

Nuclear binding, particle families and Hall carriers

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Measuring conductivity alone does not tell you whether electrons or holes dominate transport. A magnetic Hall measurement provides a sign-sensitive test.

Prerequisites: 8, 46.

- 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

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

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

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 $n \rightarrow p + e^- + \text{antineutrino}$ 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

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 method

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,

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

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.

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

Nuclear binding, particle families and Hall carriers: original GRE teaching diagram.

Check conditions and vocabulary

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

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.