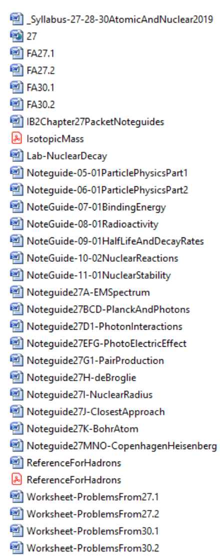
Atomic and Nuclear
Chapter 27, 28, 30, 31 Syllabus

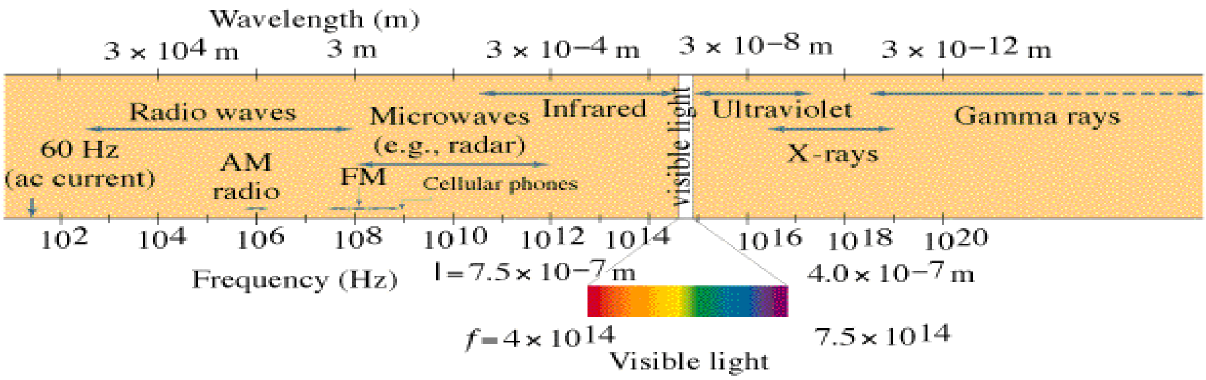
B	In c lass:	Due on this class:
1 Mar 4	**GW**-27.1 #1-15	**VF 27A, 27BCD, 27D1, 27EFG**
2 Mar 6	**GW**-27.1 #16-25 **GW**-FA27.1	**VF 27G1, 27H**
3 Mar 8	**SA27.1-Photon Theory (first 30)** **VF**-27I, 27J, 27K	Turn in: FA27.1
4 Mar 12	**GW**-27.2 #1-18	**VF 27I, 27J, 27K , 27L, 27MNO**
5 Mar 14	**GW**-27.2 Parts A and B	**VF 32A, 32B, 32C, 32D**
6 Mar 18	**GW**-Part C **GW**-FA27.2	**VF 32E**
7 Mar 20	**SA27.2-Atomic Physics (first 30)** **VF**-30A, 30B	Turn in: FA27.2
8 Mar 22	**GW**-30.2 #1-16 **GW**-FA30.2	**VF 30A, 30B, 30M, 30N, 30N1, 30O**
Yay Spring Break Yay Spring Break Yay Spring Break Yay Spring Break Yay Spring Break Yay!		
9 Apr 3	**SA30.2-Nuclear Reactions (first 30)** **VF**-30C, 30D, 30F **DI**-Hiroshima (30P)	Turn in: FA30.2
10 Apr 5	**GW**-30.1 #1-7	**VF 30C, 30D, 30F, 30G, 30H**
11 Apr 9	**GW**-30.1 #8-24 **GW**-FA30.1	**VF 30I, 30J, 30K, 30L**
12 Apr 11	**SA30.1-Radioactive Decay (first 30)** **VF**-30Q	Turn in: FA30.1
13 Apr 16	**GW-**Decay Lab **GW-**Young's Double Slit Lab (EC)	Turn in: Decay Lab
	April 18, 22, 24, 26 - IB Review	

Assignments

- 2 Labs:
  - Decay Lab – Determine the half-life of a computer-simulated nuclear decay
  - Young's Double Slit - EC lab for IB
- 4 Formative/Summative Assessments
  - 27.1 – Photons
  - 27.2 – Atomic and Particle
  - 30.1 – Radioactivity
  - 31.1 – Nuclear Reactions



Noteguide for Electromagnetic Spectrum - Videos 27A **Name___________________________**



Reviewing Waves:

$v = f\lambda$

$v = c$ = speed of light = 3.00×10^8 m/s

f = frequency (Hz)

λ = wavelength (m) 1 nm = 1×10^{-9} m

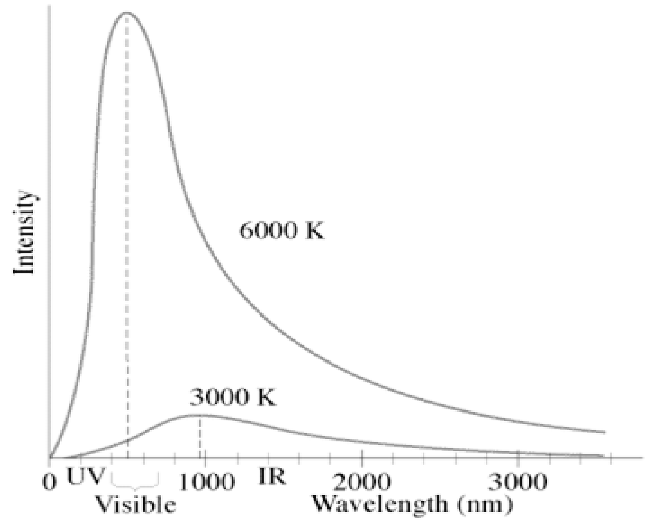
Example: What is the wavelength of a 91.1 MHz radio wave?

Whiteboards:

1. What is the frequency of a 12.2 cm microwave? (ovens use this) (2.46×10^9 Hz)
2. What is the frequency of a 600. nm light wave? (5.00×10^{14} Hz)

Noteguide for Photons - Videos 27BCD **Name______________________________**

27B: Planck



27C: Photon Theory: Light is made of particles.

$E = hf$ $\lambda = \frac{hc}{E}$

E = Photon energy (Joules)
h = Planck's constant = 6.626×10^{-34} Js
f = frequency of oscillations (Hz, s^{-1})
c = speed of light = $3.00\text{x}10^{8}$ m/s
λ = Wavelength in m

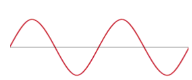
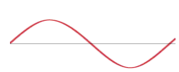
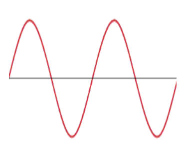
Example 1: What is the energy (in eV) of a 460. nm photon?

Example 2: A photon has an energy of 13.6 eV. What is its wavelength?

Whiteboards:

1. What is the energy (in J) of a photon with a frequency of 6.58×10^{14} Hz? (4.36×10^{-19} J)	2. What is the wavelength of a photon with an energy of 5.45×10^{-18} J? (36.5 nm or 3.65E-8 m)
3. What is the energy (in eV) of a 314 nm photon? (3.95 eV)	4. A photon has an energy of 6.02 eV. What is its wavelength? (206 nm)

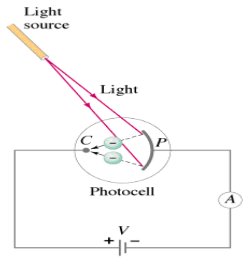
27D: Photon vs. Wave theory:

	Wave Model	**Photon Model**
Color:	**Wavelength changes** Small λ = Blue  Big λ = Red 	**Energy per photon changes** ($E = hf = hc/\lambda$) High E = Blue/UV/X-rays Low E = Red/Microwaves/radio
Brightness:	**Amplitude Changes** Bright = big  Dim = small 	**# of Photons changes** Bright = many Dim = few

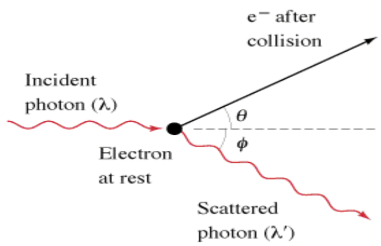
Noteguide for Photon Interactions - Videos 27D1 **Name______________________________**

Photon Interactions with matter:

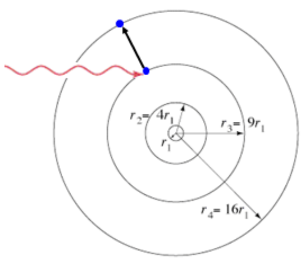
Photo-electric Effect - photon ejects electron from a metal surface



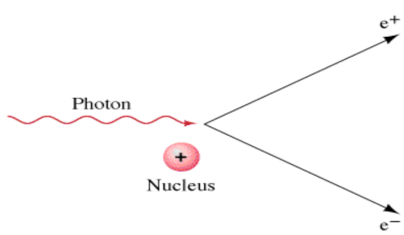
Compton Scattering - Photon scatters (bounces) off an electron. Electron and photon go off in different directions, and photon's wavelength goes down. (Loses energy...)

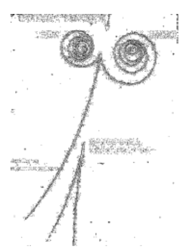


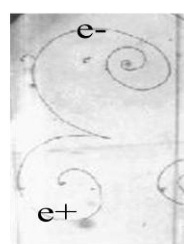
Absorption - Photon energy is the same as a transition energy, so it bumps an electron up an energy level and is absorbed



Pair Production - A photon passing by a mass (nucleus, or electron) spontaneously creates a matter-anti matter pair.







Complementarity - Either the wave model, XOR the photon model explains light

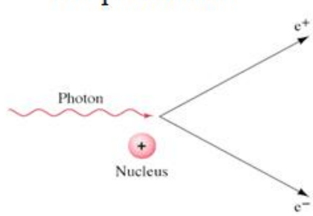
So - is light a wave or a particle?

<u>Wave behaviour:</u>

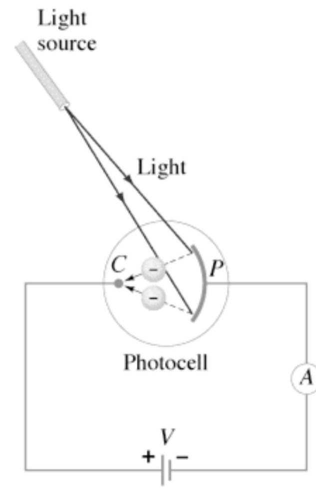
Refraction
Interference
Diffraction

<u>Particle behaviour:</u>

Photoelectric effect
Compton scattering
Absorption
Pair production



Noteguide for Photo-Electric Effect - Videos 27EFG **Name________________________**



27EF: Photo-Electric Effect – Electrons being ejected from a metal by light.

Photon Energy = Work + Kinetic Energy

$hf = \phi + E_{max}$

$hf = hf_o + eV$

ϕ - Work function (Depends on material)

f_o - Lowest frequency that ejects

e - Electron charge

V - The uh stopping potential

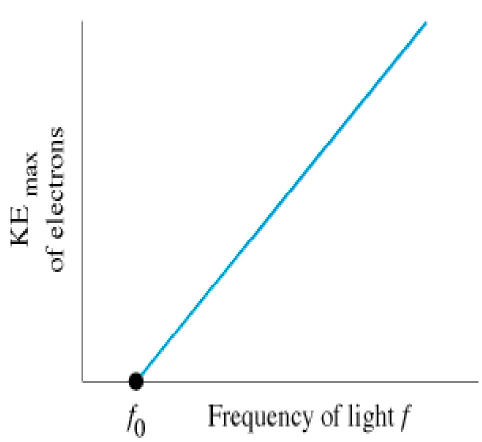
Example 1: A certain metal has a work function of 3.25 eV. When light of an unknown wavelength strikes it, the electrons have a stopping potential of 7.35 V. What is the wavelength of the light?

Example 2: 70.9 nm light strikes a metal with a work function of 5.10 eV. What is the maximum kinetic energy of the ejected photons in eV? What is the stopping potential?

Whiteboards:

1. Photons of a certain energy strike a metal with a work function of 2.15 eV. The ejected electrons have a kinetic energy of 3.85 eV. (A stopping potential of 3.85 V) What is the energy of the incoming photons in eV? (6.00 eV)	2. Another metal has a work function of 3.46 eV. What is the wavelength of light that ejects electrons with a stopping potential of 5.00 V? (147 nm)
3. 112 nm light strikes a metal with a work function of 4.41 eV. What is the stopping potential of the ejected electrons? (6.67 V)	4. 256 nm light strikes a metal and the ejected electrons have a stopping potential of 1.15 V. What is the work function of the metal in eV? (3.70 eV)

27G: Data:

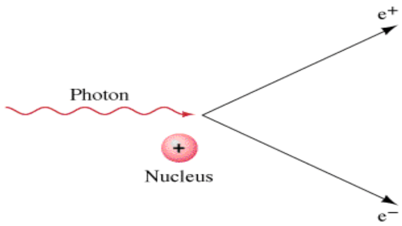


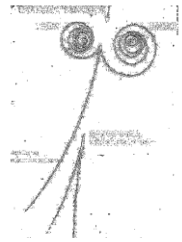
Photon Theory Predicts:

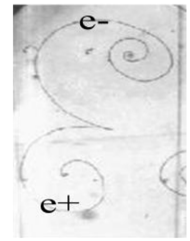
Wave Theory Predicts:

Noteguide for Pair Production - Videos 27G1 **Name_______________________________**

Pair Production - A photon passing by a mass (nucleus, or electron) spontaneously creates a matter-anti matter pair.







Photon energy = Energy to create matter + Kinetic energy of pair

Electron rest mass	m_e	9.110×10^{-31} kg = 0.000549 u = 0.511 MeV c^{-2}
Proton rest mass	m_p	1.673×10^{-27} kg =1.007276 u = 938 MeV c^{-2}
Neutron rest mass	m_n	1.675×10^{-27} kg =1.008665 u = 940 MeV c^{-2}
Unified atomic mass unit	u	1.661×10^{-27} kg = 931.5 MeV c^{-2}

Example 1: What energy photon (in MeV) is needed to create a electron-positron pair each with a kinetic energy of 0.34 MeV? What is the wavelength of that photon?

Example 2: A 0.00025 nm photon creates a electron-positron pair. What is the kinetic energy of each particle?

Whiteboards:

1. A photon creates a electron-positron pair each with a kinetic energy of 0.170 MeV. What is the energy of the photon? (in MeV) (1.362 MeV)	2. A 2134 MeV photon creates a proton, antiproton pair, each with how much kinetic energy? (129 MeV)
3. A photon with a wavelength of 5.27113×10^{-13} m creates a electron-positron pair with how much kinetic energy each? (answer in keV) (666 keV) (heheheheh)	

Noteguide for de Broglie Waves - Videos 27H **Name**______________________________

de Broglie – If light can act as a particle, then matter can act as a wave.

The wavelength/momentum of a particle:

$$p = \frac{h}{\lambda}$$

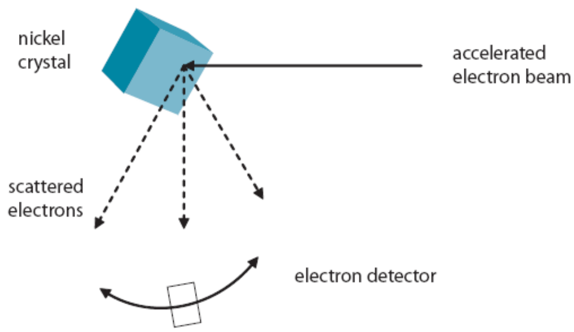
p = momentum (kg m/s)
h = Planck's constant = 6.626×10^{-34} Js
λ = wavelength (m)

The momentum of a particle:

$$p = mv$$

p = momentum (kg m/s)
m = mass (kg)
v = velocity (m/s)

Davisson-Germer:



$$p = \frac{h}{\lambda} \qquad E_k = \tfrac{1}{2}mv^2 \qquad p = mv \qquad v = f\lambda$$

Example 1: What is the de Broglie wavelength of a 0.145 kg baseball going 40. m/s?

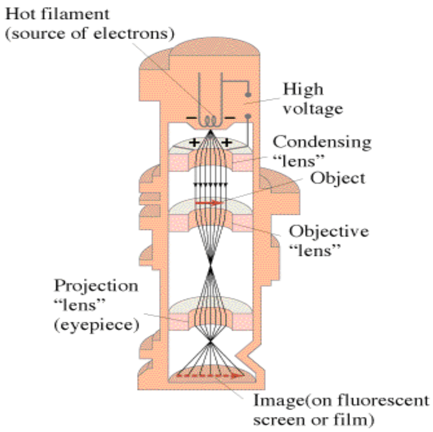
Example 2: What is the velocity of a proton ($m = 1.673 \times 10^{-27}$ kg) with a de Broglie wavelength of 600 nm?

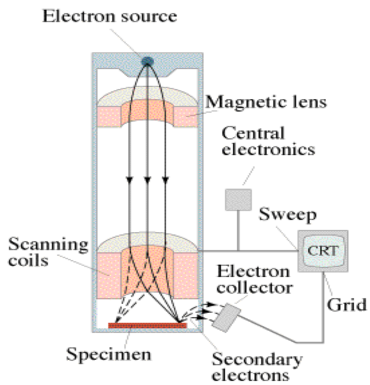
Example 3: Through what potential must you accelerate an electron so that it has a wavelength of 1.0 nm?

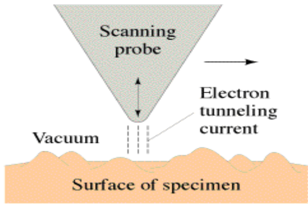
Whiteboards:

1. What is the de Broglie wavelength of an electron (m = 9.11×10^{-31} kg) going 1800 m/s? (404 nm)	2. What is the momentum of a 600. nm photon? (1.10×10^{-27} kg m/s)
3. What is the mass of a particle that has a de Broglie wavelength of 450 nm, and a velocity of 40.0 m/s? (3.68×10^{-29} kg)	4. Electrons in a microscope are accelerated through 12.8 V. (m = 9.11×10^{-31} kg) What de Broglie wavelength will they have? (3.428×10^{-10} m)

Part 2:



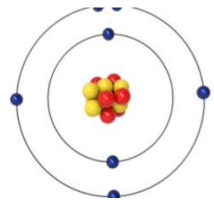




Noteguide for Nuclear Radius - Videos 27I **Name_____________________________**

Atoms are ≈ 10^{-10} m in radius

Nuclei are ≈ 10^{-15} m in radius



$$R = R_0 A^{1/3}$$

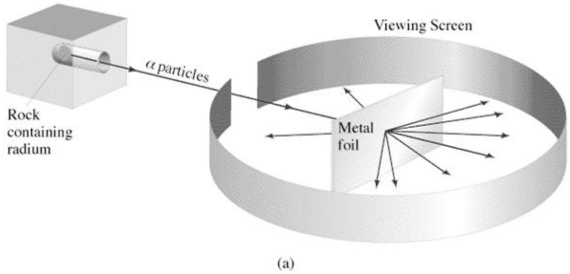
R - Nuclear radius (m)
R_o - Fermi Radius (1.20×10^{-15} m)
A - Mass # (#p +#n)

Example 1: What is the radius of a Uranium 235 nucleus? (A = 235)

Whiteboard:
What is the radius of a Carbon-12 nucleus? (2.75 fm or 2.75×10^{-15} m)

Noteguide for Closest Approach - Videos 27J **Name______________________________**

Rutherford – Discovered the nucleus by scattering alpha particles (2 protons, 2 neutrons bound together) off of gold foil.



Relationship between energy voltage and charge:

$$E_P = qV_e$$

V_e = Voltage (V)
q = Charge (C)
E_p = Electrical Potential energy (J)

Voltage due to a point charge:

$$V_e = \frac{kq}{r}$$

V_e = Potential near a point charge (V)
k = 8.99×10^9 Nm^2/C^2
q = Charge (C)
r = distance to charge (m)

Kinetic Energy:

$$E_k = \frac{1}{2}mv^2$$

E_k = Kinetic Energy (J)
m = mass (kg)
v = velocity (m/s)

Example 1: What is the closest approach of an alpha (q = 2e, m = 6.644E-27 kg) particle going 2.6×10^6 m/s if it approaches a carbon nucleus head on?

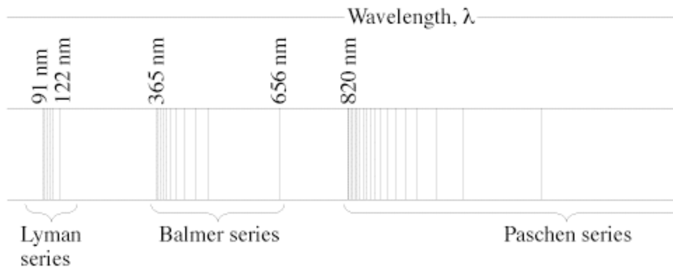
Example 2: Through what potential must you accelerate an alpha particle to penetrate a Uranium (Z = 92) nucleus? (r = 7.4 fm) (1 fm = 1×10^{-15} m)

Whiteboards:
What is the closest approach in nm of an Alpha (2p2n) particle going 15,000 m/s to a Gold (Z = 79) nucleus? (49 nm)

An Alpha particle's closest approach brings it to within 47 fm of a Gold nucleus.
What is its energy in eV? (4.8 MeV or 4.8×10^{6} eV)

Noteguide for Bohr Atom - Videos 27KL **Name______________________________**

27K: Bohr develops a quantum theory for the atom to explain the spectral lines.
The spectral lines follow a pattern:

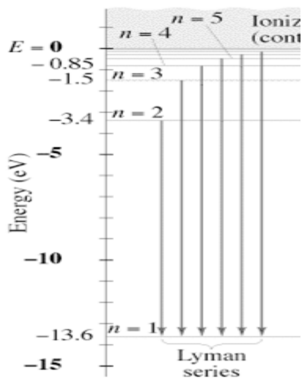


$1/\lambda = R(1/2^2 - 1/n^2)$, n = 3, 4, ...(Balmer) (Visible)
$1/\lambda = R(1/1^2 - 1/n^2)$, n = 2, 3, ...(Lyman) (UV)
$1/\lambda = R(1/3^2 - 1/n^2)$, n = 4, 5, ...(Paschen) (IR)

Three Assumptions of the Bohr Model:

1. Electrons exist in stationary states that don't radiate energy.
(More about this later - these are resonances)

2. Photons are created from the energy given off by downward electron transitions:



Example 1 – What is the wavelength of the first Lyman line?

3. Angular momentum of the electrons is quantised. (Even multiples of h-bar)

$$mvr = \frac{nh}{2\pi}$$

Example 2 - Show that mvr = L = Iω,

Ultimately, the energy levels can be simplified to:

$$E = -\frac{13.6}{n^2}eV$$

n - principal quantum number (orbital)
E - Total energy of electron (KE + PE) in eV

Example 3: What is the energy level of the 4th orbital, and the 2nd orbital?

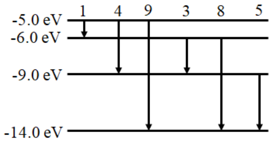
What wavelength of light corresponds to a 4 to 2 transition for a Hydrogen atom? (The 2nd Balmer line)

Limitations of the Bohr Model:

- Works well for H, but doesn't even work for He
- Did not explain
    - Spectral fine structure
    - Brightness of lines
    - Molecular bonds
- Theory was not complete.
- But otherwise it generally kicked tuckus

Whiteboards:

1. What possible photon energies can you get from these energy levels? (there are 6 different ones)



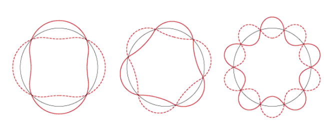
(1, 4, 9, 3, 8, 5 eV)

2. What is the wavelength of the photon released from the third Lyman spectral line (from -.85 to -13.6 eV)? (97 nm)

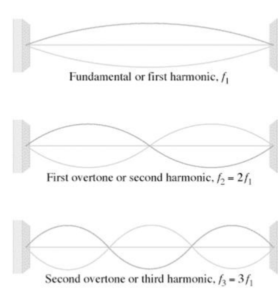
3. What is the wavelength of the photon associated with an electron transition from n = 6 to n = 1 in a hydrogen atom? Is the photon being absorbed, or emitted? (93.8 nm, emitted)

4. What is the wavelength of the photon associated with an electron transition from n = 2 to n = 3 in a hydrogen atom? Is the photon being absorbed, or emitted? (657 nm absorbed)

27L: Show that the quantisation amounts to the circumference of the orbit being integer multiples of the de Broglie wavelength. (Bohr did not base his quantum hypothesis on this - it was used after the fact to explain and justify)

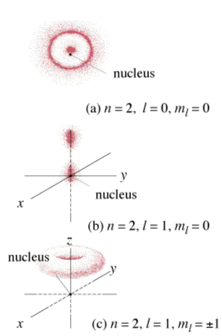


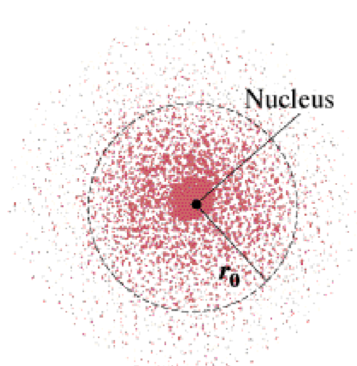
$$mvr = \frac{nh}{2\pi} \qquad p = \frac{h}{\lambda}$$



Schrodinger Wave Equation:

$P(r) = |\psi|^2 \Delta V$



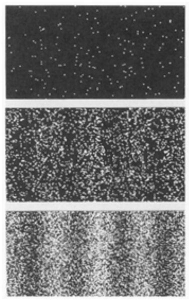


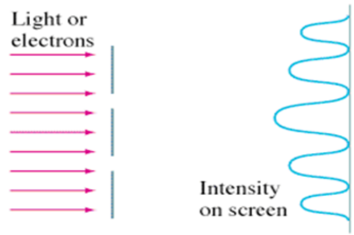
Noteguide for Copenhagen and Heisenberg - Videos 27MNO   Name________________________

27M:

Copenhagen Interpretation – Demo laser

- Electrons interfere even when sent one at a time (why?)
- Copenhagen: ψ = Schrödinger wave function of electron
- "Probability waves" interfere (ψ^2 = probability)





27N: Heisenberg – The more accurately you know an object's position, the less accurately you can know its momentum because observing tiny things like electrons changes their momentum, and resolution is on the order of the wavelength of the photon you use.

Key formula: $p = \frac{h}{\lambda}$ Small λ = large p, Large λ = small p

Observing an electron with a small wavelength:

Observing an electron with a large wavelength:

Momentum-position:

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

Δx = Range of position (m)
Δp = Range of momentum (kg m/s)
h = Planck's Constant ($6.626\text{x}10^{-34}$ Js)

Energy-time

$$\Delta E \Delta t \geq \frac{h}{4\pi}$$

ΔE = Range of energy (J)
Δt = Range of time (s)
h = Planck's Constant ($6.626\text{x}10^{-34}$ Js)

Example 1: What is the uncertainty in the position of a 0.145 kg baseball with a velocity of 37.0 ± 0.3 m/s?

Example 2: An electron stays in the first excited state of hydrogen for a time of approximately $\Delta t = 1.0 \times 10^{-10}$ s Determine the uncertainty in the energy of the electron in the first excited state.

Whiteboards

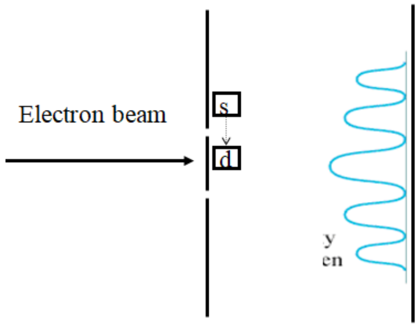
1. What is the uncertainty of the energy of an electron for an interval of $2.1\text{x}10^{-16}$ s? ($\Delta E = 2.5 \text{ x } 10^{-19}$ J)	2. To effect an alpha decay, an alpha particle must "borrow" 27.0 MeV of energy. What time does it have to escape? 27.0 MeV = $(27.0\text{x}10^{6}$ eV$)(1.602\text{x}10^{-19}$ J/eV) ($\Delta t = 1.22 \text{ x } 10^{-23}$ s)
3. You know an electron's position is ±0.78 nm, what is the minimum uncertainty of its velocity? ($v = 3.7 \text{ x } 10^{4}$ m/s)	4. A proton has an uncertainty in its velocity of $5.20\text{x}10^{6}$ m/s. (That's the total range) What is the minimum uncertainty in its position? ($\Delta x = 6.06 \text{ x } 10^{-15}$ m)

270: The Einstein Bohr Debate:

Einstein objected to:

Famous Einstein Quote:

Gedanken experiment **(to disprove complementarity)**



- Detect which slit the electron went through with light beam (particle behaviour)
- If interference pattern appears, then we have both wave and particle behaviour
- Complementarity says it must be either

(Why this experiment would not work:)

Problems from 27.1 - Photon Theory

$c = f\lambda$

1. What is the frequency of a 3.00 m long radio wave? (1.00x10^{8} Hz)
2. What is the frequency of a 400. nm light wave? (7.50x10^{-14} Hz)
3. What is the frequency of a 12.0 cm microwave? (2.50x10^{9} Hz)
4. What is the wavelength of a 91.1 MHz FM radio wave? (3.29 m)
5. What is the wavelength of a 60.0 Hz radio wave? (5.00x10^{6} m)

$\lambda = \frac{hc}{E}$

Elementary charge	e	1.60×10^{-19} C

6. What is the wavelength of a 2.13 eV photon? (583 nm)
7. What is the energy in eV of a 400. nm light wave? (3.10 eV)
8. What is the energy in eV of a 700. nm light wave? (1.77 eV)
9. What is the wavelength of a 1.20 MeV photon? (1.03x10^{-12} m)
10. What is the energy of a 0.00130 nm photon in eV? (9.54x10^{5} eV)

$E_{\text{max}} = hf - \Phi$

11. 415 nm light ejects photo-electrons from a metal with a work function of 2.06 eV. What is the stopping potential of the photo-electrons? (0.930 V)
12. 213 nm light ejects photo-electrons from a metal with a work function of 3.10 eV. What is the kinetic energy of the photo-electrons in eV? (2.73 eV)
13. 117. nm light ejects photo-electrons that have a stopping potential of 3.56 V from a metal. What is the work function of the metal in electron volts? (7.05 eV)
14. Light ejects photo-electrons that have a stopping potential of 1.17 V from a metal with a work function of 2.36 eV. What is the wavelength of the light? (352 nm)
15. 315 nm light ejects photo-electrons from a metal that have a stopping potential of 2.65 V. What is the work function of the metal in electron volts? (1.29 eV)

Electron rest mass	m_e	9.110×10^{-31} kg = 0.000549 u = 0.511 MeV c^{-2}
Proton rest mass	m_p	1.673×10^{-27} kg =1.007276 u = 938 MeV c^{-2}
Neutron rest mass	m_n	1.675×10^{-27} kg =1.008665 u = 940 MeV c^{-2}

$\lambda = \frac{hc}{E}$

16. A photon creates a proton/anti proton pair each with 180. MeV of kinetic energy. What is the maximum wavelength the photon could have? (5.55x10^{-16} m)
17. A photon with a wavelength of 7.21x10^{-13} m creates an electron/positron pair each with what maximum kinetic energy? (0.349 MeV)
18. A photon creates an electron/positron pair each with 3.20 MeV of energy. What is its wavelength? (1.67x10^{-13} m)
19. A 5.85x10^{-16} m photon creates a neutron/anti neutron pair each with what kinetic energy? (121 MeV)
20. A 3.20x10^{-15} m photon creates a charged matter/anti matter pair each having a kinetic energy of 53.9 MeV. What is the rest mass of the particles created in MeV? (140. MeV)

$p = mv$ $\quad p = \frac{h}{\lambda}$ ←This is not in the data packet

21. What is the velocity of a **proton** with a de Broglie wavelength of 450. nm? (0.880 m/s)
22. What is the mass of a particle that has a de Broglie wavelength of 926 nm, and a velocity of 0.265 m/s? (2.70x10^{-27} kg)
23. What is the de Broglie wavelength of an **electron** with a velocity of 1750 m/s? (416 nm)
24. What is the velocity of **proton** with a de Broglie wavelength of 1.00 x 10^{-10} m? (3.96x10^{3} m/s)
25. A particle going 1200. m/s has a de Broglie wavelength of 137 nm. What is the mass of the particle? (4.03x10^{-30} kg)

Problems from 27.2 - Atomic Physics

Closest Approach: $E_K = \frac{1}{2}mv^2$ and $E_P = qV_e = \frac{kq_1q_2}{r}$ $q_1 = 2e$, $q_2 = Ze$

26. An alpha particle ($m = 6.64x10^{-27}$ kg) going $5.14x10^6$ m/s will get how close to a silver (Z = 47) nucleus if it hits head on? ($2.47x10^{-13}$ m)
27. A speeding alpha particle ($m = 6.64x10^{-27}$ kg) hits a mercury (Z = 80) nucleus head on. If it comes within 17.0 nm of the nucleus' center, how fast was it going to start with? ($2.56x10^4$ m/s)
28. An alpha particle ($m = 6.64x10^{-27}$ kg) going $4.12x10^6$ m/s will get how close to a bismuth (Z = 83) nucleus if it hits head on? ($6.80x10^{-13}$ m)
29. A speeding alpha particle ($m = 6.64x10^{-27}$ kg) hits a lead (Z = 82) nucleus head on. If it comes within 12.0 nm of the nucleus' center, how fast was it going to start with? ($3.08x10^4$ m/s)
30. An alpha particle ($m = 6.64x10^{-27}$ kg) going $2.37x10^6$ m/s will get how close to a gold (Z = 79) nucleus if it hits head on? ($1.95x10^{-12}$ m)

Electron Transitions: $E = -\frac{13.6}{n^2}eV$ and $\lambda = \frac{hc}{E}$

31. What is the wavelength of the photon associated with an electron transition from n = 3 to n = 1 in a hydrogen atom? Is the photon being absorbed, or emitted? (103 nm, emitted)
32. What is the wavelength of the photon associated with an electron transition from n = 3 to n = 6 in a hydrogen atom? Is the photon being absorbed, or emitted? (1095 nm, absorbed)
33. What is the wavelength of the photon associated with an electron transition from n = 2 to n = 1 in a hydrogen atom? Is the photon being absorbed, or emitted? (122 nm, emitted)
34. What is the wavelength of the photon associated with an electron transition from n = 2 to n = 4 in a hydrogen atom? Is the photon being absorbed, or emitted? (487 nm, absorbed)
35. What is the wavelength of the photon associated with an electron transition from n = 6 to n = 2 in a hydrogen atom? Is the photon being absorbed, or emitted? (411 nm, emitted)

Nuclear Radius or Heisenberg: $R = R_0A^{1/3}$ or $\Delta x \Delta p \geq \frac{h}{4\pi}$ or $\Delta E \Delta t \geq \frac{h}{4\pi}$

36. What is the radius of C-14 nucleus? ($2.89x10^{-15}$ m)
37. What is the likely mass number of a nucleus with a radius of $3.51x10^{-15}$ m? (25)
38. To effect an alpha decay, an alpha particle must "borrow" 31.1 MeV of energy. What time does it have to escape? ($1.06x10^{-23}$ s)
39. An Alpha particle takes $1.80x10^{-23}$ s to "tunnel" through a potential barrier. What is the amount of energy it can "borrow" during this time in MeV? (18.3 MeV)
40. An electron has an uncertainty in its velocity of $\pm 2.10x10^4$ m/s. What is the minimum uncertainty in its position? ($1.38x10^{-9}$ m)
41. An electron has an uncertainty in its position of $2.40x10^{-10}$ m (total range) . What is the minimum uncertainty (the total range) of its velocity? ($2.41x10^5$ m/s)
42. A proton has an uncertainty in its position of $3.51x10^{-15}$ m (total range). What is the minimum uncertainty (the total range) of its velocity? ($8.98x10^6$ m/s)
43. A proton has an uncertainty in its velocity of $\pm 4.30x10^6$ m/s. What is the minimum uncertainty in its position? ($3.66x10^{-15}$ m)

Part A: Find the missing decay product:

1	$\tau^- \rightarrow \pi^- + \pi^o + ??$ υ_τ	$?? \rightarrow \pi^+ + \pi^o + \overline{\upsilon_\tau}$ τ^+	$\tau^- \rightarrow \upsilon_\tau + ?? + \overline{\upsilon_e}$ e^-	$\tau^+ \rightarrow \overline{\upsilon_\tau} + e^+ + ??$ υ_e
2	$\tau^- \rightarrow ?? + \mu^- + \overline{\upsilon_\mu}$ υ_τ	$\tau^+ \rightarrow ?? + \mu^+ + \upsilon_\mu$ $\overline{\upsilon_\tau}$	$?? \rightarrow e^- + \overline{\upsilon_e} + \upsilon_\mu$ μ^-	$\mu^+ \rightarrow e^+ + ?? + \overline{\upsilon_\mu}$ υ_e
3	$\mu^- \rightarrow e^- + \overline{\upsilon_e} + \upsilon_\mu + e^+ + ??$ e^-	$\mu^+ \rightarrow e^+ + ?? + \overline{\upsilon_\mu} + e^+ + e^-$ υ_e	$K_L^o \rightarrow \pi^+ + ?? + \overline{\upsilon_\mu}$ μ^-	$K^+ \rightarrow ?? + \upsilon_\mu$ μ^+

Part B: For these reactions, indicate if it is possible, or indicate <u>every</u> law it violates:

1	$p + n \rightarrow K^+ + \eta^o + \Xi^o$ No, baryon number	$p + n \rightarrow p + \overline{p} + \overline{n}$ No, charge and baryon number	$n + n \rightarrow \Lambda^o + \Sigma^o$ Yes?	$n + n \rightarrow \Omega^+ + \Omega^-$ No, baryon number
2	$p + p \rightarrow \Omega^+ + e^+ + \Lambda^o + \Sigma^o + n$ No, Le	$p + p \rightarrow p + n + n + \Omega^+$ Yes?	$p + p \rightarrow \tau^+ + \upsilon_\tau + \mu^+ + \overline{\upsilon_\mu}$ No, Baryon and Lμ	$p + n \rightarrow n + n + \tau^+ + \upsilon_\tau$ Yes?
3	$p + \overline{p} \rightarrow \tau^- + \Lambda^o + \Omega^+ + \overline{\upsilon_\tau}$ Yes?	$p + \overline{n} \rightarrow \tau^+ + \tau^-$ No, charge	$\overline{n} + n \rightarrow \tau^+ + \tau^-$ Yes?	$p + \overline{p} \rightarrow \Sigma^- + \Omega^+$ Yes?

Part C: Write the quark combinations that make up a proton and a neutron: p =__________ n =__________
Identify the following quark combinations as either a meson, or a baryon. Determine the baryon number, strangeness, and the charge of each:

		Baryon or Meson?	B = ?	S = ?	q = ?
1	$s\overline{s}$	M	0	0	0
2	dsc	B	+1	-1	0
3	$\overline{u}\overline{u}\overline{u}$	B	-1	0	-2
4	$s\overline{u}$	M	0	-1	-1
5	$d\overline{s}$	M	0	+1	0
6	sss	B	+1	-3	-1
7	$\overline{u}\overline{u}\overline{c}$	B	-1	0	-2
8	$u\overline{s}$	M	0	+1	+1
9	$c\overline{d}$	M	0	0	+1
10	$\overline{s}\overline{s}\overline{c}$	B	-1	+2	0
11	ucc	B	+1	0	+2
12	$s\overline{b}$	M	0	-1	0

Charge	Quarks			Baryon number
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$

All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of −1

Data Packet reference for decays:

Charge	Leptons		
−1	e	μ	τ
0	υ_e	υ_μ	υ_τ

All leptons have a lepton number of 1 and antileptons have a lepton number of −1