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) Na^{3-}

6 [Ne] [↑↓] 3s [↑|↑|↑] 3p

(ii) Na^{3+}

[He] [↑↓] 2s [↑↓|↑|↑] 2p

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

(i) a neutral atom with $[Xe]4f^{14}5d^{10}6s^{2}6p^{2}$

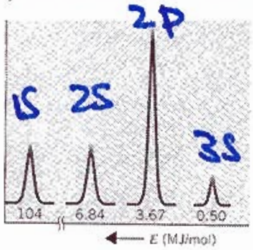
Pb

9

(ii) an atom with net charge 3– and $[Ar]3d^{10}4s^{2}4p^{6}$

As^{3-}

(iii) an atom with net charge 4+ and the PES spectrum shown



looks like $1s^2 2s^2 2p^6 3s^1 \Rightarrow n_e = 11$
with net charge 4+ $\Rightarrow n_p = 11 + 4 = 15$
$\therefore P^{4+}$

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

(i) K and K^+ K is larger [Ar]$4s^1$ uses n=4 shell

14 whereas K^+ is [Ar] only n=3 shell

(ii) Ar and K^+ both have same e^- configuration [Ar]
but K^+ has 19 p^+ whereas Ar has 18 p^+
$\therefore$ K^+ nucleus has stronger coulombic pull on same no. e^- $\Rightarrow$ Ar is larger

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 Michelson and Morley that in atomic hydrogen the line associated with the transition from n = 3 to n = 2 is in fact a doublet (pair of lines at almost identical wavelength).

7

invoke l which allows for s & p orbitals within same shell ⇒ slight difference in energy compared to Bohr value for $\Delta E_{3 \Rightarrow 2}$

e.g. $\Delta E_{3p \rightarrow 2}$ & $\Delta E_{3s \rightarrow 2}$

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

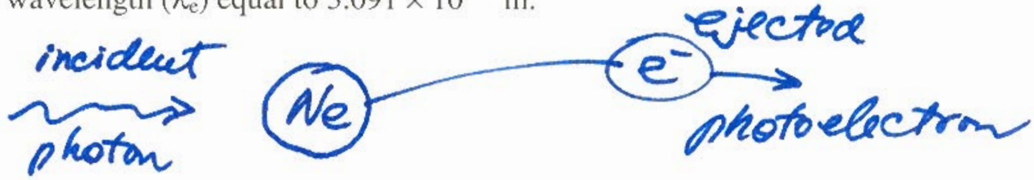
7

Pd^- is isoelectronic with Ag which has unpaired e^- ∴ net magnetic moment ∴ in divergent magnetic field Pd^- beam will split into two

Problem #3 (34%)

(a) The first ionization energy of neon is determined by photoelectron spectroscopy (PES). Calculate the wavenumber ($\bar{\nu}$) of incident radiation that will result in the production of photoelectrons with de Broglie wavelength (λ_e) equal to 3.091×10^{-10} m.

23



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

$E_{incident\ photon} = hc\bar{\nu}$ $\quad E_{binding} = 1^{st}$ I.E. of Ne

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

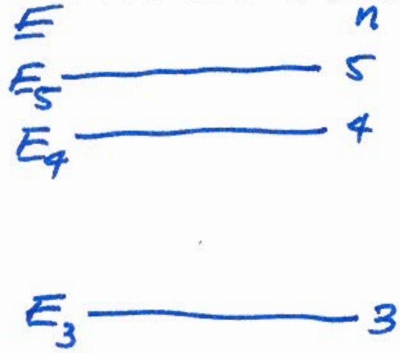
$$hc\bar{\nu} = \frac{h^2}{2m\lambda_e^2} + I.E. \Rightarrow \bar{\nu} = \left(\frac{h^2}{2m\lambda_e^2} + I.E.\right)/hc$$

$$\therefore \bar{\nu} = \left[\frac{(6.6\times10^{-34})^2}{2\times9.11\times10^{-31}\times(3.091\times10^{-10})^2} + (21.564\times1.6\times10^{-19})\right] \Big/ (6.6\times10^{-34}\times3\times10^{8})$$

$$= 3.00\times10^{7}\ m^{-1}$$

(b) In the emission spectrum of He^+ calculate the shortest wavelength (λ) involving electron transitions between n = 3, 4, and 5.

11



shortest $\lambda \Rightarrow$ greatest ΔE

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

$$= \left[1.1\times10^{7}(2)^2\left(\frac{1}{3^2} - \frac{1}{5^2}\right)\right]^{-1}$$

$$= 3.20\times10^{-7}\ m$$

Problem #4 (23%)

The reaction of alumina (Al_2O_3) with carbon (C) can produce aluminum (Al) along with carbon monoxide (CO). A reactor is charged with 99.9 kg of Al_2O_3 and 22.2 kg of carbon, 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.

$$Al_2O_3 + 3C \rightarrow 2Al + 3CO$$

A.W. $Al = 26.98$ $Al_2O_3 = 101.96$
$O = 16.00$
$C = 12.01$ $CO = 28.01$

99.9 kg Al_2O_3 + 22.2 kg C
⇓ ÷ by MW ⇓ ÷ by AW
980 moles 1848 moles

980 : 1848 = 1 : 1.89 < 1 : 3 ∴ not enough C to reduce all the Al_2O_3 present
⇒ C is ltg. reagent
∴ assume 100% consumption of C
1848 moles C will reduce enough Al_2O_3 to produce $\frac{2}{3}$ × 1848 moles of Al = <u>33.24 kg Al</u>

and 1848 moles CO = <u>51.76 kg CO</u>

leaving $\left(980 - \left(\frac{1}{3} \times 1848\right)\right)$ moles Al_2O_3

= 364 moles Al_2O_3 = <u>37.11 kg Al_2O_3</u>

check 99.9 + 22.2 = 122.1 kg
37.11 + 51.76 + 33.24 = 122.1 kg ✓