Exotic Mesons: Are There Any? by B. B. Brabson

At Indiana University we are in the midst of a search for an object which has not been seen in experiments to date. This object is called an exotic meson. All mesons observed so far (more than 100, including the three familiar pi mesons - π^+ , π^0 , π^-) fit nicely into a theoretical model of fundamental particles called the "simple quark model". According to this model, all mesons in the world are made out of a pair of objects, a quark, q , and an antiquark, $\bar{q}$. An exotic meson is, very simply, one which doesn't fit this simple model.

a normal meson

an exotic meson

If exotic particles exist, then we must revise our elementary concepts of the composition of matter to incorporate these more complex structures.

The quark idea, formulated in 1964 by M. Gell-Mann and G. Zweig, envisions all observed strongly-interacting particles as being made up of three "super-fundamental" particles, the quarks, along with their anti-particles. Mesons (strongly interacting particles with integral values of intrinsic spin) are made up of a quark and an antiquark while baryons like the proton and neutron (strongly interacting particles with half-integral spin) are made up of three quarks. Thus,

; charge = +1e.

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where the three kinds of quarks and their electric charges are:

q_1	q_2	q_3
charge = $+2/3 e$	charge = $-1/3 e$	charge = $-1/3 e$

Their antiparticles have opposite charge:

$\bar{q}_1$	$\bar{q}_2$	$\bar{q}_3$
charge = $-2/3 e$	charge = $+1/3 e$	charge = $+1/3 e$

How can you tell if a meson is or is not made of two quarks? That is, how do you recognize an exotic meson? Since quarks have electric charge of either $+2/3 e$ or $-1/3 e$ (and antiquarks have charge either $+1/3 e$ or $-2/3 e$), then a meson of charge $= 2e$ is automatically exotic. No combination of a quark and an antiquark can add up to charge $2e$. An example of an exotic meson with charge $+2e$ would be:

The Indiana High Energy Physics Group is looking for just such a doubly charged object. We label these exotic mesons X^{++} (or X^{--}) to indicate their double charge.

Why would one ever expect to find an exotic meson? The simple quark model, where all mesons are made of $q\bar{q}$, works extremely well. All (~100) known mesons can be accommodated using this model. By searching for mesons which don't fit the simple picture, aren't we just "stirring up trouble"? Maybe nature has a rule that says "Only two quarks allowed per meson.". If there is such a rule, then to find out how good a rule it is and when

it applies is very important. If we look very thoroughly for exotics and don't find any, then the rule must be pretty solid. On the other hand, maybe there isn't such a rule. After all, quarks must be attracted by antiquarks because we find normal mesons all the time. In fact, they are so strongly attractive that we have yet to find a quark by itself. Also, quarks must be attractive to other quarks since 3-quark systems like the proton exist. An exotic meson with 2 quarks and 2 antiquarks should therefore be quite stable since each component is strongly attracted to the other three.

meson

baryon

exotic

Where should one look for exotics? The Indiana University Group is looking for exotic mesons with double charge, i.e., those that can be made up of two quarks and two antiquarks. A logical way to create such a meson would be to bring together a group of quarks with a group of antiquarks, and let the mutually attractive forces form an exotic. Baryons (qqq) are an excellent source of quarks and antibaryons ($\bar{q}\bar{q}\bar{q}$) a source of antiquarks. Schematically, then, one brings together a baryon and an antibaryon to form an exotic.

In this diagram each line shows the path of a quark or antiquark. Baryons are readily available in the laboratory as protons and neutrons. Antibaryons are also available at accelerators, but are not nearly as plentiful as π mesons. Since π mesons spend part of the time dissociated into Baryon and Antibaryon, they also can be used as an antibaryon source. Our experiments to create exotics are summarized in this diagram.

We scatter a beam of π^- mesons from a target of Deuterium (containing protons and neutrons). An antibaryon from the dissociated π^- hits the target baryon to form an exotic meson. Such events are easy to recognize since a fast proton also comes out of the creation process. The experiment is, therefore, represented by the equation:

The Indiana University High Energy Physics Group, together with physicists from Vanderbilt University and Purdue University, has collected

over 150,000 events of this type at the Stanford Linear Accelerator Center (S.L.A.C.). These events each contain a forward proton as shown above. Also, all other charged particle tracks have been recorded as photographs of the S.L.A.C. Streamer Chamber which completely surrounded our target. It is here that we are looking for the exotic X^{--} and its decay products. The pictures taken allow us to make a detailed search from 10 to 50 times more sensitive than previous exotic particle searches. The results of this experiment are being sought with eager anticipation, and will be available in a few months. Our understanding of the structure of matter will then be hopefully a little more profound.

How are exotic mesons related to the idea of charmed particles? In the old days (before 1952) all known mesons and baryons could have been explained by the simple quark model with only two kinds of quarks:

$$\begin{array}{cc} \textcircled{q_1} & \text{and} & \textcircled{q_2} \\ \text{charge} = & & \text{charge} = \\ +2/3 \text{ e} & & -1/3 \text{ e} \end{array}$$

For example, the good old proton is

Then, a new age dawned which we could call the Age of Strangeness. A new quark, $\textcircled{q_3}$, the strange quark, was now needed to explain the internal constitution of all baryons and mesons. The new class of particles (which contained this q_3) were called strange particles. Though the number of kinds of quarks expanded to three kinds, the simple quark model was still perfectly good. (Still need $q\bar{q}$ for mesons, qqq for baryons) Last November (1974), another new age dawned called the Age of Charm. A new quark $\textcircled{q_4}$ was now needed to explain the internal structure of all

charge =
+2/3

baryons and mesons. The new ψ or J meson could not be made up of the three old quark types q_1, q_2, q_3 . Though the number of kinds of quarks expanded to four kinds, the simple quark model was still okay. Mesons are still $q\bar{q}$, etc.

If exotic mesons exist, it is the simple quark model itself which must be changed, not how many kinds of quarks are available. In fact, if exotics are found, one would expect that some of them would be charmed. That is, one of the two quarks or two antiquarks could be the q_4 quark.

In summary, just as the periodic table of elements is determined by the way the constituents of the nucleus (protons and neutrons) interact, the table of fundamental particles is determined by the way the constituents of the fundamental particles (quarks) interact. Therefore, the existence (or non-existence) of exotic particles lies at the heart of our understanding of fundamental particle physics.