Eightfold Way Activity

Objective

To identify patterns in the masses of particles, and observe how a model of 3 quarks can qualitatively explain the observed patterns of these many particles. This introduces the famous "Eightfold way" approach of Murray Gell-Mann and Yuval Ne'eman, and motivates the quark model of hadrons. Variations of this activity can be done for the periodic table of elements.

Supplies

- Index cards
- Marker

Setup

Form several decks of cards. On each card of each deck, the mass and charge will be listed for a known particle. The list of mass and charge combinations to write on each card is listed below. Shuffle the cards within each deck, but don't mix decks.

Deck A (Baryons, spin-1/2)

- m=940, q = 0
- m=938, q = +1
- m=1197, q = −1
- m=1193, q = 0
- m=1189, q = +1
- m=1322, q = −1
- m=1315, q = 0

Deck B (Baryons, spin-3/2)

- m=1232 , q = −1
- m=1232 , q = 0
- m=1232 , q = +1
- m=1232 , q = +2
- m=1387 , q = −1
- m=1384 , q = 0
- m=1383 , q = +1
- m=1535 , q = −1
- m=1532 , q = 0

Deck C (Mesons, spin 0)

- m=140, q = −1
- m=135, q = 0
- m=140, q = +1
- m=494, q = −1
- m=498, q = 0
- m=498, q = 0 (second case)
- m=494, q = +1
- m=958, q=0

Deck D (Mesons, spin 1)

- m=770, q = −1
- m=770, q = 0
- m=770, q = +1
- m=892, q = −1
- m=892, q = 0
- m=892, q = 0 (second case)
- m=892, q = +1
- m=1019, q=0

Instructions

Baryon Pattern Finding

Ask participants to form teams, and give each team one of the baryon decks (A and B). Ask them to group particles of similar (or same) masses into rows, and sort from lowest to highest charge within each group. What trends or shapes are seen?

Baryon Decomposition

Introduce 3 hypothetical particles (quarks) that can combine to form the particles:

- Up (u): q=+2/3,
- Down (d): q=−1/3,
- Strange (s): q=−1/3, and much heavier than up and down

Ask the teams to combine a number of these quarks to form each of the particles in their groups, and write the hypothesized combination on each card. Electric charge must be conserved. Additionally, every strange quark added to a particle adds significantly more mass to that particle.

How many quarks are required to form the particles in these decks? Which particles have the most strange quarks?

Now give the names of the particles in each deck.

- Spin-1/2 family: Nucleons (n, p), Sigma family(Σ), Cascade family (Ξ)
- Spin-3/2 family: Delta family (Δ), Sigma* family (Σ*), Cascade* family (Ξ*)

Meson Pattern Finding

Now give each team one of the meson decks (C and D). Again ask them to group particles of similar (or same) masses into rows, and sort from lowest to highest charge within each group. What trends or shapes are seen? Note that some particles are apparently repeated with either the same mass or even the same mass and charge, although they are fundamentally different.

Meson Decomposition

Now introduce the antiparticles to the 3 quarks that can combine to form the particles:

- Anti-Up ($\overline{u}$): q=−2/3,
- Anti-Down ($\overline{d}$): q=+1/3,
- Anti-Strange ($\overline{s}$): q=+1/3, and much heavier than up and down

Note that the charges are now opposite to the quarks. Now ask teams to combine one quark with one anti-quark to form the particles in their groups. Electric charge must be conserved, and again every strange or anti-strange quark added to a particle adds significantly more mass to that particle.

Now give the names of the particles in each deck.

- Spin 0 family (scalars): pions, kaons, eta'
- Spin 1 family (vectors): rho, kaon* (K*), phi (φ)