THE STANDARD MODEL OF ELEMENTARY PARTICLES CHART
THE ULTIMATE PERIODIC TABLE
WHAT CAN WE LEARN FROM IT?

This activity can be done as a lecture-discussion presentation or can be used by individual students to learn about The Standard Model from The Standard Model Chart.

To the student: The purpose of this activity is to familiarize yourself with The Standard Model of Elementary Particles by studying The Standard Model of Elementary Particles Chart referred to from now on as the Chart. You will need to have a copy of the Chart in front of you to do this activity. (A small version of the Chart is shown on page 2, and a poster-size Chart is available from the Fermilab Education Office by using the order form found in Part III of this book.)

As you look at the Chart you will see that it is divided into four sections. The two top sections list a total of 24 elementary particles. You will need information from these two sections to answer the following questions.

1. The two top sections are labeled _____ and _____.

2. For the time being lets disregard the right-hand side of the Chart and look at the left side labeled Matter. This category is further divided into two groups of six particles. These groups of particles are given the names _____ and _____.

3. List the flavors (names) of the six quarks of matter.

_____, _____, _____,

_____, _____, _____

4. List the flavors (names) of the six leptons.

_____, _____, _____,

_____, _____, _____

5. The symbol for each quark is _____.

6. Using the Chart, write the symbols for the following particles:

up quark _____ down quark _____
top quark _____ charm quark _____

7. Look at the leptons on the Chart; their symbols (except for the electron) are Greek letters. Fill in the symbols below.

lepton	**symbol**	**name of Greek letter**
muon	_____	mu
tau	_____	tau
neutrino	_____	nu

Since there are three different neutrinos, how do their symbols distinguish them from one another?

_____

Write the symbol for an electron neutrino. _____

8. Given the list of particles below, circle the quarks. (Do this first without looking at the Chart if you can.)

up, neutrino, electron, down, tau, charm, strange

9. Using the legend in the lower right-hand corner of the Chart, write down the charge and approximate mass of each of the following:

PARTICLE	CHARGE	MASS
up		
strange		
top		
electron		
tau		
neutrino		

10. Why can mass be measured in Mev/c^2 ?

11. Using the Chart, complete the following: _____ have charges that are integers and _____ have charges that are fractions.

12. Baryons are particles that are made from quarks. The most common baryons are the neutron and the proton. Applying the law of conservation of charge (that is, no charge can be created or destroyed), what is the minimum number of quarks that must be joined to make up one baryon that has a charge of either +1, -1, or 0? _____
Show the proof of your answer here.

CHECK THIS ANSWER WITH THE INSTRUCTOR BEFORE CONTINUING.

13. List three combinations of quarks that will give you a baryon with a charge of:
a) +1 b) -1 c) 0

EXAMPLE - a baryon composed of ccs has a charge of +2/3 + 2/3 - 1/3 = +1.

QUARK COMBINATIONS FOR

+1	-1	0
_____	_____	_____
_____	_____	_____
_____	_____	_____

14. The quarks and leptons in Column 1 of the Chart make up all the stable matter such as protons and neutrons. (Neutrons are stable relative to other particles although they can decay.) Apply this information to write the quark configuration for a proton and for a neutron.

proton _____ neutron _____

15. Add up the masses of the quarks to find the minimum mass of the proton and neutron.

proton _____ neutron _____

16. Which leptons are found in Column (or Family) I? _____ Do you think these are stable too? _____

17. The quarks from Columns II and III form particles that have lifetimes that are much shorter than the proton and neutron, yet they do live long enough to be detected. These particles can be formed from quarks from all three columns. The flavor of the quarks is determined by charge, mass and by the presence or absence of certain properties that are not completely understood but have been given the following names: strangeness, charm, beauty or bottomness, truth or topness. To use the quark model to build these baryons you need more information about the baryons and the quarks. This information is found on the "Quark & Lepton Properties" (page 37) and "Baryon Properties" (page 38) charts. You can get these charts from your instructor. (You will note that truth and beauty are not on the latter chart because no baryons have been detected that possess these properties although there are other particles called mesons that do.)

EXAMPLE: Determine the quark configuration of a sigma minus (S^-). From the chart we find that the sigma minus has a charge of -1, mass of 1197, and strangeness of -1. A strange quark is needed for the strangeness of -1. The strange quark also has a charge of -1/3. Since charm, beauty and truth are all zero, the other quarks must come from Column I and have a charge of -1/3 each. Only the down quark qualifies. Conservation of mass is not violated since the mass of the three quarks is less than the mass of the sigma minus. Therefore, the quark configuration of the sigma minus is dds.

Determine the quark configuration for the following:

Lambda zero (Λ^o)

Omega minus (Ω^-)

Xi minus (Ξ^-)

Check your answers to #17 before going on to #18.

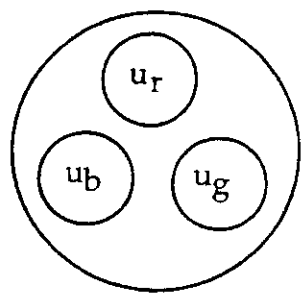
18. Perhaps you were bothered in #17 that a baryon could contain two quarks of the same kind. Since the Pauli Exclusion Principle prohibits an atom from containing two electrons with the same quantum numbers, you may have wondered if this would apply in some way to quarks in a baryon. Well, the answer is yes. Although a baryon may contain two or three quarks of the same flavor, these quarks differ in another property. Scientists are not certain of the physical significance of this property, but in The Standard Model it is given the name color. Quarks are assigned the colors of red, green or blue. Each baryon contains a quark of each color to form the color white. Where on the Chart does it indicate the colors of the quarks? _____

Do leptons have color? _____

19. Sketch the baryons in #14 and #17 and assign colors to the quarks. Let circles represent the baryons and smaller circles represent the quarks. EXAMPLE: Proton representation:

Neutron:
(n^o)

Lambda zero
(Λ^o)



Xi minus
(Ξ^-)

Omega minus
(Ω-)

20. Now lets look at the right side of the Chart marked Antimatter. Using the Chart explain how the antiparticles differ from the particles in:

a) charge _____
b) mass _____
c) symbol _____
(Which particle is an exception?) _____
d) color _____

21. An antibaryon is made from antiquarks.
EXAMPLE: The antiquark configuration for an antiproton is $\bar{u}\bar{u}\bar{d}$ since it has a charge of -1, strangeness = 0.

Write the antiquark configuration and make diagrams as in #19 for the following:

antineutron

antisigma minus

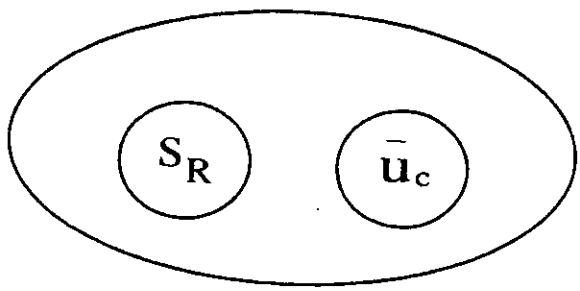
antiomega plus

HAVE THESE ANSWERS CHECKED BEFORE YOU CONTINUE.

22. Mesons are particles that are short-lived but nevertheless detected. They are composed of one quark and one antiquark. Their colors are complementary, that is, they must add up to be white or neutral.

EXAMPLE: a K minus (K^-) has charge = -1, strangeness = -1, charm = 0, beauty = 0, truth = 0. K minus is composed of an s quark (strangeness = -1, charge = -1/3) and an anti-up quark (charge = -2/3).

$s\bar{u}$ (red + cyan = white)



Using the "Meson Properties" (page 40) and "Quark & Lepton Properties" (page 35) charts, write and draw the quark configuration of the following mesons:

Anti K zero

B zero

Eta

D plus

Can you have more than one configuration for any of these?_____ If so, write out all possibilities.

23. The chart in the bottom left-hand corner lists the Gauge Bosons. These are the carriers of the four fundamental forces in nature. List the four forces and their carriers.

FORCE	CARRIER
_____	_____
_____	_____
_____	_____
_____	_____

24. Which particles are charged? _____

25. Which force has the shortest range? _____

26. Which force(s) is/are affected by the color? _____

27. Which force is the weakest? _____

28. Which force holds the quarks together to form baryons? _____