnetic wave as seen by Young's double slit experiment that created an interference pattern. • The constructive and destructive interference pattern results from the superposition of the waves coming from the slits. • The slits width needs to be within 1,000 x's the size of the wavelength of the wave or it will not diffract (spread out) through the opening. • When photons of light are sent through the double slit one at a time, there is still a diffraction pattern. Video 2: Albert Einstein and the Photoelectric Effect (2:35) • Einstein won the Nobel Prize for explaining the photoelectric effect. • Hooke believed that light was a wave, Young's double slit experiment showed wave properties, and Maxwell's equations showed that light was an electromagnetic wave. • The photoelectric effect showed that the energy needed to eject electrons from a metal had to come from a source with a high enough frequency of light or no electrons would leave the metal. • Einstein said that light was made of wave-packets (photons) that could act like a wave in some situations, a particle in other situations, and neither in other situations. • Millikan disagreed with Einstein's hypothesis, so he carefully came up with ways to measure the photoelectric effect to try to disprove Einstein. However, at the end, his precise experiments reinforced that Einstein was right. Video 3: What the HECK is Light?! (4:00) • Light is created when charges speed up, slow down, or change direction. • Electrons cannot orbit the atom because continually changing direction and losing energy makes the electron collapse into the nucleus. • Light needs matter (charges) to be created, but it does not need it to travel because it is an electromagnetic wave. • Young showed that light behaved like a wave with his double slit experiment. • More photons in the beam of light means more brightness. • Very small things exhibit waves and particle behavior. • Photons (particles of light) have frequency. • Macroscopically, you are dealing with tons of particle-waves, which encourages them to choose one side or the other, so we do not observe this duality in day-to-day experiences.
Group Two Videos
Video 1: The Quantum Experiment That Broke Reality (13:31) • Waves passing through a double slit create an interference pattern. • Constructive and destructive interference happens from superposition of waves at different distances away from each of the slits.

• Young showed that light waves should form interference patterns, and Maxwell's equations showed that light was a wave. However, the photoelectric effect showed that light was made of particles called photons. • The amazing result was that the interference pattern showed up even when one photon at a time was fired, which brings up the question *what was it interfering with to create the pattern?* • Each photon leaves a hit in a seemingly random location, but when a large number of hits are combined together, the interference pattern shows up again. • Electrons and even full atoms exhibit the same behavior as photons in similar experiments. • Wave interacts with itself to produce the interference pattern. Video 2: Single Photon Interference (6:00) • Interference Pattern from double slit experiment with laser caused by constructive and destructive interference with different distances light must travel in each path. • Changes to firing one photon at a time at double slit. At first, it seems to be a random distribution, but when enough results are combined, the interference pattern re-merges. • Quantum Mechanical Objects, like photons, are different from macroscopic objects. Sometimes they act like a wave, and sometimes they act like a particle.
Group Three Videos
Video 1: I Did the Double Slit Experiment at Home (15:25) • Double slit experiment breaks up laser beam with strand of hair. • Light is like a platypus. It does not make sense to say it is a duck or a beaver. • When you block one side of the split beam, you get a continuous line on the screen, but when both sides are unblocked, there are parts of the line that disappear, which show that it is the result of the two waves creating destructive interference rather than no light getting to that location. It shows that light is a wave not a particle. • Explains that bright spots have constructive interference with a lot of amplitude when the crests or troughs meet and that dark spots have a crest and trough meeting which cancels the amplitude at the location. • Waves are actually real, and you can trace lines from slits to each of the fringes of bright light. • A laser under 5mW is considered safer for demonstrations and experiments. Video 2: What the Heck is a Photon?! (6:07) • Saying a photon is a packet of energy is very vague. Photon is the smallest piece of light. • The wavelength of low energy light could be the size of a city, but fundamental particles do not really take up space, so a photon of light is not a wavelength of light. • In order for our eyes to pick up the light from an object, there must be at least 9 photons per 100 milliseconds; otherwise, our eyes will not register the light. • We do not see the light coming from distant galaxies because the rate the photons come to us is too small, so we just see darkness even though photons are still arriving.

- Photons are packets of energy that have specific properties. Charge = 0, Spin = 1 with two possible orientations, and Rest Mass = 0 are properties of photons.
- These properties enable photons to have a speed of about 300 million meters per second, the energy to be proportional to their momentum (E = pc), and the inability to experience time or space (spacetime^2 = time^2 - space^2).
- Using a smoke machine, double slit, and laser pointer you see that the double slit really splits the beam into many beams that go to each of the fringes showing that light is a wave.

TOPIC 2: DE BROGLIE WAVELENGTH

Presentations are focused on the De Broglie Wavelength.

Group Four Videos

Video 1: De Broglie Wavelength (11:21)

- Photoelectric Effect shows that light could not be treated just like a wave because in the experiment light could only deliver energy in discrete packets (E=hf).
- Double slit experiment shows that light was a wave that created an interference pattern when light from two slits came together at the screen.
- Scientists accepted that light can have wave-like properties in some experiments and particle-like properties in other experiments.
- In 1924, Louis De Broglie hypothesized that since light (a wave) could act like a particle, electrons (particles) could act like waves. Electrons should have their own wavelength like photons. Hypothesized that everything could act like a wave or a particle depending on the experiment.
- De Broglie wavelength for matter ($\lambda = \frac{h}{p}$) says that the wavelength of the particle was equal to Planck's constant divided by the momentum of the particle since the same equation was used for the wavelength of a photon of light.
- To derive this relationship:
- Light has no mass, but the real equation for momentum is not mass times velocity (p ≠mv). When traveling near the speed of light need to use $E_{Total}^2 = (m_o c^2)^2$ + (pc)^2. Since the rest mass of the photon equals zero, this equation simplifies to $E_{Total} = pc$.
- The energy of a photon is Planck's constant times the frequency of the photon (E = hf).
- Plugging into $E_{Total} = pc$ creates hf = pc, which becomes $\frac{h}{p} = \frac{c}{f}$
- Since v = λf and the speed of light is c. c = λf, which means that $\lambda = \frac{c}{f} = \frac{h}{p}$.
- Again, De Broglie hypothesized that the same equation that was used for photons of light could be applied to particles of matter, like electrons ($\lambda = \frac{h}{p}$).
- To show this, Davisson and Germer shot electrons through a double slit and were able to see the interference pattern of the electrons showing the wave-like nature of matter.

- Are able to take the idea that everything can have wave-like, or particle-like behavior, based on the experiment, and build understanding, like the Bohr model of the atom and Schrodinger's equation.

Video 2: The de Broglie Wavelength (2:05)

- Calculate the de Broglie wavelength of an electron.
- Wavelength equals Planck's constant divided by the mass times velocity ($\lambda = \frac{h}{mv}$).
- Example: Calculate the wavelength on an electron traveling 6.04 x 10^7m/s.

$\lambda = \frac{h}{mv} = \frac{6.626\ x\ 10^{-34} J{\cdot}s}{(9.11\ x\ 10^{-31}\ kg)(6.04\ x\ 10^{7} m/s)}$ 1.20 x $10^{-11} m$

- Electrons have a very tiny mass. If you look at the wavelength of an object with a mass of a few kilograms, the wavelength is so small that we are incapable of measuring it, which is why we never see the wave-like properties of everyday objects.

TOPIC 3: HEISENBERG UNCERTAINTY PRINCIPLE

Presentations are focused on the Heisenberg Uncertainty Principle.

Group Five

Video 1: What is the Heisenberg Uncertainty Principle? (4:44)

- You can never simultaneously never know the exact position and velocity of an object.
- This is not caused by the act of measuring; it is not a measurement problem.
- Everything in the universe behaves like a wave and like a particle at the same time.
- In quantum mechanics, exact position and exact velocity have no meaning.
- A particle exists in a single place at one time 100% right there; 0% everywhere else.
- A wave is a disturbance spread out in space like ripples in a pond. You can identify the wavelength of a wave. It is not in a single position, but it has a good probability of being in lots of different positions.
- Wavelength is related to momentum = mass x velocity. So, a fast-moving particle has a short wavelength and a massive particle has a short wavelength.
- Everyday objects have very small wavelengths because they have a lot of mass and so even when they are moving slowly, they have a lot of momentum.
- A baseball thrown in air has a wavelength of a billionth of a trillionth of a trillionth. It is far too tiny to detect.
- You can measure the wavelength of very tiny objects, like atoms or electrons.
- When you measure a pure wave's momentum, it has no position.
- You can know the particle position exactly, but you do not know its wavelength, so you do not know its momentum.
- Mix particles and waves to get a graph that has waves but only in a small area.
- Combine waves with different wavelengths (different momentum). The resulting interference creates more certainty in location, but less certainty in momentum.
- To know the momentum better, add more waves, which increases error in the exact position.
- To know the position or know more about the exact position creates more error in momentum, which means less precision in momentum.

- This is not an error in measurement, but it relates to the structure of wave and particle properties in objects.

Video 2: What Heisenberg's Uncertainty Principle "Actually" Means (8:54)

- Three options of what Heisenberg uncertainty means:
- Choice 1: Wrong. There is no certain position and momentum for particles.
- Choice 2: Wrong. It is not a measurement or the effect of the measurement of the momentum and position of the observed particle.
- Choice 3: Correct. There is a superposition of multiple positions, but the particle is more likely to be in certain positions.
- You can get a smaller and smaller range of positions (not from measurement error), but the range in momentum will get bigger and bigger at the same time.
- The range in position times the range in momentum must be above a certain value. Making one more precise makes the other vary more.

Group Six

Video 1: Heisenberg's Uncertainty Principle Explained (4:11)

- Green laser fired through a single slit. At first, the bright spot gets narrower as the slit gets narrower, but once the slit is thin enough, the bright spot begins to become wider as the light diffracts.
- Heisenberg's Uncertainty Principle states that the uncertainty in position times the uncertainty in momentum must be greater than Planck's constant divided by four times pi ($\Delta x \Delta p \geq \frac{h}{4\pi}$).
- By decreasing uncertainty in position by narrowing the slit, you come to a point where the uncertainty in momentum in the horizontal direction must increase so that photons must veer off to the left or to the right to not violate Heisenberg's Uncertainty Principle.

Video 2: The Uncertainty Principle is NOT about "Uncertainty" (3:16)

- Should be called the Heisenberg Randomness Principle.
- The description that the more you know about a particle's position, the less you know about a particle's momentum has nothing to do with our ability to measure either of the quantities.
- The principle should be written in terms of multiplying the standard deviations, which indicates that the more that you decrease the region in which it was likely to find one variable, it increases the region in which it was likely to find the other variable. The multiplied values of the two regions need to be greater than a certain minimum value.
- This means that it is impossible to measure both values exactly.
- The Heisenberg Uncertainty Principle leads to the following two statements:
- We will never be able to predict either the position or the momentum perfectly.
- If our chances of predicting one go up, the chances of predicting the other one goes down.
- The wave function of an electron inside of an atom is basically the size of the atom. It is not that we do not know the position, it is that it does not have a position.

• In addition to position and momentum the energy, lifetime, spin, and mass of quantum particles are all quantities that do not have a precise value. Video 3: What is the Uncertainty Principle? (1:04) • Some of quantum weirdness is just normal wave behavior. • The better we know about where a particle is, the less we know about where it is going. • A wave is spread out everywhere, but a wave pulse is in a smaller region. However, a wave pulse does not wave, and so it does not have a frequency.
TOPIC 4: FOURIER TRANSFORMATIONS
Presentations are focused on how the Fourier Series explains the need for the Heisenberg Uncertainty Principle.
Group 7
Video 1: Understanding the Uncertainty Principle with Quantum Fourier Series (14:48) • The macroscopic world seems to be built of individual particles with well-defined properties of position, momentum, spin, and mass, but quantum mechanics says that particles arise from a combination of particles with infinite varying properties. Vacuum itself is the sum of an infinite number of particles. • Heisenberg Uncertainty Principle ($\Delta x \Delta p \geq \frac{h}{4\pi}$) • Perfectly nail down particles position, and you will have complete uncertainty about its momentum. • Not due to measurement even though the measurement can affect the system. It is a limit on how much information can be known about a quantum system. • Example with sound wave: • Sound wave is the intensity of the wave as it passes by. So it can be shown on an intensity vs. time graph. • Complex sound from an orchestra can be broken down into the sum of the individual sinusoidal waves passing by location of the observer over time. • Fourier's theorem states that any complex wave pattern can be broken down into the sum of individual sine waves of different frequencies. • Rather than intensity vs. time a complex wave can also be viewed as the weighted amplitude vs. frequency of the combination of sine waves that make up the complex wave. • Switching from a graph with time to a graph with frequency is called a Fourier transformation. • Any sound wave can be represented in terms of time or frequency. • Time and frequency are Fourier pairs or conjugate variables. • You can make any shape sine wave by adding waves with different frequencies. • You can create a wave packet by adding waves to destructively interfere everywhere except in one region. • The tighter you want to make the wave packet, the more waves with different frequencies you need to add.

- The sharper you want the change to occur, the higher frequency waves you need to add to make the change happen more quickly.
- A spike at one point in time requires an infinite number of individual infinite frequency waves to be added together.
- Perfectly known frequency would be a simple sine wave that extends infinitely in time. So, the time of its existence is undefined.
- Back to the quantum world:
- Wave function is the solution to the Schrodinger equation which contains all the information about a quantum system.
- For a standing quantum, wave position and momentum become the two parts of the Fourier pair.
- Using momentum rather than frequency for light waves, Louis de Broglie realized that matter has wave properties, like wavelength. So, momentum rather than frequency is also used for matter waves.
- Matter waves are wave functions that can be described in terms of position or momentum just like sound was described in terms of time or frequency.
- Any particle or wave function can be represented by a combination of many locations in space with accompanying intensities. Like a particle smeared out in space.
- Also, could be one position with many different momentums. Like a particle smeared out in momentum space.
- Position and Momentum have the same uncertainty relationship that time and frequency had with the sound wave.
- The Born Rule: The magnitude of the wave function squared is the probability distribution for the particle.
- The square of the position wave function tells you the likelihood of finding the particle at a certain location. As the position is measured more precisely, the range of possible momenta becomes larger.
- The square of the momentum wave function tells you the likelihood of finding the particle with a certain momentum. As the momentum is measured more precisely the range of possible positions becomes larger.
- An example of this is a single slit where the narrower that you make the slit the more precisely you know the position which means that the range of momenta values increases, which is seen as a larger spread of values (diffraction) as the direction of particles becomes more uncertain.
- Heisenberg's Uncertainty Principle is a statement of how much of a quantum system's information is accessible. It is the outcome of measuring particles as the superposition of waves.
- The fact that both position and momentum cannot be known precisely simultaneously is a property of the wave function itself. Precision in one is constructed by uncertainty in the other.

Group 8
Video 1: Heisenberg's Uncertainty Principle EXPLAINED (for beginners) (14:42) • Most commonly, Heisenberg's Uncertainty Principle is used to describe a relationship between how much we know about two quantities: position and momentum. The principle tells us that there is a fundamental and universal limit to how much we can simultaneously know about both. In other words, the more confidently we know the position (of, let's say, a particle), the less confident we can be about its momentum. Now the word "uncertainty" just refers to the width of the probability distribution that describes a particle's position or momentum in the quantum world. • Before we find out where the Uncertainty Principle comes from, we will discuss a commonly used description that gets thrown around regarding the principle. It's known as the Observer Effect, and it's the idea that the light we send into a particle in order to glean information about its position and momentum actually ends up changing the behavior of the particle. High energy, small wavelength light tells us with more certainty the position of the particle but changes its momentum a lot so we are less certain about this. Low energy, large wavelength light doesn't give us much information about the position of the particle but does tell us more about its momentum. Annoyingly though, the observer effect is NOT the Uncertainty Principle. It's just a possible explanation for it, as suggested by Heisenberg himself. • So where can we look to find the origins of the Uncertainty Principle? Well, a good place to start is to understand Fourier Transforms. Fourier transforms come about by first breaking down mathematical functions into sine wave building blocks - kind of like how we break vectors down into horizontal and vertical components. The sine wave building blocks are sine waves of different frequencies. We can then take the amplitude of each of the sine wave building blocks and plot that against the frequency of that sine wave to give us a new plot. This new plot is known as the Fourier Transform of the original function that we broke down. • The interesting thing to note is that if a function is super wide on its horizontal axis, then its Fourier transform is going to be super narrow, and vice versa. This is useful when we bring the whole thing back round to the Uncertainty Principle. • Now remember, in quantum mechanics we use "wave functions" to describe the probability distributions of position and momentum. But here's the clincher: The momentum wave function is the Fourier transform of the position wave function. This means that if we have a super-wide position wave function (so it could be in a larger range of values, and thus we are more uncertain about it), then the momentum wave function is narrow (so it's in a smaller range of values and we are more certain about the momentum) and vice versa. This is where the principle comes from - the more we know about position, the less we know about momentum, and vice versa.

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