CH3771 Nuclear Chemistry Final Exam

(January 26, 2017)

- You will have 3 hours to complete this exam.
- Use of slides or book is not allowed
- Please add your name and student number on each sheet that you use and number the sheets
- Please do not use a pencil to write your answers
- You MUST show your work in order to receive any partial credit for incorrect answers.
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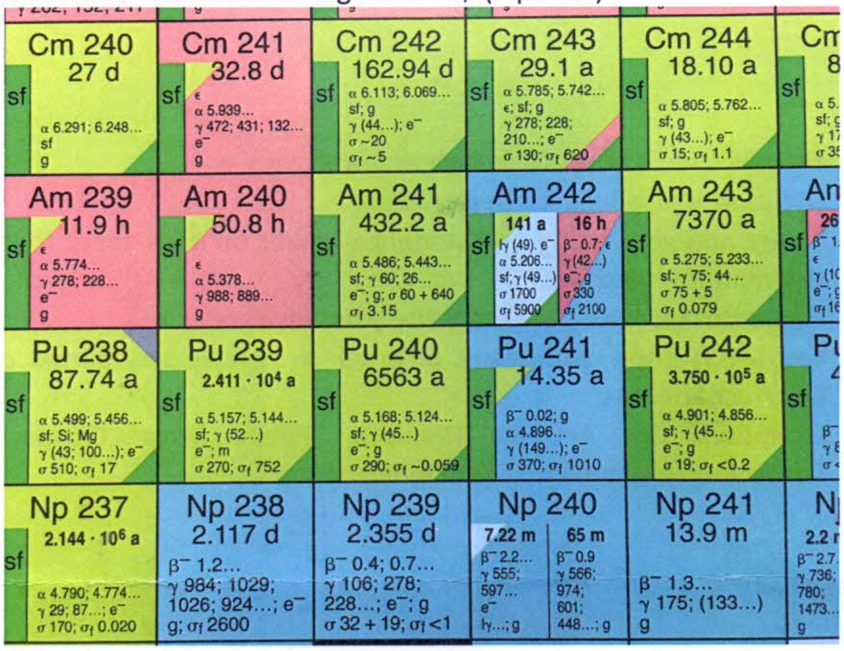
GOOD LUCK!

Question 1

To produce 2.5 kBq of ^{241}Am, 1 g of ^{239}Pu are irradiated for 30 days in a nuclear reactor ($\phi=10^{15}$cm^{-2}s^{-1}).

a) Write a scheme of all reactions and decays taking place, that are relevant for calculating the production yield of ^{241}Am. All data that you need is available in the nuclide chart shown below. The cross section for (n,γ) reactions is given as σ. The fission cross section is given as σ_f. (2 points)



b) Write down the exact formula needed to calculate the production yield of ^{241}Am when irradiating ^{239}Pu with neutrons. To derive this you can use the general formula used for such calculations given below (not obligatory, you can also start from scratch). The final unit of the yield should be activity (Bq). (1 point)

$$N_n = C_1 e^{-\Lambda_1 t} + C_2 e^{-\Lambda_2 t} + \cdots C_n e^{-\Lambda_n t}$$

$$C_1 = \frac{\Lambda_1^* \Lambda_2^* \ldots \Lambda_{n-1}^*}{(\Lambda_2 - \Lambda_1)(\Lambda_3 - \Lambda_1)\ldots(\Lambda_n - \Lambda_1)} N_1^0$$

$$C_2 = \frac{\Lambda_1^* \Lambda_2^* \ldots \Lambda_{n-1}^*}{(\Lambda_1 - \Lambda_2)(\Lambda_3 - \Lambda_2)\ldots(\Lambda_n - \Lambda_2)} N_1^0$$

...

$$C_n = \frac{\Lambda_1^* \Lambda_2^* \ldots \Lambda_{n-1}^*}{(\Lambda_1 - \Lambda_n)(\Lambda_2 - \Lambda_n)\ldots(\Lambda_{n-1} - \Lambda_n)} N_1^0$$

c) Calculate or give the value of all constants (e.g. Λ_n, Λ^*_n, N_1^0, t, λ) that are needed for the equation you have given in b). Give them in the units you would use for the calculation. (3 points)

Question 2

In 100g of a uranium containing mineral 0.06 cm^3 of Helium (at 0°C) were found. The uranium content of the mineral was 3 ppm. How old was the mineral? (^{238}U, natural abundance 99.275%, $t_{1/2}=4.468\times10^9$ a) (2 points)

Question 3

The radionuclide $^{64}_{29}Cu$ is unstable ($t_{1/2}$=12.7h).

a) Which of the following 4 decays will it decay by: electron capture, beta minus emission, beta plus emission or alpha emission? <u>For each decay type write the balanced equation.</u> Given: m_n=1.008664 amu, M_{He}= 4.002603 amu, m_e= 5.485799x10^{-4} amu and the table below. (3 points)

b) What type of medical application can ^{64}Cu be used for? (1 point)

c) What other applications outside medicine are possible? (1 point)

Table B.1. Atomic mass tables *(cont.)*

N	Z	A	El	Atomic Mass (μu)	N	Z	A	El	Atomic Mass (μu)	N	Z	A	El	Atomic Mass (μu)
30	31		Ga	60 949170	40	27		Co	66 940610	38	34		Se	71 927112
29	32		Ge	60 963790	39	28		Ni	66 931570	37	35		Br	71 936500
28	33		As	60 980620	38	29		Cu	66 927750	36	36		Kr	71 941910
39	23	62	V	61 973140	37	30		Zn	66 927130.9	35	37		Rb	71 959080
38	24		Cr	61 955800	36	31		Ga	66 928204.9	45	28	73	Ni	72 946080
37	25		Mn	61 947970	35	32		Ge	66 932738	44	29		Cu	72 936490
36	26		Fe	61 936770	34	33		As	66 939190	43	30		Zn	72 929780
35	27		Co	61 934054	33	34		Se	66 950090	42	31		Ga	72 925170
34	28		Ni	61 928348.8	32	35		Br	66 964790	41	32		Ge	72 923459.4
33	29		Cu	61 932587	42	26	68	Fe	67 952510	40	33		As	72 923825
32	30		Zn	61 934334	41	27		Co	67 944360	39	34		Se	72 926767
31	31		Ga	61 944180	40	28		Ni	67 931845	38	35		Br	72 931790
30	32		Ge	61 954650	39	29		Cu	67 929640	37	36		Kr	72 938930
29	33		As	61 973200	38	30		Zn	67 924847.6	36	37		Rb	72 950370
40	23	63	V	62 976750	37	31		Ga	67 927983.5	35	38		Sr	72 965970
39	24		Cr	62 961860	36	32		Ge	67 928097	46	28	74	Ni	73 947910
38	25		Mn	62 949810	35	33		As	67 936790	45	29		Cu	73 940200
37	26		Fe	62 940120	34	34		Se	67 941870	44	30		Zn	73 929460
36	27		Co	62 933615	33	35		Br	67 958250	43	31		Ga	73 926940
35	28		Ni	62 929672.9	43	26	69	Fe	68 957700	42	32		Ge	73 921178.2
34	29		Cu	62 929601.1	42	27		Co	68 945200	41	33		As	73 923929.1
33	30		Zn	62 933215.6	41	28		Ni	68 935180	40	34		Se	73 922476.6
32	31		Ga	62 939140	40	29		Cu	68 929425	39	35		Br	73 929891
31	32		Ge	62 949640	39	30		Zn	68 926553.5	38	36		Kr	73 933260
30	33		As	62 963690	38	31		Ga	68 925581	37	37		Rb	73 944470
40	24	64	Cr	63 964200	37	32		Ge	68 927972	36	38		Sr	73 956310
39	25		Mn	63 953730	36	33		As	68 932280	47	28	75	Ni	74 952970
38	26		Fe	63 940870	35	34		Se	68 939560	46	29		Cu	74 941700
37	27		Co	63 935814	34	35		Br	68 950180	45	30		Zn	74 932940
36	28		Ni	63 927969.6	33	36		Kr	68 965320	44	31		Ga	74 926501
35	29		Cu	63 929767.9	43	27	70	Co	69 949810	43	32		Ge	74 922859.5
34	30		Zn	63 929146.6	42	28		Ni	69 936140	42	33		As	74 921596.4
33	31		Ga	63 936838	41	29		Cu	69 932409	41	34		Se	74 922523.6
32	32		Ge	63 941570	40	30		Zn	69 925325	40	35		Br	74 925776
31	33		As	63 957570	39	31		Ga	69 926028	39	36		Kr	74 931034
41	24	65	Cr	64 970370	38	32		Ge	69 924250.4	38	37		Rb	74 938569
40	25		Mn	64 956100	37	33		As	69 930930	37	38		Sr	74 949920
39	26		Fe	64 944940	36	34		Se	69 933500	48	28	76	Ni	75 955330
38	27		Co	64 936485	35	35		Br	69 944620	47	29		Cu	75 945990
37	28		Ni	64 930088.0	34	36		Kr	69 956010	46	30		Zn	75 933390
36	29		Cu	64 927793.7	44	27	71	Co	70 951730	45	31		Ga	75 928930
35	30		Zn	64 929245.1	43	28		Ni	70 940000	44	32		Ge	75 921402.7
34	31		Ga	64 932739.3	42	29		Cu	70 932620	43	33		As	75 922393.9
33	32		Ge	64 939440	41	30		Zn	70 927727	42	34		Se	75 919214.1
32	33		As	64 949480	40	31		Ga	70 924705.0	41	35		Br	75 924542
31	34		Se	64 964660	39	32		Ge	70 924954.0	40	36		Kr	75 925948
41	25	66	Mn	65 960820	38	33		As	70 927115	39	37		Rb	75 935071

31	19		K	49 972780	36	19	55	K	54 999390	28	31		Ga	58 963370
30	20		Ca	49 957518	35	20		Ca	54 980550	27	32		Ge	58 981750
29	21		Sc	49 952187	34	21		Sc	54 967430	38	22	60	Ti	59 975640
28	22		Ti	49 944792.1	33	22		Ti	54 955120	37	23		V	59 964500
27	23		V	49 947162.8	32	23		V	54 947240	36	24		Cr	59 949730
26	24		Cr	49 946049.6	31	24		Cr	54 940844.2	35	25		Mn	59 943190
25	25		Mn	49 954244.0	30	25		Mn	54 938049.6	34	26		Fe	59 934077
24	26		Fe	49 962990	29	26		Fe	54 938298.0	33	27		Co	59 933822.2
23	27		Co	49 981540	28	27		Co	54 942003.1	32	28		Ni	59 930790.6
22	28		Ni	49 995930	27	28		Ni	54 951336	31	29		Cu	59 937368.1
34	17	51	Cl	51 013530	26	29		Cu	54 966050	30	30		Zn	59 941832
33	18		Ar	50 993240	25	30		Zn	54 983980	29	31		Ga	59 957060
32	19		K	50 976380	36	20	56	Ca	55 985790	28	32		Ge	59 970190
31	20		Ca	50 961470	35	21		Sc	55 972660	27	33		As	59 993130
30	21		Sc	50 953603	34	22		Ti	55 957990	39	22	61	Ti	60 982020
29	22		Ti	50 946616.0	33	23		V	55 950360	38	23		V	60 967410
28	23		V	50 943963.7	32	24		Cr	55 940645	37	24		Cr	60 954090
27	24		Cr	50 944771.8	31	25		Mn	55 938909.4	36	25		Mn	60 944460
26	25		Mn	50 948215.5	30	26		Fe	55 934942.1	35	26		Fe	60 936749
25	26		Fe	50 956825	29	27		Co	55 939843.9	34	27		Co	60 932479.4
24	27		Co	50 970720	28	28		Ni	55 942136	33	28		Ni	60 931060.4
23	28		Ni	50 987720	27	29		Cu	55 958560	32	29		Cu	60 933462.2
34	18	52	Ar	51 998170	26	30		Zn	55 972380	31	30		Zn	60 939514

Question 4

List 2 positive and 2 negative aspects of iNAA. (1 Point)

Question 5

In the last decade alpha radionuclide therapy is being used more and more in the fight against cancer.

a) Explain <u>from a biological point of view</u> if alpha particles are suitable for cancer treatment (HINT: think of LET, tracks and kind of damage caused by alpha particles). Compare briefly with photon radiation. (2 points)
b) Which alpha emitting radionuclide are most often used? (1 point)
c) Explain what the recoil effect is and propose a possible solution (2 points)

Question 6

The Mossbauer effect is only possible when there is recoilless emission and absorption of a gamma photon.

a) Calculate the recoil energy of a single ^{57}Fe atom upon the emission of a gamma photon of 14.4 keV. (1 point)
b) Based on the obtained result explain why the Mossbauer effect can only happen in solids. (Tip: The natural line width of the gamma emission is of the order of 10^{-8} eV) (2 points)

Question 7

The hospital has decided to purchase a $^{99}Mo/^{99m}Tc$ generator from a different supplier that claims that their generator is cheaper and better. Your boss has entrusted you, the nuclear chemist, with the task of checking the quality of the generator.