(6 pts) 1. Provide the following information for $^{134}$Xe$^{+14}$.

1 point  a. Atomic number $54$

1 point  b. Number of nucleons $114$

1 point  c. Number of electrons $40$

2 points  d. From looking at your periodic table, would you expect this nucleus to be radioactive or stable?  

If radioactive, what kind of decay will this nuclide undergo? $\beta^+$ or $\beta^-$.

1 point  e. What is the geometric cross-section of this nucleus? Show all your work. (Use $r_0 = 1.20 \text{ fm}$)

$$R = r_0 A^{1/3} = (1.2 \text{ fm})(114)^{1/3}$$

$$R = 5.81 \text{ fm}$$

$$A = \pi r^2$$

$$A = 106.05 \text{ fm}^2$$

(10 pts) 2. A target of $^{13}$C is bombarded with a 60 MeV $^{20}$O beam which has an intensity of $1.0 \times 10^4$ particles per second. The target is $43 \mu m$ thick. If the cross-section for fusing the oxygen and carbon nuclei together to form silicon is 100 millibarns, what is the reaction rate? (The density of $^{13}$C (graphite) is 2.3 g/cm$^3$.)
(10 pts) 3. Describe in detail the principle of operation of each of the following accelerators. Use equations and well labeled diagrams as necessary.

a) tandem Van de Graaf

\[ \Delta E_{\text{total}} = (lq+l^2) e \Delta V \]

- Constant \( E \) field
- Two stage acceleration

\[ \frac{\chi^2}{\Delta V} \rightarrow \frac{\chi^2}{\Delta V} \rightarrow \text{Beam} \rightarrow \text{DC} \]

\[ \Delta E_1 = lq e \Delta V \]
\[ \Delta E_2 = Ze \Delta V \]

Total energy gain = \( \Delta E = \Delta E_1 + \Delta E_2 = (lq+l^2) e \Delta V \)
b) linear accelerator

\[ \Delta E = \Delta V \times \text{gen} \]

- no acceleration in drift tubes
- \( \Delta V \) between tubes accelerate particle
- all drift tubes are pulsed at some frequency (RF)
- drift tubes get longer as particle accelerates
  (particles reach gaps at same time)
(10 pts) 4. Use the graph below to determine:

   a) the thickness of Al (density=2.7 g/cm³) necessary to stop a 40 MeV proton
   b) What is the range in aluminum of a 600 MeV ^12C ion?

   Show all of your work

\[ \begin{align*}
\text{Graph} & \quad \text{Range (mg cm}^{-2}) \quad F_r \text{ or } E_r / A \text{ (MeV)} \\
0 & \quad 20,000 \quad 10 \quad 20 \quad 30 \quad 40 \\
20,000 & \quad 30,000 \quad 2,000 \quad 3,000 \quad 4,000 \\
10,000 & \quad 20,000 \quad 0.74 \text{ cm} \\
5,000 & \quad 10,000 \quad 0.37 \text{ cm}
\end{align*} \]

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5,000 & \quad 10,000 \quad 0.37 \text{ cm}
\end{align*} \]

\[ \begin{align*}
\text{(a)} & \quad \rho \text{Al} = 2.7 \text{ g/cm}^3 \quad 40 \text{ MeV proton} \quad \text{range} = 2,000 \text{ mg/cm}^2 \\
& \quad \frac{2000 \text{ mg/cm}^2}{2700 \text{ mg/cm}^2} = 0.74 \text{ cm}
\end{align*} \]

\[ \begin{align*}
\text{(b)} & \quad R = \frac{A_z}{Z_i^2} \left( \frac{E_i}{A_i} \right) \quad \frac{R_p (E_i/A_i)}{6} = \frac{1}{3} R_p (50 \text{ MeV}) = \frac{1}{3} (3,000 \text{ mg/cm}^2) \\
& \quad R = 1000 \text{ mg/cm}^2 \quad \frac{1000 \text{ mg/cm}^2}{2700 \text{ mg/cm}^2} = 0.37 \text{ cm}
\end{align*} \]
(12 pts) 5. Which feature(s) of the liquid-drop model best explains the following?

a. Nuclear fission is less probable for $^{252}_{98}$Cf than $^{266}_{106}$Sg
   - $^{266}$Sg is less stable due to: Coulomb term

b. $^{40}_{20}$Ca has a higher average binding energy than $^{24}_{12}$Mg
   - $^{24}_{12}$Mg is less stable due to: surface term

c. $\Delta(^{100}_{44}\text{Ru}) = -89.21$ MeV; $\Delta(^{114}_{50}\text{Cd}) = -74.24$ MeV
   - $^{114}$Cd is less stable due to: Coulomb term

(10 pts) 6. Calculate the total binding energy and the average binding energy for each of the following nuclides.

$$TBE = Z\Delta_H + N\Delta_n - \Delta(Z\chi)$$
$$\langle BE \rangle = \frac{TBE}{A}$$

a. $^7$Li
   - $TBE = 3(7.289) + 4(8.07) - 14.908$ [MeV]
   - $TBE = 39.243$ MeV
   - $\langle BE \rangle = 5.6$ MeV

b. $^{197}$Au
   - $TBE = 79(7.289) + 118(8.07) - (-31.157)$ [MeV]
   - $TBE = 1559.37$ MeV
   - $\langle BE \rangle = 7.92$ MeV
(10 points) 7. Answer the questions below with respect to the figure shown above. All of the nuclides shown have $A=128$.

a. If I start with a sample of $^{128}\text{La}$, what will happen (i.e. what do I observe)?

$$^{128}\text{La} \xrightarrow{\text{decay}} ^{128}\text{Ba} \xrightarrow{\text{decay}} ^{128}\text{Ca} \xrightarrow{\text{decay}} ^{128}\text{Xe}$$

Stops at the stable Xe.

b. If I start with a sample of $^{128}\text{Sn}$, what will happen (i.e. what do I observe)?

$$^{128}\text{Sn} \xrightarrow{\text{decay}} ^{128}\text{Sb} \xrightarrow{\text{decay}} ^{128}\text{Te}$$

Stops at the stable Te.

c. If I start with a sample of $^{128}\text{Te}$, what will happen (i.e. what do I observe)?

Nothing happens. Stays $^{128}\text{Te}$.

d. What term in the liquid drop formula can be thought of as “causing these changes to occur”?

Charge term and asymmetry term

e. Why are there two parabolas? Which parabola is the upper parabola and which is the lower parabola?

Two parabolas because it's a plot of even $A$ nuclei.

Top parabola is odd–odd case,
Bottom parabola is even–even case.
(8 pts) 8. A) Write the balanced nuclear reaction for the alpha decay of $^{222}$Rn.

B) Given that the mass excess for an alpha particle is 2.425 MeV, calculate the $Q$ value of the reaction? (You may find the excerpt from the Nuclear wallet cards appended helpful).

C) Is this reaction spontaneous? Why or why not. (explain your answer).

D) What will the observed energy of the alpha particle be?

\[ \text{Q} = \text{Q}_{\text{reactant}} - \text{Q}_{\text{product}} \]
\[ Q = 16.366 - 2.425 - 8.351 \text{ [MeV]} \]
\[ Q = 5.59 \text{ MeV} \]

(12 pts) 9. The nuclide $^{164}X$ is observed to decay by alpha decay to a stable nucleus. Alpha particles with energies of 5.400 MeV, 4.700 MeV, and 4.200 MeV are measured by an enterprising C460 student. She measures one third as many 4.700 MeV alpha particles as 5.4 MeV alpha particles and half as many 4.200 MeV alpha particles as 4.7 MeV alpha particles.

a) Write a balanced equation expressing this decay. Be sure to be as exact as possible.

\[ ^{164}X \rightarrow ^4\text{He} + ^{160}Y \]

b) Draw as detailed a spectrum as possible of the emitted alpha particles. For simplicity you can neglect recoil effects (momentum conservation).
c) Draw the level diagram associated with this decay mode. Be sure to be as detailed as possible using all the information you are given.

\[ \begin{align*}
\text{Parent} &\quad (\; X \; ) \\
\text{Daughter} &\quad (\; Y \; )
\end{align*} \]

\[ \begin{align*}
\alpha_1 &= 4.2 \text{ MeV} \\
\alpha_2 &= 4.7 \text{ MeV} \\
\alpha_3 &= 5.4 \text{ MeV}
\end{align*} \]

(8 pts) 10. Describe in detail one type of detector (you choose a reasonable type) that the enterprising student in Problem #9 could use to measure the alpha particles. Keep in mind that the student needs to not only detect the alphas but needs to measure their energies accurately. Your answer can include well labeled diagrams as the operating principle of the detector is described.
(4 pts) 11. What is the maximum energy nitrogen ions that a 13 MV Tandem Van de Graaf can accelerate to?

\[ \Delta V = 13 \text{ MV} \]

\[ \Delta E = (1\text{-}1\text{H}+\text{Z})e\Delta V \]

\[ q = -1 \]

\[ \Delta E = (1\text{-}1\text{H}+7)e(13 \text{ MV}) \]

\[ \Delta E = 8(13 \text{ MeV}) \]

\[ \Delta E = 104 \text{ MeV} \]