

# 25.1 Nuclear binding, particle families and Hall carriers

Name: \_\_\_\_\_ Class: \_\_\_\_\_ Date: \_\_\_\_\_ **Total: 10 marks**

**KEY WORDS** binding energy per nucleon • Hall coefficient

## Objective

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. Original public practice; not an ETS paper.

## 1 Key knowledge and worked examples

Binding B is the nucleon mass deficit times  $c^2$ ; compare B/A across mass numbers. Its broad maximum lies near iron/nickel. Light fusion or heavy fission can release energy by increasing total binding. Reaction  $Q=(\text{initial} - \text{final rest mass})c^2$  requires the specified isotopes/products, not just element names.

Leptons include electrons, muons and neutrinos without constituent quarks. A negative muon shares electron charge  $-e$  and spin  $1/2$  but differs in mass/flavour. Ordinary mesons contain quark–antiquark pairs; baryons contain three quarks, antibaryons three antiquarks.

Check charge, energy, momentum, baryon and relevant lepton numbers. Proton uud has charge  $+e$ ; neutron udd is neutral. Beta-minus decay  $n \rightarrow p + e^- + \text{antineutrino}$  includes the antineutrino for lepton balance and kinematics. Mass alone does not classify a particle.

For a one-carrier Hall model with stated directions/convention,  $R_H = 1/(nq)$ . Its sign follows charge: electron-like negative, hole-like positive. Resistivity alone does not identify carrier sign. Two-carrier semiconductors need mobility-weighted contributions; raw voltage polarity requires fixed leads and field direction.

### ■ 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 |

## 2 Practice

**2.1** Choose one answer. Which ordinary constituent description is correct? [1]

- **A** Lepton: one quark; baryon: one antiquark
- **B** Lepton: no constituent quarks; baryon: three quarks
- **C** Lepton: three quarks; meson: none
- **D** Muon: quark–antiquark pair
- **E** Baryon: always one quark and one antiquark

**2.2** Choose one answer. Under  $R_H = 1/(nq)$  for a single carrier, a negative coefficient identifies: [1]

- **A** Positive holes
- **B** Zero carrier density
- **C** Electron-like negative charge
- **D** No magnetic force
- **E** A neutral carrier with  $q=0$

**2.3** A nucleus has binding energy 72 MeV and mass number 9. B/A is \_\_\_\_\_ MeV. Show your relation and units. [2]

[2]

[4]

## Solutions

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**2.1 B** Leptons are not constituent-quark composites; ordinary baryons contain three quarks.

Compare the rejected options: Lepton: one quark; baryon: one antiquark; Lepton: three quarks; meson: none; Muon: quark–antiquark pair; Baryon: always one quark and one antiquark. Use the stated model and conditions.

**2.2 C** Density is positive, so coefficient sign follows charge sign.

Compare the rejected options: Positive holes; Zero carrier density; No magnetic force; A neutral carrier with  $q=0$ . Use the stated model and conditions.

**2.3 8.** Divide total binding by nucleon count:  $72/9=8$ .

**2.4** False. A muon is a charged lepton; names do not establish quark composition.

**3.1** 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.