

Solid-state, nuclear and particle models

GRE undergraduate preparation · local supported objectives

Choose the physical question

Reasoning

A semiconductor's conductivity depends on available states and carriers, not merely on the number of electrons in the material. Use band and carrier descriptions Apply radioactive decay and binding-energy ideas Check conservation laws in particle reactions

Choose the system and model

Reasoning

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.

Use the governing relation

Reasoning

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

Apply the conditions

Reasoning

Radioactive populations obey $N = N_0 e^{-\lambda t}$, activity λN and half-life $\ln 2 / \lambda$. Binding energy comes from a mass deficit multiplied by c^2 ; compare binding energy per nucleon when discussing stability.

Check the conclusion

Reasoning

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 reasoning 1

Reasoning

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.

Worked relation 2

Reasoning

Apply this relation only under the conditions just stated.

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

Worked reasoning 3

Reasoning

A mass decrease of 0.0040 atomic mass units gives

Worked relation 4

Reasoning

Apply this relation only under the conditions just stated.

$$Q = \Delta Mc^2 = (0.0040 \text{ u})(931.5 \text{ MeV/u}) = 3.73 \text{ MeV}.$$

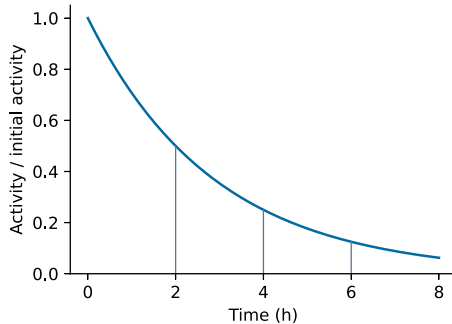
Worked reasoning 5

Reasoning

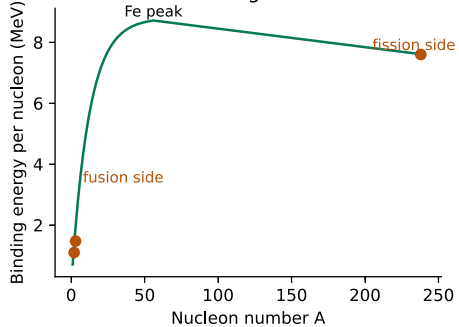
Positive Q means energy release. Charge, nucleon number, energy and momentum must still balance; Q alone does not establish a reaction rate.

Read the original diagram

$T_{1/2} = 2$ h: halving each interval



Schematic: binding rises towards Fe



- Original GRE teaching diagram: Solid-state, nuclear and particle models
- Identify the axes, units, directions and the stated model.

Independent transfer · attempt

Reasoning

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]**

Independent transfer · reasoning

Reasoning

Momentum conservation gives equal and opposite momenta of magnitude p . Nonrelativistic energies are $K_1 = p^2/(2m)$ and $K_2 = p^2/(6m)$, hence ratio 3:1. Their sum is Q , so $K_1 = 3Q/4$ and $K_2 = Q/4$. Speeds obey $v_1/v_2 = (p/m)/(p/(3m)) = 3$. Award momentum, energy ratio, partition and speed ratio. Equal momentum does not mean equal energy.

Check assumptions and limits

Reasoning

Activity and surviving population both decay, but their units differ: activity is transitions per second.

Keep the technical distinctions

Reasoning

band gap : An energy interval with no allowed bulk electronic states in the band model. half-life : Time for a radioactive population to halve.

Check yourself

- Define band gap and give its condition of use.
- Define half-life and give its condition of use.
- Redo the original transfer with a changed parameter; check a limiting case.