

### Sample questions for Quiz 3, 22.101 (Fall 2006)

Following questions were taken from quizzes given in previous years by S. Yip. They are meant to give you an idea of the kind of questions (what was expected from the class in previous times) that have been asked in the past. Percentage credit is indicated for each question based on 100% for a 90-min Quiz (closed book). Problem numbering means nothing here.

You will have to decide for yourself what connections, if any, there may be between these questions and the Quiz 3 that will be conducted on Dec. 13, 2006.

#### Problem 1 (20%)

Define concisely what is Compton scattering. Derive the relation between incident gamma energy  $\hbar\omega$  and scattered gamma energy  $\hbar\omega'$  for Compton scattering which also involves the scattering angle  $\theta$ . What is the similarity (and difference) between this relation and the corresponding relation involving incident and scattered energies in neutron elastic scattering?

#### Problem 2 (30%)

Consider the measurement of monoenergetic gammas (energy  $\hbar\omega$ ) in a scintillation detector whose size is small compared to the mean free path of the secondary gammas produced by interactions of the incident (primary) gammas in the detector.

(10%) (a) Sketch the pulse-height spectrum of low-energy gammas, say  $\hbar\omega < 500$  keV. Explain briefly the important characteristics of this spectrum in terms of the different interactions that can take place.

(10%) (b) Repeat (a) for higher-energy gammas,  $\hbar\omega > 2$  MeV.

(10%) (c) What other peaks can appear in the pulse-height spectrum if the detector were not small? Give a sketch and explain briefly.

#### Problem 3 (30%)

(15%) (a) You are told the reaction  $^{13}\text{C}(d,p)^{14}\text{C}$  has a resonance at a deuteron energy  $E_d$  (LCS), and following this,  $^{14}\text{C}$  undergoes  $\beta$ -decay to  $^{14}\text{N}$ . Draw the energy level diagram for this situation in which you show explicitly how the following energies can be calculated in terms of known masses and  $E_d$ : (1) kinetic energy available for reaction  $T_0$ , (2) Q value for the reaction, (3) deuteron separation energy, (4) proton separation energy, and (5)  $Q_\beta$ .

(15%) (b) On the basis of (a), predict whether or not the reaction  $^{11}\text{B}(\alpha,n)^{14}\text{N}$  will have a resonance, and if so, at what energy of the  $\alpha$  particle this will occur. (Since you are not

given numerical values, you should leave your answer in terms of defined quantities such as masses and various energies.)

Problem 4 (20%)

Sketch the energy variation of an observed resonance in (a) neutron elastic scattering (resonance scattering in the presence of potential scattering), and (b) neutron inelastic scattering. Comment on the characteristic features in the cross sections, especially the low-energy behavior below the resonance. What is the connection between the energy at which the observed cross sections show a peak and the energy of the nuclear level associated with the resonance? (You may assume it is the same level in both cases.)

Problem 5 (20%)

Sketch the peaks that one would observe in the pulse-height spectra of a small detector in the presence of a 2-Mev gamma ray source, including any radiation from the background. For each peak identify the radiation interaction process that gives rise to it and indicate the energy at which this peak would appear.

Problem 6 (25%)

Consider the compound nucleus reaction of inelastic scattering of neutrons at energy  $T_1$  (LCS) by a nucleus  ${}^A_ZX$ .

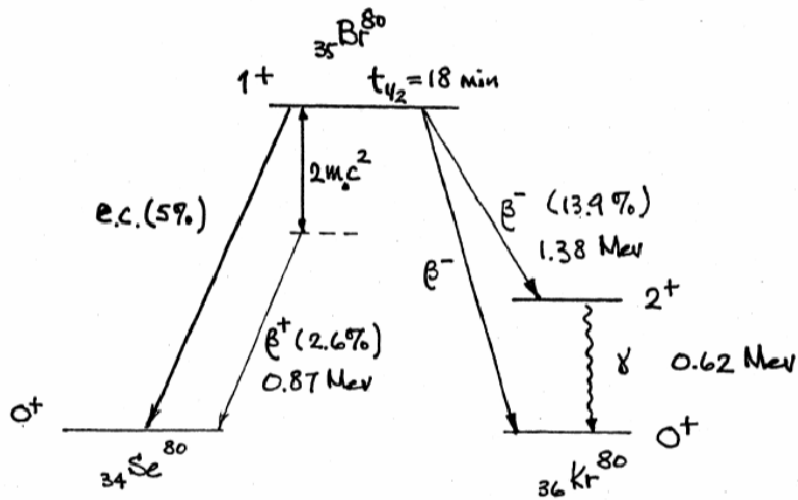
- Draw the energy level diagram showing the different energies that one can use to describe this reaction (including the Q value).
- Write down the corresponding Breit-Wigner cross section in terms of some of the energies shown in (a). Define all the parameters appearing in your expression.

Problem 7 (10%)

Consider the reaction  $a + b \rightarrow c + d$ , where Q is nonzero and particle b is stationary. What can you say about the magnitude and direction of the velocity of the center-of-mass before and after the reaction?

Problem 8 (20%)

The decay scheme of  ${}^{80}\text{Br}$  is shown below. Classify the various decay modes and estimate all the decay constants that you can.



Problem 9 (15%)

At time  $t = 0$  you are given an atom that can decay through either of two channels, a and b, with known decay constants  $\lambda_a$  and  $\lambda_b$ . Find the probability that it will decay by channel a during the time interval between  $t_1$  and  $t_2$ , with  $t_1$  and  $t_2$  arbitrary. Interpret your result.

Problem 10 (20% total)

Consider a beam of collimated, monoenergetic neutrons (energy  $E$ ) incident upon a thin target (density  $N$  atoms per cc) of area  $A$  and thickness  $\Delta x$  at a rate of  $I$  neutrons/sec. Assume the cross sectional area of the beam is greater than  $A$ . An energy sensitive detector subtended at an angle  $\theta$  with respect to the incident beam direction is set up to measure the number of neutrons per second scattered into a small solid angle  $d\Omega$  about the direction  $\underline{\Omega}$  and into a small energy interval  $dE'$  about  $E'$ . Let this number be denoted by  $\Pi$ .

- (15%) Define the double (energy and angular) differential scattering cross section  $d^2\sigma/d\Omega dE'$  in terms of the physical situation described above such that you relate this cross section to the scattering rate  $\Pi$  and any other quantity in the problem. (You may find it helpful to draw a diagram of the specified arrangement.)
- (5%) How is  $d^2\sigma/d\Omega dE'$  related to the angular and energy differential cross sections,  $d\sigma/d\Omega$  and  $d\sigma/dE'$ , respectively (no need to define the latter, assume they are known)?

Problem 11 (25%)

In neutron elastic scattering by hydrogen where the target nucleus is assumed to be at rest, the ratio of final to initial neutron energy is  $E'/E = (1/2)(1 + \cos \theta_c)$ , where  $\theta_c$  is the scattering angle in CMCS. Suppose you are told the angular distribution of the scattered neutrons is proportional to  $\cos \theta_c$  for  $0 \leq \theta_c \leq \pi/2$  and is zero for all other values of  $\theta_c$ . Find the corresponding energy distribution  $F(E \rightarrow E')$ . Sketch your result and discuss how it is different from the case of isotropic angular distribution.

Problem 12 (20% total)

Give a brief and concise answer to each of the following.

- (a) (7%) What is the physical picture of the model used to estimate the decay constant in alpha decay (give sketch). Why does the model give an upper limit for the decay constant?
- (b) (4%) What is electron capture and with what process does it compete?
- (c) (4%) What is internal conversion and with what process does it compete?
- (d) (5%) Give a sketch of the variation of the neutron cross section of C in the energy region below 0.1 Mev and explain the features.

Problem 13 (20%)

In neutron radiation damage studies an incident neutron with energy E collides with an atom in the crystal lattice, called the primary knock-on atom (PKA), causing it to recoil and displace a number of other atoms in the solid.

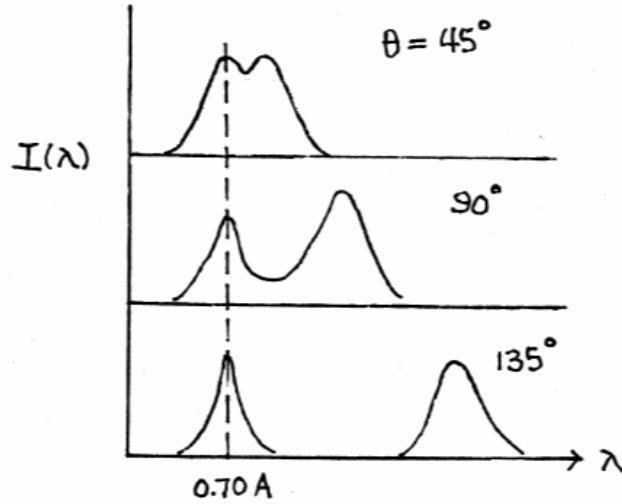
- (a) (8%) Calculate the average recoil energy of the PKA (mass A). State all assumptions involved in your calculation.
- (b) (12%) Let the number of atoms displaced by a PKA with energy T be denoted by  $\nu(T)$  which behaves as follows

$$\begin{aligned} \nu(T) &= 0 && \text{for } 0 < T < E_d \\ &= T/2E_d && E_d < T < L_c \end{aligned}$$

where  $E_d$  is the energy to displace an atom, and  $L_c$  is the energy above which all the energy loss is by electronic excitation. Find the average number of atoms displaced as a function of E in the range,  $0 < E < L_c$ . Call this quantity  $N_E$ . (Note: Neither  $\nu$  nor  $N_E$  are distributions.)

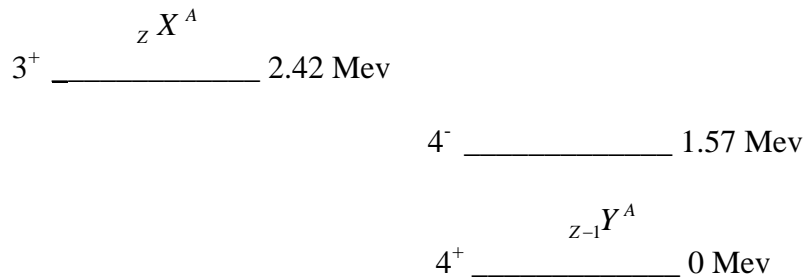
Problem 14 (15%)

When a beam of photons with wavelength  $0.7 \text{ \AA}$  is scattered by carbon at various scattering angles, the observed spectra behave in a way as sketched schematically. What is the process responsible for the peak at  $0.7 \text{ \AA}$ ? What is the process responsible for the other peak in the spectrum? Comment on the variation with scattering angle of the two peaks.



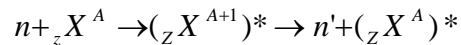
Problem 15 (20%)

For the energy-level diagram shown below, identify all the transitions that can take place. For each transition determine the decay mode and the decay energy (Q-value).



Problem 16 (15%)

Consider neutron inelastic scattering at incident energy  $T_1$  (LCS) where the reaction can be written as



Is the Q-value positive or negative? Draw the energy-level diagram depicting the kinetic and rest-mass energies involved in the reaction, and show how the kinetic energies are related to  $T_1$  and any other energies in the problem. You may assume target nucleus is at rest.

Problem 17 (30% total, 6% each)

Give a short and concise answer to each of the following questions

- (a) Suppose you are detecting a  $\gamma$ -ray at energy  $\hbar\omega = 2$  Mev using a large scintillation detector. Sketch the energy distribution that you would observe, indicating both the origin and position (the energy on a linear energy scale) of each peak.
- (b) Sketch (as quantitatively as you can) the mass attenuation of lead for  $\gamma$ -rays with energy from 0.01 Mev to 100 Mev, showing the individual contributions from the various processes of interaction.
- (c) Sketch the model used for calculating the decay constant for  $\alpha$ -decay (no calculation), and explain the energies and distances in your sketch.
- (d) Sketch the distributions of neutron energies for neutron elastic scattering at energy E by target nuclei with mass A in a medium at temperature T, for  $E/k_B T = 0.1, 1, \text{ and } 4$ .
- (e) Sketch the total cross section of water for neutron energies from 0.001 ev to 10 ev. Explain the meaning of free-atom and bound-atom cross sections and indicate where they would appear in your sketch.

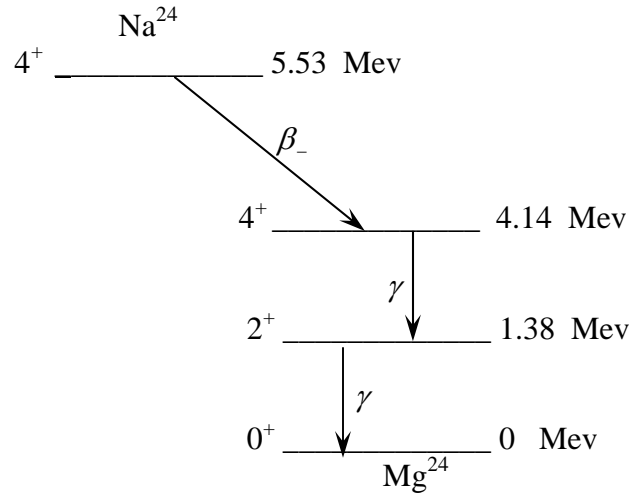
Problem 18 (25%)

- (a) (15%) Angular differential cross sections (in CMCS) for  $C^{12}$  (left panel) and  $U^{238}$  (right panel) for two incident neutron energies, 0.5 Mev and 14 Mev, are shown below. Interpret (explain) all the features, including the difference between carbon and uranium.



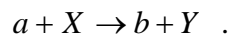
Mev, but in addition two groups of positrons with distinct end-point energies are also observed. There were no  ${}_{10}\text{Ne}^{24}$  found.

- (8%) What could be the process giving rise to the positrons?
- (8%) What are the expected end-point energies of the two positron groups?
- (9%) What are the decay modes for the indicated transitions?



Problem 21 (25% total, 5% each) Give short and concise answer to each question.

- Sketch first the neutron scattering probability  $F(E \rightarrow E')$  as a function of  $E'/E$  for the conditions of elastic scattering, target nucleus (mass  $M$ ) at rest, and scattering is isotropic in CMCS. Then in the same sketch show what happens when the target is no longer at rest (consider several ratios of  $E/k_B T$ , where  $T$  is the target temperature).
- Sketch the mass attenuation coefficient of Pb for gamma radiation in the energy range 0.01 Mev to 100 Mev, showing the individual contributions from the various interactions considered in class.
- Explain the Gamow factor and its significance in describing nuclear decay.
- State the condition on the kinetic energy of the incoming particle ( $T_a$ ) which is necessary and sufficient for the indicated reaction to occur (take  $T_X = 0$ ),



- Draw the energy level diagram for the indicated reaction showing all the energies involved

$$n+_z X^A \rightarrow (_z X^{A+1})^* \rightarrow n'+(_z X^A)^* .$$