Announcements

1. Reminder – two more presentation sessions –

   Friday (today) 4 PM

   Sunday 1:30 PM

2. Changed HW's 31 & 32 due date to 4/30/03

3. Today's topics – nuclear physics

   Nuclear reactions

   Nuclear radiation

Products of nuclear decay

$\alpha \equiv {}^4_2He^{++}$

$\beta \equiv e^-$ or e^+

$\gamma \equiv$ (photon)

also –

${}^1_0n$ (neutron)

${}^1_1p$ (proton)

ν (neutrino)

Rate of nuclear decay $$\left|\frac{dN}{dt}\right| = \lambda N = \frac{\ln 2}{T_{1/2}} N$$

1 Ci = 3.7 x 10^{10} decays/s

1 Bq = 1 decay/s

Effects of radiation in matter

Release of energetic particles –

α, n, p → move atoms in materials

e^-, e^+, γ → remove or excite electrons

→ cause chemical reactions

Quantitative measures of radiation dose

rad ("radiation absorbed dose"): amount of radiation that increases the energy of 1kg of absorbed materials by 0.01 J.

gray (Gy): 1 Gy = 100 rad

RBE ("relative biological effectiveness" factor): ratio of biological damage of radiation type to that of γ rays

rem ("radiation equivalent in man"): rad x RBE

sievert (Sv): 1 Sv = 100 rem

Some RBE factors

Radiation type	RBE
γ rays	1
β particles	1-1.7
n (slow)	4-5
n & p (fast)	10
α particles	10-20
heavy ions	20

Some typical values of dose

Source	Dose
Background radiation	0.13 rem/year
Recommended limit	0.5 rem/year
Diagnostic chest X-ray	0.01 rem
Mammogram	0.1 rem
Fatal dose	400-500 rem

Example: (from your text)

A sealed capsule containing the radiopharmaceutical ${}^{32}_{15}P$ with an initial radioactivity of 5.22×10^6 Bq, is implanted into a 0.1 kg tumor. Each decay produces e^- particles at an energy of 7×10^5 eV. Determine the absorbed dose in a 10 day period. $T_{1/2}$ =14.26 days. Assume all emitted particles are absorbed.

dose = RBE x (number of decays) x (energy released)/mass

RBE → 1

number of decays → $N_0\left(1-\left(\frac{1}{2}\right)^{10/14.26}\right)$

energy released → $7 \times 10^5 \times 1.6 \times 10^{-19}$ J

mass → 0.1 kg

$$N_0 = \left|\frac{dN}{dt}\right|_0 \Big/ \frac{\ln 2}{T_{1/2}} = 5.22 \times 10^6 \Big/ \frac{\ln 2}{14.26 \times 86400} = 9.2785 \times 10^{12}$$

dose = 4 J/kg = 400 rem = 4 Sv

Guide to nuclear reactions

General rules

Total A (number of nucleons (Z+N)) is conserved

Total charge is conserved

protons and neutrons can convert to each other

$$n \rightarrow p + e^{-} + \bar{\nu}$$ ← antineutrino

$$p \rightarrow n + e^{+} + \nu$$ ← neutrino

(e^{+}: positron)

Neutrinos were first detected in 1956 by Fred Reines and George Cowan, who showed that a nucleus undergoing beta decay emits a neutrino with the electron. Neutrinos are VERY weakly interacting and recent evidence suggests they have a mass of < 0.1 eV.

Examples of nuclear reactions

$^{14}_{6}C \rightarrow ^{14}_{7}N + e^{-} + \bar{\nu}$ Used for carbon dating

$$T_{1/2}\left(^{14}_{6}C\right) = 5730 \text{ yrs.}$$

$^{7}_{4}Be + e^{-} \rightarrow ^{7}_{3}Li + \nu$ Nucleus captures an electron

$^{11}_{6}C \rightarrow ^{11}_{5}B + e^{+} + \nu$ Positron emission

$^{12}_{5}B \rightarrow ^{12}_{6}C^{*} + e^{-} + \bar{\nu}$

$^{12}_{6}C^{*} \rightarrow ^{12}_{6}C + \gamma$

Beta decay followed by gamma decay

More nuclear reactions

$${}^{1}_{1}H + {}^{7}_{3}Li \rightarrow 2 \cdot {}^{4}_{2}He$$

Energy accounting :

for a general reaction of the type a+X→Y+b

energy released as kinetic energy of the products can be calculated:

$$Q=(M_a+M_X-M_Y-M_\beta)c^2$$

In this case, $Q=(1.007825+7.016003-2*4.002602)\ c^2$

$=17.348$ MeV

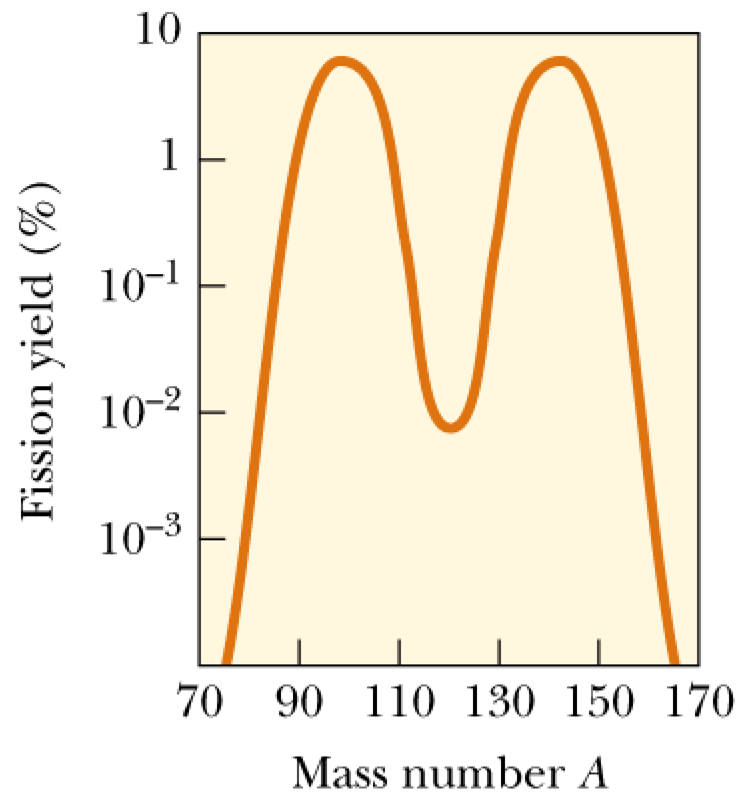
More nuclear reactions

$${}^{1}_{1}H + {}^{19}_{9}F \rightarrow \boxed{?} + {}^{4}_{2}He$$

$${}^{1}_{1}H + {}^{19}_{9}F \rightarrow {}^{16}_{8}O + {}^{4}_{2}He$$

Nuclear fission

$$n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3n$$



Peer instruction question

Which of the following reactions is not possible?

$$(A)\, n + {}^{235}_{92}U \rightarrow {}^{140}_{54}Xe + {}^{94}_{38}Sr + 2n$$

$$(B)\, n + {}^{235}_{92}U \rightarrow {}^{132}_{50}Sn + {}^{101}_{42}Mo + 3n$$

$$(C)\, n + {}^{239}_{94}Po \rightarrow {}^{127}_{53}I + {}^{93}_{41}Nb + 3n$$

Other fission reactions

$$n + {}^{238}_{92}U \rightarrow {}^{239}_{92}U \rightarrow {}^{239}_{93}Np + e + \overline{\nu}$$

$$ {}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + e + \overline{\nu}$$

"Natural abundances of U"

${}^{238}{}_{92}U$	99.27%	$T_{1/2}$=4.47x10^9 yr
${}^{235}{}_{92}U$	0.72%	$T_{1/2}$=7.04x10^8 yr