3.091 OCW Scholar

Self-Assessment Exam
Structure of the Atom

Solution Key

2009 Test #1, Problem #1

Uranium metal can be produced by the reaction of uranium tetrafluoride (UF_4) with magnesium (Mg) in a sealed reactor heated to 700ºC. The by-product is magnesium fluoride (MgF_2). To ensure that all the magnesium is consumed in the reaction, the reactor is charged with excess UF_4, specifically 10% more than the stoichiometric requirement of the reaction. To produce 222 kg of U, how much UF_4 must be introduced into the reactor? Assume complete conversion of Mg. Express your answer in kg.

$UF_4 + 2Mg \rightarrow U + 2MgF_2$

$222 \text{ kg U} = \frac{222\times10^3 \text{ g}}{238 \text{ g/mol}} = 933 \text{ mol U}$

stoichiometry of rxn dictates 1 mol UF_4 needed to make 1 mol U

∴ to provide UF_4 at 10% excess requires

$1.1 \times 933 \text{ mol} = 1026 \text{ mol}$

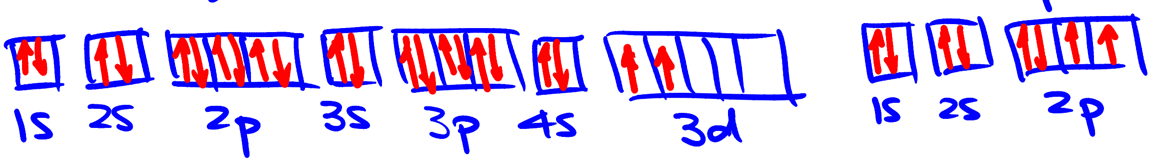
molecular mass of $UF_4 = 238 + 4\times19 = 314 \text{ g}$

∴ mass of UF_4 needed is $\frac{1026\times314}{1000} = 322 \text{ kg}$

2009 Test #1, Problem #2

(a) In box notation, give the complete electron configuration of each of the following gas-phase species:

(i) Ca^{2-} [Ar] $4s^2 3d^2$ (ii) Mg^{4+} [He] $2s^2 2p^4$



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

(i) a neutral atom with $[Xe]4f^{14}5d^{10}6s^{2}6p^{1}$ (ii) an atom with net charge 4+ and $[Ar]3d^3$

Tl Mn^{4+}

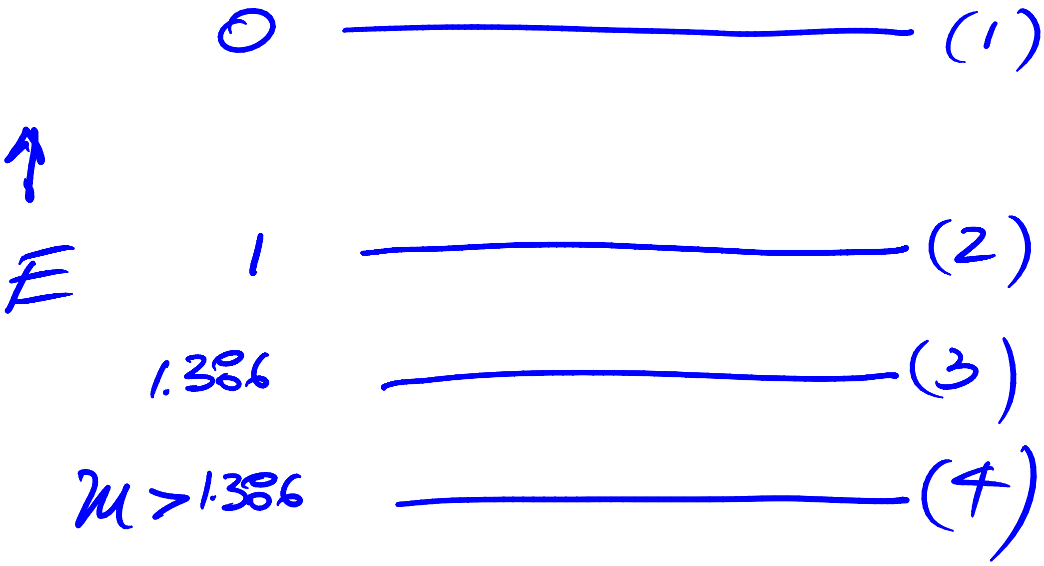
(c) Write the quantum numbers (*n, l, m, s*) of ***one*** of the 3*d* and ***one*** of the 4*s* electrons in iron (Fe).

$(3, 2, m, s)$ where $m = \pm2, \pm1, 0$; $s = \pm\frac{1}{2}$

$(4, 0, 0, s)$ where $s = \pm\frac{1}{2}$

2009 Test #1, Problem #4

For a given cation, C, and anion, A, show the following four energy states on the same energy-level diagram: (1) ions at infinite separation; (2) ion pair CA; (3) ion line CACACA…; (4) crystalline solid of CA. Assume that the comparison is based upon identical numbers of ions in all four states. The diagram need not be drawn to scale; however, you must convey relative values of the different energy states.



2009 Test #1, Problem #6

Atoms of ionized helium gas (He^+) are struck by electrons in a gas discharge tube operating with the potential difference between the electrodes set at 8.88 V. The emission spectrum includes the line associated with the transition from n = 3 to n = 2. Calculate the minimum value of the de Broglie wavelength of scattered electrons that have collided with He^+ and generated this line in the emission spectrum.

excitation of e^-s in He^+ from $n=2$ to $n=3$ requires

$$\Delta E = KZ^2\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = 13.6(2)^2\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = 7.56\,eV$$

ballistic e^-s traveling b/w electrodes have K.E. in the amount of $qV = (e)(8.88\,V) = 8.88\,eV$

$\therefore$ after excitation of e^-s within He^+, ballistic e^-s are scattered with residual K.E.

$8.88 - 7.56 = 1.32\,eV$

$\Rightarrow$ de Broglie wavelength is $\lambda = \frac{h}{p} = \frac{h}{mv}$

$$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2}$$

$$\therefore \lambda = \frac{h}{(2mE)^{1/2}}$$

$$= \frac{6.6\times10^{-34}}{(2\times9.11\times10^{-31}\times1.32\times1.6\times10^{-19})^{1/2}}$$

$$= 1.06\times10^{-9}\,m$$

2009 Test #2, Problem #2

(a) You discover that someone has been using your x-ray generator and has changed the target/anode. To determine the chemical identity of the new target, you go ahead and operate the x-ray generator and find the wavelength, λ, of the K_α peak to be 0.250 Å. What element is the target made of?

$$\bar{\nu}_{K_\alpha} = \frac{3}{4}R(Z-1)^2 = \frac{1}{\lambda} \Rightarrow Z = 1 + \left(\frac{4}{3\lambda R}\right)^{1/2}$$

$$\therefore Z = 1 + \left(\frac{4}{3\times 2.50\times 10^{-10}\times 1.1\times 10^{7}}\right)^{1/2} = 23$$

∴ The element is V (vanadium)

(b) Hilary Sheldon conducts an experiment with her x-ray diffractometer. A specimen of tantalum (Ta) is exposed to a beam of monochromatic x-rays of wavelength set by the K_α line of titanium (Ti). Calculate the value of the smallest Bragg angle, θ_{hkl}, at which Hilary can expect to observe reflections from the Ta specimen.

DATA: λ_{K_α} of Ti = 2.75 Å; lattice constant of Ta, a = 3.31 Å

$\lambda = 2d\sin\theta$ ∴ smallest θ is associated with the largest d spacing

Ta is BCC ∴ $h+k+l$ even ∴ largest (hkl) is $(011) \Rightarrow \theta = \sin^{-1}\left(\frac{\lambda}{2d}\right)$ where $d = \frac{a}{(h^2+k^2+l^2)^{1/2}} = \frac{3.31}{(0+1+1)^{1/2}} = 3.31/\sqrt{2}$

$$= \sin^{-1}\left(\frac{2.75}{2\times \frac{3.31}{\sqrt{2}}}\right) = 36^\circ$$

(c) Sketch the emission spectrum (intensity *versus* wavelength) of an x-ray target that has been bombarded with ***photons*** instead of with electrons. Assume that the incident photons have more than enough energy to dislodge K-shell electrons in the target. On your spectrum label the features associated with K_α radiation, K_β radiation, and L_α radiation.

with photons, expect to see characteristic lines but NO BREMSSTRAHLUNG ∴ interaction between photons & atoms of target causes no photon deflection