8.1 Solid-state, nuclear and particle models

Name: _____ Class: _____ Date: _____ **Total: 10 marks**

KEY WORDS band gap • half-life

Objective

Use band and carrier descriptions; Apply radioactive decay and binding-energy ideas; Check conservation laws in particle reactions. Original public practice; not an ETS paper.

1 Key knowledge and worked examples

Filled bands cannot carry ordinary current without accessible nearby states. Metals have partially filled or overlapping bands; semiconductors have a small band gap . Donor and acceptor doping change carrier populations.

Fermi–Dirac occupancy is 1/[exp((E−μ)/(kT))+1]. At zero temperature it becomes a step at the Fermi energy; thermal broadening does not make every state half occupied.

Radioactive populations obey N=N0e^(−λt), activity λN and half-life ln2/λ. Binding energy comes from a mass deficit multiplied by c^2; compare binding energy per nucleon when discussing stability.

Nuclear and particle processes must conserve charge, energy, momentum and the applicable quantum numbers. Beta decay includes a neutrino or antineutrino; a two-body electron-only story cannot explain its continuous energy spectrum.

■ Worked method

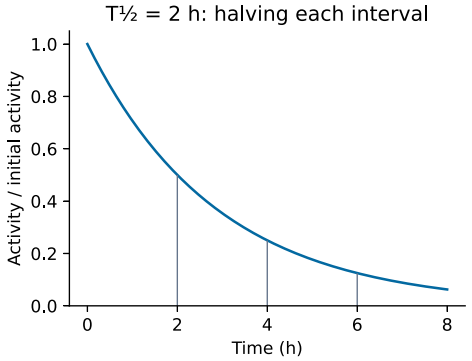
Binding energy is the positive energy required to separate a nucleus into free nucleons. For a reaction use total initial and final rest masses, with a consistent mass convention.

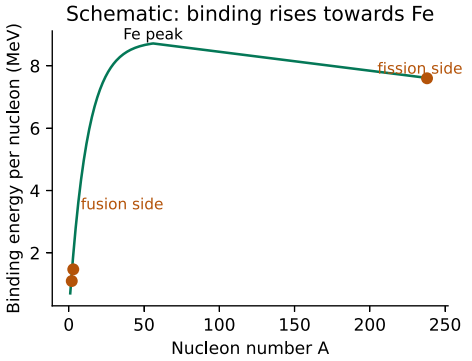
$$Q = (M_i - M_f)c^2.$$

A mass decrease of 0.0040 atomic mass units gives

$$Q = \Delta M c^2 = (0.0040\,\mathrm{u})(931.5\,\mathrm{MeV/u}) = 3.73\,\mathrm{MeV}.$$

Positive Q means energy release. Charge, nucleon number, energy and momentum must still balance; Q alone does not establish a reaction rate.





2 Practice

2.1 Choose one answer. After two half-lives, the remaining fraction is: [1]

- **A** 1/2
- **B** 1/4
- **C** 1/8

2.2 Choose one answer. Donor doping commonly supplies: [1]

- **A** additional electron carriers
- **B** only photons
- **C** no mobile carriers

2.3 After four half-lives, one part in _____ remains. Show your relation and units. [2]

2.4 Decide whether this claim is true. Justify it: Charge conservation alone is sufficient to validate any particle reaction. [2]

3 Exam-style questions

3.1 A neutral stationary parent nucleus decays into two neutral fragments with masses m and 3m. Released kinetic energy is Q, small compared with either rest energy. Find each fragment's kinetic energy and speed ratio. [4]