Problem #1 (29%)

(a) In box notation, give the complete ground-state electron configuration of each of the following gas-phase species. You may use noble-gas abbreviations for the inner shells, if you wish.

(i) Mg^{2-}

[Ne] [↑↓] 3s [↑ | ↑ |] 3p

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(ii) Ne^{2+}

[He] [↑↓] 2s [↑↓ | ↑ | ↑] 2p

(b) Give the chemical identity of the species with these ground-state electron configurations:

(i) a neutral atom with $[Xe]4f^{14}5d^{10}6s^26p^3$

Bi

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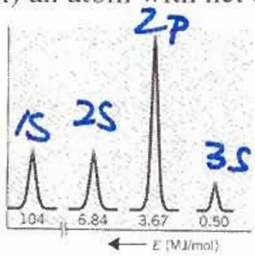
(ii) an atom with net charge 2– and $[Kr]5s^1$

Br^{2-}

(iii) an atom with net charge 2– and the PES spectrum shown



looks like $1s^2 2s^2 2p^6 3s^1 \Rightarrow n_e = 11$
with net charge $2- \Rightarrow n_p = 11 - 2 = 9$
$\therefore F^{2-}$

(c) For each of the following pairs, (1) identify the larger atom or ion and (2) give a brief explanation justifying your choice.

(i) Be and Be^{2+}

Be is larger with e^- configuration $[He]2s^2$ uses $n=2$ shell whereas $Be^{2+} \equiv [He]$ has electrons in only $n=1$ shell

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(ii) He and Be^{2+}

He is larger. both have same e^- configuration but Be^{2+} has $4p^+$ whereas He has $2p^+$ $\therefore$ Be^{2+} nucleus has stronger Coulombic pull on same no. e^-

(Problem #2 (14%)

(a) Sommerfeld introduced two new quantum numbers, *l* and *m*, to address certain shortcomings of the Bohr model. By invoking either *l* or *m*, explain the observation of Starck that in an applied electric field certain lines in the spectrum of atomic hydrogen appear to split into multiples.

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- invoke m to allow for degeneracy of p, d, & f orbitals
- under influence of magnetic field they become distinguishable

(b) Making reference to the underlying physical principle, describe how a beam of cadmium cations (Cd^+) would behave in the Stern-Gerlach experiment (passage of a beam of atoms through a divergent magnetic field).

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Cd^+ is isoelectronic with Ag which has unpaired e^- ∴ net magnetic moment

∴ in divergent magnetic field Cd^+ beam will split into two

Problem #3 (34%)

(a) Mercury vapor is analyzed by photoelectron spectroscopy (PES) using electromagnetic radiation of wavelength (λ) 9.15×10^{-8} m. Calculate the de Broglie wavelength (λ_e) of the photoelectrons associated with the first ionization energy.

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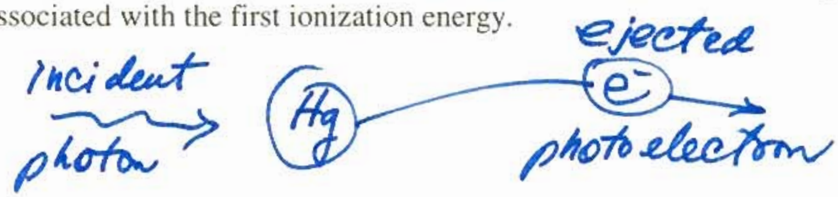

energy balance: $E_{incident\ photon} = E_{photoelectron} + E_{binding}$

$E_{incident\ photon} = \frac{hc}{\lambda}$; $E_{binding} = 1^{ST}$ I.E. of Hg

$E_{photoelectron} = \frac{1}{2}mv^2 = \frac{p^2}{2m}$ (where $\lambda_e = h/p$) $= \frac{h^2}{2m\lambda_e^2}$

$\therefore$ need to solve for λ_e

$\therefore \frac{hc}{\lambda} = IE + \frac{h^2}{2m\lambda_e^2} \Rightarrow \frac{h^2}{2m\lambda_e^2} = \frac{hc}{\lambda} - IE \Rightarrow \lambda_e = \frac{h}{\sqrt{2m\left(\frac{hc}{\lambda} - IE\right)}}$

$\therefore \lambda_e = \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31}\left(\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{9.15 \times 10^{-8}} - (10.437 \times 1.6 \times 10^{-19})\right)}} = 6.96 \times 10^{-10}\ m$

(b) In the emission spectrum of Li^{2+} calculate the lowest wavenumber ($\bar{\nu}$) involving electron transitions between n = 4, 5, and 6.

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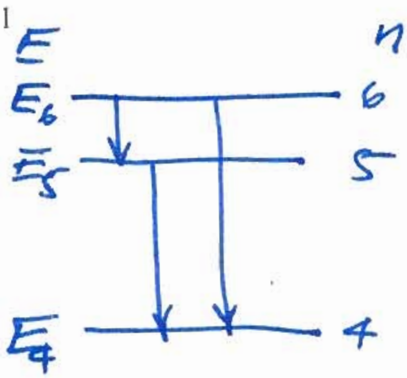

lowest $\bar{\nu} \Rightarrow$ smallest ΔE

$\therefore 6 \rightarrow 5$

$\bar{\nu} = RZ^2\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

$= 1.1 \times 10^7 (3)^2 \left(\frac{1}{5^2} - \frac{1}{6^2}\right)$

$= 1.21 \times 10^6\ m^{-1}$

Problem #4 (23%)

The reaction of sodium (Na) with tantalum pentachloride ($TaCl_5$) at 300°C can produce tantalum (Ta) along with sodium chloride (NaCl). A reactor is charged with 999 kg of $TaCl_5$ and 222 kg of sodium, and the reaction is driven to completion. Calculate how much of each species is present at the end of the reaction. Express your answer in kg.

$5Na + TaCl_5 \rightarrow Ta + 5NaCl$

A.W. Ta = 180.95   M.W. $TaCl_5$ = 358.20
Na = 22.99   NaCl = 58.44
Cl = 35.45

999 kg $TaCl_5$ + 222 kg Na
⇓ ÷ by MW.   ⇓ ÷ by MW.
2789 moles   9656 moles

2789 : 9656 = 1 : 3.46 < 1 : 5 ∴ not enough Na to reduce all $TaCl_5$ ⇒ Na is ltg. reagent

∴ assume 100% consumption of Na

⇒ 9656 moles Na will reduce enough $TaCl_5$ to produce 9656 moles NaCl = <u>564 kg NaCl</u>
and 1/5 × 9656 moles Ta = <u>349 kg Ta</u>

leaving (2789 − (1/5 × 9656)) moles $TaCl_5$ = 858 moles $TaCl_5$
= <u>307 kg $TaCl_5$</u>

check 999 + 222 = 1221

307 + 349 + 564 = 1221 ✓