

Nuclear binding, particle families and Hall carriers

GRE undergraduate preparation · local supported objectives

Choose the physical question

Reasoning

Measuring conductivity alone does not tell you whether electrons or holes dominate transport. A magnetic Hall measurement provides a sign-sensitive test. Compare binding energy per nucleon and reaction energy Distinguish leptons, mesons and baryons with conservation constraints Infer dominant carrier sign from the one-carrier Hall model

Choose the system and model

Reasoning

Binding energy B is the energy needed to separate a nucleus into its constituent free nucleons, equal to the corresponding mass deficit times c^2 . Binding energy per nucleon B/A is the relevant comparison across different mass numbers; a heavier nucleus can have greater total B but lower B/A . The broad B/A maximum is near the iron/nickel region. Light-nucleus fusion and very-heavy-nucleus fission can release energy when products have greater total binding. For a reaction, $Q = (\text{initial rest mass} - \text{final rest mass})c^2$; positive Q means released energy. Always compare the actual specified isotopes and final products, not just their element names.

Use the governing relation

Reasoning

Leptons such as electrons, muons and neutrinos are not made of constituent quarks in the Standard Model. A negative muon has charge $-e$ and spin $1/2$, like an electron, but has a different mass and belongs to a different flavour family; it is not a meson despite its historical name. Hadrons contain quarks: ordinary mesons have one quark and one antiquark, and ordinary baryons have three quarks. Corresponding antibaryons have three antiquarks. These elementary classification models do not imply every composite particle is a simple baryon or meson.

Apply the conditions

Reasoning

Check charge, energy, momentum, baryon number and relevant lepton numbers in a proposed process. A proton's uud quarks sum to charge $+e$; neutron udd sums to zero. Beta-minus decay $n \rightarrow p + e^- + \bar{\nu}_e$ conserves electric charge and includes the antineutrino to balance lepton number and kinematics. A particle's mass alone does not classify it as a quark, lepton or hadron. Reaction thresholds may require kinetic energy beyond an exothermic rest-mass difference when other constraints apply.

Check the conclusion

Reasoning

In a simple one-carrier conductor, transverse magnetic Lorentz force builds a Hall electric field until transverse carrier force balances. With a stated tensor/sign convention, Hall coefficient is $R_H = 1/(nq)$; negative q gives electron-like negative coefficient, positive q gives hole-like positive coefficient. Resistivity magnitude alone does not reveal this sign. Set current, magnetic field and voltage directions consistently before reading raw polarity. Semiconductors with electrons and holes both contributing require a mobility-weighted two-carrier model; the simple coefficient need not equal the inverse total carrier density.

Worked reasoning 1

Reasoning

In a one-carrier Hall effect model, use $R_H = 1/(nq)$ with a fixed lead convention. For electrons, $q = -e$, $n = 5.0 \times 10^{22}$ per cubic metre,

Worked relation 2

Reasoning

Apply this relation only under the conditions just stated.

$$R_H = -\frac{1}{ne} = -\frac{1}{(5.0 \times 10^{22} \text{ m}^{-3})(1.60 \times 10^{-19} \text{ C})} = -1.25 \times 10^{-4} \text{ m}^3/\text{C}.$$

Worked reasoning 3

Reasoning

Negative coefficient indicates electron-like carriers under this model, not a negative density. Raw voltage polarity is meaningful only with declared field and lead directions.

Read the original diagram

Particle families in the ordinary constituent model

Examples	Ordinary constituent model	Family
Electron / muon	None	Lepton
Pion / kaon	Quark + antiquark	Meson
Proton / neutron	Three quarks	Baryon

- Original GRE teaching diagram: Nuclear binding, particle families and Hall carriers
- Identify the axes, units, directions and the stated model.

Independent transfer · attempt

Reasoning

For neutron beta-minus decay, verify electric charge, baryon number and electron-lepton number for $n \rightarrow p + e^- + \bar{\nu}_e$. Explain why omitting the antineutrino fails and why a continuous electron spectrum is compatible with energy conservation.

[4]

Independent transfer · reasoning

Reasoning

Charge: $0 = 1 - 1 + 0$. Baryon number: $1 = 1 + 0 + 0$. Electron-lepton number: $0 = 0 + 1 - 1$. Omitting the antineutrino violates the latter balance and leaves incorrect two-body kinematics. Three final bodies share available energy in different proportions while conserving total energy/momentum in each event. Award each conservation check and spectrum/omission explanation.

Check assumptions and limits

Reasoning

Compare binding per nucleon, not just total binding. A muon is a lepton, and Hall sign requires the declared measurement convention and carrier model.

Keep the technical distinctions

Reasoning

binding energy per nucleon	: Nuclear binding energy divided by
nucleon count. Hall coefficient	: Signed proportionality relating transverse
Hall field to current density and magnetic field under a stated convention.	

Check yourself

- Define binding energy per nucleon and give its condition of use.
- Define Hall coefficient and give its condition of use.
- Redo the original transfer with a changed parameter; check a limiting case.