Name Key Block ________ Date ____________

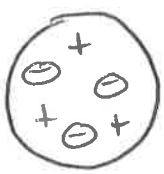
Quantum Model of the Atom

PART A – WAVES & QUANTUM MECHANICS

1. Discuss the experiment and contribution to atomic structure theory provided by each of the following scientists:

a) Thomson

- Cathode Ray experiment provided first evidence of charged particles (–) in matter.
- Beam of electrons (current) when exposed to electric or magnetic fields, bent away from the (–) plate = (–) particles present & the amount of diffraction per coulomb of charge of the plate showed a small mass of the particle



Plum-Pudding

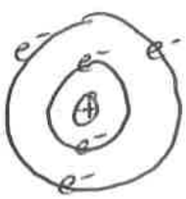
b) Rutherford

- Gold Foil experiment provided evidence for a nuclear model of the atom
- α particles ($2p^+/2n^0$) rarely reflect/deflect when passing through foil
  - Deflection/Reflection = (+) charge area (concentrated)
  - Rare deflection = tiny (+) charge region, rest is "empty" (–) charge region

e⁻ cloud

c) Bohr

- Light Emission evidence: samples of elements always emit the same color light waves when excited w/energy
- Same color = same λ = same energy. Therefore, e⁻ must be traveling b/w energy levels that are a specific, quantized amount of energy apart



d) Schrödinger

- Combines both the e⁻ cloud theory & quantized energy level theory & is therefore supported by both.
- e⁻ occupy orbitals in sublevels, each of which are a quantized amount of energy apart & their location can be predicted by the wave equation to form probability maps.

2. Which pieces of experimental evidence support the idea that electrons have wave-like properties as well as properties of a particle?

Wave: Dual slit experiment → shows e^- behavior of constructive and destructive interference, a wave property

Particle: Photoelectric Effect (for light) → shows light behavior as "packets" of energy. Increasing brightness of light increases # of e^- emitted, doesn't ↑ their energy

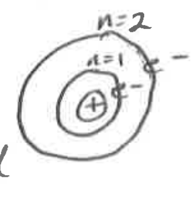
Cathode Ray (for e^-) → show beam of e^- bend in a specific charge/angle relationship that shows they are particles w/ mass.

3. Explain the difference between Schrödinger's orbitals and Bohr's electron orbits.

Schrödinger
- Probability Maps
  - Combine e^- cloud model w/ quantized energy level model
  - Where e^- are likely to be found (95%)

0 1s; 8 ∞ $2p_x$, $2p_z$

Bohr
- Planetary Orbital
  - e^- occupy quantized energy levels in ground orbital unless excited



4. What is the wavelength of light (nm) that has a frequency $4.62 \times 10^{14}\ s^{-1}$?

A) 1.54×10^{-3} nm B) 1.39×10^{23} nm (C) 649 nm) D) 1.07×10^{6} nm E) 932 nm

$c = \lambda f$

$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8 \frac{m}{s}}{4.62 \times 10^{14} \frac{1}{s}} = 6.49 \times 10^{-7} m \left(\frac{1 \times 10^9 nm}{1 m}\right) = 649\ nm$

5. The energy of a photon that has a wavelength of 12.3 nm is __________ J.

A) 2.72×10^{-50} (B) 1.62×10^{-17}) C) 4.42×10^{-23} D) 1.99×10^{-25} E) 1.51×10^{-17}

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

$12.3\ nm \left(\frac{1 m}{1 \times 10^9 nm}\right) = 1.23 \times 10^{-8} m$

$E = \frac{(6.62 \times 10^{-34} Js)(3.0 \times 10^8 \frac{m}{s})}{1.23 \times 10^{-8} m} = 1.62 \times 10^{-17} J$

6. The n = 5 to n = 3 transition in the Bohr hydrogen atom corresponds to the __________ of a photon with a wavelength of __________ nm.

A) absorption, 657 nm
B) emission, 657 nm
(C) emission, 1280 nm)
D) absorption, 1280 nm
E) emission, 389 nm

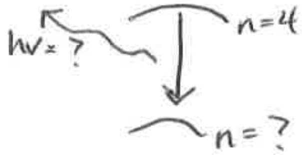
emission

Falling to n=3 will release a low energy wave in the IR range (low energy = long wave) according to the Paschen Series

7. A photon with a wavelength of 72.2 nm is emitted when an electron drops from n=4 to an unknown ground state.

↳ 7.22×10^{-8} m

a) How far apart, with respect to energy, are the levels the electron travelled between?



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

$$= \frac{(6.62 \times 10^{-34}\ \text{Js})(3.0 \times 10^{8}\ \frac{m}{s})}{7.22 \times 10^{-8}\ m} = \boxed{2.75 \times 10^{-18}\ \text{J}}$$

b) Which ground state level did the electron fall to? Support your answer.

- A 72.2 nm wave is a UV wave, which was emitted during this process
- High energy UV waves are emitted during the Lyman series, which describes e⁻ falling to an n=1 ground state.

c) Another electron in the atom absorbs a wavelength of 612nm, allowing it to jump from n=2 to n=3. Compare the energy of the 612nm wave to that of the 72.2nm wave and explain why each wave caused different excitation/emission jumps. (A complete answer will discuss Coulombic force)

$$E_{612} = \frac{hc}{\lambda} = \frac{(6.62 \times 10^{-34}\ \text{Js})(3.0 \times 10^{8}\ \frac{m}{s})}{6.12 \times 10^{-7}\ m} = \boxed{3.25 \times 10^{-19}\ \text{J}}$$

lower energy wave

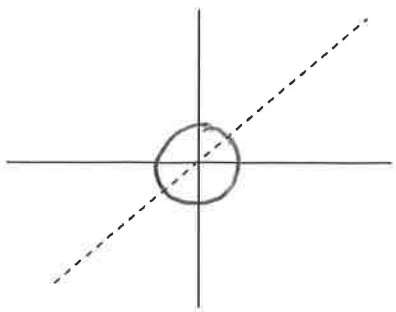
More energy is required to excited from n=1 to n=4 as an n=1 e⁻ is closer to the nucleus (↑F attraction per Coulomb's Law) and is not experiencing any shielding. Additionally, ~~and~~ an n=1 → n=4 jump is a farther distance of movement from the nucleus than n=2 → n=3 and should therefore require more energy.

PART B – QUANTUM NUMBERS

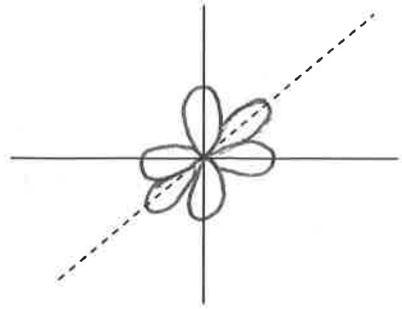
8. For each quantum number, list the symbol and give a brief description.

Quantum #	Symbol	Description
Principal	n	Energy Level (1, 2, 3, 4, etc)
Angular Momentum	l	Sublevel (s, p, d, f) s=0 p=1 d=2 f=3
Magnetic	m_l	Orbital (1s, $2p_x$, $2p_y$, $2p_z$, etc) from $-l$ to $+l$
Spin	m_s	e⁻ spin ($+\frac{1}{2}$ or $-\frac{1}{2}$)

9. Draw the shapes of the following types of orbitals:



s-orbital



p_{xyz}-orbitals

10. Explain why electrons are found as pairs in orbitals.

e^- would repel electrostatically due to similar charge (−) if they occupied similar space. They are allowed to pair due to opposing spins, creating opposing magnetic poles. A 3rd e^- would repel due to charge & similar poles (spin)

11. Complete the following table to indicate the total number of orbitals in each energy level (n). In the remaining columns, specify how many of those orbitals are s, p, d, and f.

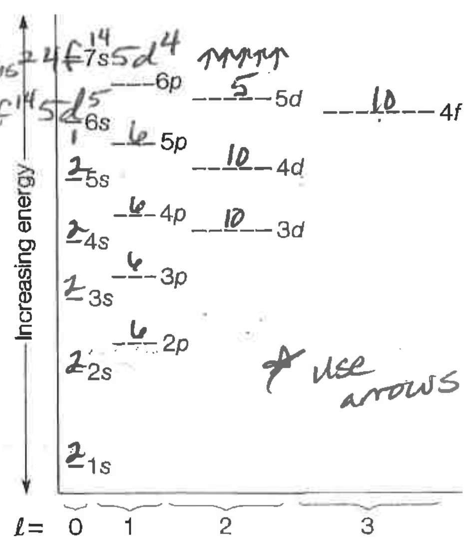
Level *n*	Total # of orbitals	# of *s*-orbitals	# of *p*-orbitals	# of *d*-orbitals	# of *f*-orbitals
1	1	1	—	—	—
2	4	1	3	—	—
3	9	1	3	5	—
4	16	1	3	5	7

12. a) Write out the full electron configuration for tungsten (W).

74 e^- wrong $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^4$

right $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^1 4f^{14} 5d^5$

b) Properly fill in the AUFBAU diagram to the right for tungsten (W).



c) Check your AUFBAU diagram in (b). Does it represent the most stable configuration? If yes, explain why it does. If no, correct the diagram and explain why you changed it.

An e^- would be borrowed from 6s to 5d to gain stability in the 5d sublevel by having it half full

Br = $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$

13. Which of the following quantum states is not possible for an electron of a neutral bromine atom?

A) 2, 1, -1, -1/2 ✓ B) 1, 0, 0, 1/2 ✓ C) 5, 4, - 3, 1/2 ✗ D) 5, 4, -3, -1/2 ✗ E) 3, 3, 3, ½ ✗

$2p_x$ ↓ (↓ _ _) 1s ↑ (↑) 5g (not in e⁻ config) 5g (not in e⁻ config) 3f (doesn't exist)

14. An electron cannot have the quantum numbers n = __________, l = __________, ml = __________.

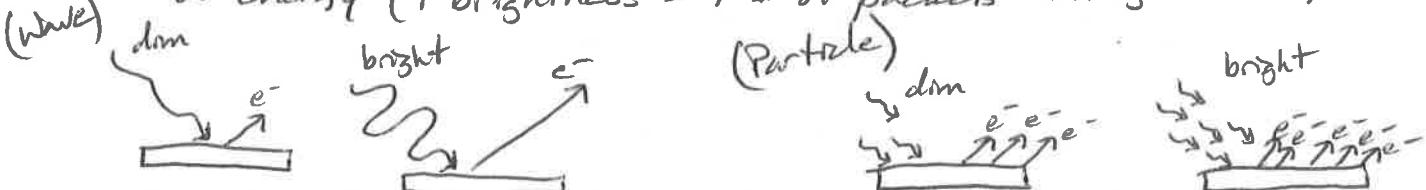
A) 1, 0, 0 ✓ B) 3, 2, (3) ✗ C) 6, 1, 0 ✓ D) 3, 2, -2 ✓ E) 3, 2, 1 ✓

1s 3d (-2 to +2) 6p 3d 3d

PART C – PHOTOELECTRIC EFFECT

15. Explain how the photoelectric effect provides evidence for the particle behavior of electromagnetic waves.

If EM waves behaved only as waves, increasing amplitude (brightness) should increase the amount of energy e⁻ are emitted with. Instead, it increases the # of e⁻ emitted, showing it is acting as a "packet" of energy (↑ brightness = ↑ # of "packets" hitting the sample



16. Identify and discuss what each function of the photoelectric effect equation represents.

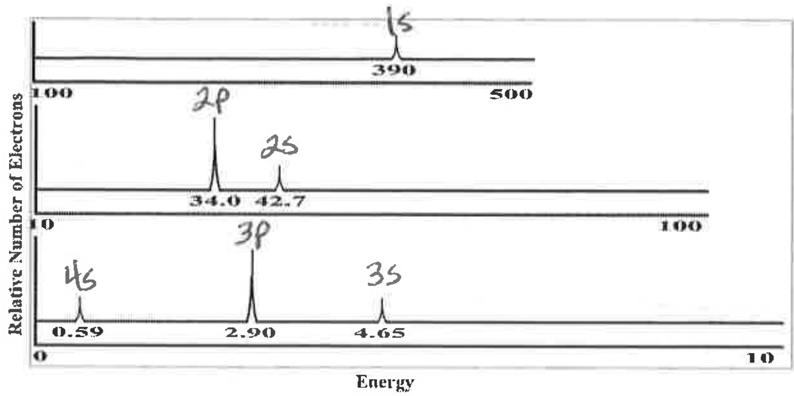
a. E_k Kinetic Energy - energy of motion (speed) the e⁻ leaves/escapes the sample with

b. E_B Binding Energy - how tightly the e⁻ is held by its nucleus, must be overcome to emit the e⁻

c. W_o Work Function - energy needed to escape (e⁻) the sample / overcome interaction with other atoms in the sample

d. hv Light Energy - energy the sample is exposed to in order to cause e⁻ emission (overcome E_B & W_o)
- valence e⁻ emission = UV
- core e⁻ emission = X-Ray

17. The following photoelectron spectroscopy data is collected for an unknown sample. The x-axis represents the binding energy (eV) of the electrons of this element.



a. Identify which sublevel each peak represents by labeling them on the graph.

b. Assuming the element is neutral, which element is represented by the spec data?

Ca (4s peak is same size as 1s, 2s, 3s = 2e⁻)

c. Explain why the 3s electrons experience a greater binding energy than the 4s electrons.

- closer to nucleus = ↓d = ↑F attraction
- less shielding = ↑q = ↑F attraction

d. Explain how the graph would change under the following scenarios.

i) A ion^{2+} of the same element is formed.

- 4s peak would disappear

ii) The neutral element with an atomic number of 21 is depicted instead.

- All peaks shift right (↑ binding energy due to ↑ p^+)
- New peak to left of 4s peak that is ½ its size

e. What is the minimum wavelength of light needed to eject a 4s electron for the element shown? The work function for your unknown is 2.9 eV.

↳ no left over energy ⇒ $E_K = 0$

$$E_K = E_{h\nu} - E_B - W_0$$

$$0 = E_{h\nu} - 0.59\,eV - 2.9\,eV$$

$$E_{h\nu} = 3.49\,eV\left(\frac{1.602\times10^{-19}\,J}{1\,eV}\right) = 5.59\times10^{-19}\,J$$

$$E_{h\nu} = \frac{hc}{\lambda}$$

$$5.59\times10^{-19}\,J = \frac{(6.62\times10^{-34}\,Js)(3.0\times10^{8}\,\frac{m}{s})}{\lambda}$$

$$\lambda = 3.35\times10^{-7}\,m\left(\frac{1\times10^{9}\,nm}{1\,m}\right) = \boxed{355\,nm}$$

$W_0 = 2.9\ eV = 4.65\times10^{-19}\ J$ $E_B = 2.90\ eV\left(\frac{1.602\times10^{-19}\ J}{1\ eV}\right) = 4.65\times10^{-19}\ J$

f. A 3p electron is emitted with a kinetic energy of 1.34 x 10^-18 J. What frequency of light was shone on the unknown sample?

$$1.34\times10^{-18}\ J = E_{h\nu} - 4.65\times10^{-19}\ J - 4.65\times10^{-19}\ J$$

$$E_{h\nu} = 2.27\times10^{-18}\ J$$

$$2.27\times10^{-18}\ J = \frac{(6.62\times10^{-34}\ Js)(3.0\times10^{8}\ \frac{m}{s})}{\lambda}$$

$$\lambda = 8.75\times10^{-8}\ m = \boxed{87.5\ nm}$$

g. An electron is emitted with a kinetic energy of 1.7 eV. If the sample was excited using a ~~1.23x10^-8~~ m wave, which sublevel did the electron come from?
2.62×10^{-8}

$$E_{h\nu} = \frac{(6.62\times10^{-34})(3.0\times10^{8})}{2.62\times10^{-8}\ m} = 7.58\times10^{-18}\ J = 47.3\ eV$$

$$1.7\ eV = 47.3\ eV - E_B - 2.9\ eV$$

$$E_B = 42.7\ eV$$

= 2s electron

h. What type was wave was likely used in part (g)? Explain your reasoning.

X-Ray; a core e⁻ was emitted, typically achieved with high energy XPS