Activity 04:
Taming the Particle Zoo

Name: ....

We have come a long way from Dalton and the indivisible atom. First, Thomson found the electron, Rutherford discovered the proton, and in 1932 Chadwick found the neutron. Then, the list expanded over the next 30 years to include over 90 different particles. Particle physics in the 50s and 60s was much like chemistry in the 1880s: a tremendous amount of data but no widely accepted theory to provide an organizing structure.

In this activity we will examine some of these particles, identify a pattern, and explore a theory that will help us tame the particle zoo, just as Mendeleev did for the elements when he built the first Periodic Table.

Part 1: Finding Patterns

01. Take a deck of particle cards and inspect the information on the cards. [Note: S is a new property called “strangeness”.]

02. Sort the particles into **three** distinct groups based on information on the cards. Which characteristic is the best choice for this? Why?

03. Take one of the three groups. Organize its particles into rows and columns based on two of the other characteristics. Repeat for the other two groups.

04. Two of the groups should have eight members and look similar. The third group should look different and have nine members. Describe the geometric patterns that emerge from your arrangement of the cards. Patterns are often a clue to deeper structure.

05. Inspect the larger group. The pattern seems incomplete. You can complete the pattern by adding one more particle to the group. On a blank card, write down the characteristics (mass, spin, Q, S) you expect the missing piece will have. Show this prediction to your teacher.

Murray Gell-Mann won the Nobel Prize in 1969 for his theory explaining all of the known particles and predicting the omega-minus particle. Gell-Mann arranged the known particles into groups, much as you did in Part 1 of this activity. His theory was motivated by the geometric patterns that he found. He recognized that these patterns pointed to a deeper structure within matter. Just as the patterns in the Periodic Table can be explained using protons and electrons to build atoms, Gell-Mann’s patterns suggested that the particles were made of smaller, more fundamental, particles which he called quarks. Each quark has a characteristic charge and strangeness. It also has a “mirror image” antiquark with the opposite charge and strangeness.

QUARK CHARACTERISTICS

Flavour	up (u)	down (d)	strange (s)	antiup ($\bar{u}$)	antidown ($\bar{d}$)	antistrange ($\bar{s}$)
Charge	$+\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{2}{3}$	$+\frac{1}{3}$	$+\frac{1}{3}$
Strangeness	0	0	1	0	0	1

All of the known particles can be constructed by arranging quarks according to a simple set of rules:

- Baryons are made of three quarks. (Antibaryons are made of three antiquarks)
- Mesons are made of one quark and one antiquark.
- Quarks have fractional charge and combine to produce integer charge (e.g., $\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$).
- Quarks have two distinct spin states: ($\frac{1}{2}$ or $-\frac{1}{2}$). When we combine quarks, the spins either add or subtract, just like the charges do to produce either spin-0, spin-$\frac{1}{2}$, or spin-$\frac{3}{2}$ particles.

Part 2: Understanding Patterns

01. Mesons are a combination of one quark and one antiquark. The table below has all of the possible combinations of u, d, and s quarks and antiquarks. Determine the combined **Q** and **S** values for each combination. Then, match these values with the mesons in the spin-0 group that you built in Part 1.

SPIN-0 MESONS

$q\bar{q}$	$u\bar{u}$	$u\bar{d}$	$u\bar{s}$	$d\bar{u}$	$d\bar{d}$	$d\bar{s}$	$s\bar{u}$	$s\bar{d}$	$s\bar{s}$
Q		+1							
S		0							
Particle Symbol		π^{+}							

What problems do you see in your results? How could you resolve them?

02. Baryons are a combination of three quarks. The table below has all of the possible combinations of u, d, and s quarks. Determine the combined Q and S values for each combination. Then, match these values with the baryons in the spin-group and the spin-½ group that you built in Part 1.

BARYONS

qqq	uuu	uud	udd	ddd	uus	uds	dds	uss	dss	sss
Q		+1								
S		0								
Spin-3/2 Baryons		Δ^{+}								
Spin-1/2 Baryons		**p**								

What problems do you see in your results? How could you resolve them?