

# Activity: The Quest for the Nobel Prize – The Quark Game

Investigator: \_\_\_\_\_

You are a research scientist at a local university. Your team (yourself and a colleague) is studying **subatomic particles**. You concentrate your efforts on studying **Hadrons**. You decide to ignore, for the time being, the fundamental particles called **leptons** (e.g., electrons, muons, taus, and associated neutrinos), and **gauge particles** (e.g., photons, gravitons, W- and Z-bosons, and gluons).

Hadrons come in two varieties Mesons and Baryons, and all Hadrons are made of fundamental particles called **quarks**. You decide to use your “Quark Accelerator” and the recently discovered incomplete “Quark Manuscript” to create as many Hadrons as possible. The incomplete “Quark Manuscript” recently unearthed in the Smithsonian archives, lists the known quarks, their properties, and the rules for combining quarks.

The Nobel Prize, worth over \$1,000,000 dollars, will be awarded to the team that completes the “Quark Manuscript” and scores the most Hadron points. The rules for getting “Hadron Points” are listed below.

1. Creating a Meson (10 pts).
2. Creating a Baryon (20 pts).
3. Buying 5 “quark cards” (research is expensive -10 pts).
4. Correctly identify your Hadron (15 pts).
5. A WEB site (URL and printout required) with information on your Hadron or a book reference (bibliography & copy) with information on your Hadron (10 pts).

Quark Rules			
1. Quarks combine in pairs (called Mesons) or triplets (called Baryons).			
2. The net <i>charge</i> of all Hadrons must be 0, +1 or -1.			
3. The net <i>color</i> of all Hadrons is <i>white</i> . A <i>white</i> Meson has a <i>color</i> and its <i>anti-color</i> . A <i>white</i> Baryon has all three <i>colors</i> or all three <i>anti-colors</i> .			

  

Quark Manuscript			
Name	Symbol	Charge	Color
Up	u	+2/3	R G B
Anti Up	$\bar{u}$	-2/3	R G B
Down	d	-1/3	R G B
Anti Down			
Strange	s	-1/3	R G B
Charm		+2/3	
Anti Charm	$\bar{c}$		
Top	t	+2/3	
Bottom			
Anti Bottom	$\bar{b}$	+1/3	

Did you say  
Quack rules?



## Game Rules: The Quest for the Nobel Prize – The Quark Game

1. **The Manuscript:** The very first table (the incomplete quark manuscript) is filled in before the game of research begins. It is simply filled in by the students observing the patterns within the table. This table gets filled in before the students pick any cards.
2. **Doing Research:** The cards are placed face down and are obtained by doing research (paying 2 points per card). The students use the second table to keep track of research costs (cards purchased – research teams can purchase up to 5 quark cards per turn). The students do not know which quark they will get when they do research (that is why they are face down). After they buy the card the team must fill in their research cost table.
3. **Analyzing the Research:** Once a team has selected their quark cards, they can look at them to see if they can combine their quarks to form Hadrons. The research team may hold their new quark cards to use on a later turn or they may combine quark cards according to the quark rules and lay out quark combinations that make Hadrons. If the team chooses to hold their picked up cards, then the team simply says, “pass.” The next team gets a turn to do research and to create Hadrons.

If a team chooses to use their turn to create Hadrons, they must fill in the first 8-columns of the “quark creation” table. A team can only fill in this table during their turn.

4. **Challenge:** Another team may *challenge* a new layout at the beginning of their turn. If the challenge is successful (teacher arbitrates), the team making the challenge gets the cards that were incorrectly laid out. The team that makes a successful challenge does not have to pay “research costs” for these new cards. The team that lost the challenge cannot remove the research costs from their scorecard.
5. **Game Ends:** The game ends when a teacher specified time has gone by (15 to 30 minutes works well). If the deck of cards is exhausted, mix the laid out Hadrons and replace the original deck with this shuffled set of cards.
6. **Final Score Tabulation:** After combining quark cards to form Hadrons and entering the quark combination in the third table, students can look up the actual name of their mesons or baryons. Many Hadrons do not have names. So student teams should not spend an undue amount of time trying to find the name. Any Hadrons that a research team cannot find a legitimate name for may make up a name for their “un-named” Hadrons. I wouldn’t give any points for this made up name.
7. **A Second Challenge:** If another team finds a legitimate name for Hadrons not named correctly on another team’s score sheet, then either the teacher can deduct a set number of points from the team with the made up name and/or the teacher can assign bonus points to the team that found the legitimate name for the Hadron.

## Additional Information: Quark and Hadron Information

The "particle adventure game" is found on the Lawrence Berkeley National Laboratory site and can be directly accessed by typing in the URL below. This is an excellent resource.

<http://www.particleadventure.org/>

You can order and/or download pdf and jpg files of charts with information on quarks and particle physics at:

<http://www.particleadventure.org/edumat.html>

The general education resource page for the Lawrence Berkeley National Laboratory is:

[http://csee.lbl.gov/Resources/lab\\_resources.html](http://csee.lbl.gov/Resources/lab_resources.html)

The U.S. Department of Energy URL with links to all the National Laboratories is:

[http://ed.fnal.gov/doe/doe\\_labs.html](http://ed.fnal.gov/doe/doe_labs.html)

†Additional information

Quark	Charge	Color	~Mass (MeV/c <sup>2</sup> )	Spin
u	+2/3	R, G, B	2	Fermion 1/2
d	-1/3	R, G, B	5	Fermion 1/2
c	+2/3	R, G, B	1300	Fermion 1/2
s	-1/3	R, G, B	100	Fermion 1/2
t	+2/3	R, G, B	173,000	Fermion 1/2
b	-1/3	R, G, B	4,200	Fermion 1/2

Hadron Baryons	Symbol	Quarks	Charge	Color	Mass (MeV/c <sup>2</sup> )	Spin
Proton	p <sup>+</sup>	uud	+1	white	938.	Fermion 1/2
Neutron	n <sup>0</sup>	udd	0	white	940.	Fermion 1/2
Lambda <sup>0</sup>	Λ <sup>0</sup>	uds	0	white	1116.	Fermion 1/2
Sigma <sup>+</sup>	Σ <sup>+</sup>	uus	+1	white	1189.	Fermion 1/2
Sigma <sup>-</sup>	Σ <sup>-</sup>	dds	-1	white	1197.	Fermion 1/2
Xi <sup>-</sup>	Ξ <sup>-</sup>	dss	-1	white	1322.	Fermion 1/2
Xi <sup>0</sup>	Ξ <sup>0</sup>	uss	0	white	1315.	Fermion 1/2
Omega <sup>-</sup>	Ω <sup>-</sup>	sss	-1	white	1672.	Fermion 3/2
Delta <sup>+</sup>	Δ <sup>+</sup>	uud	+1	white	1232.	Fermion 3/2
Delta <sup>0</sup>	Δ <sup>0</sup>	udd	0	white	1232.	Fermion 3/2
Delta <sup>-</sup>	Δ <sup>-</sup>	ddd	-1	white	1232.	Fermion 3/2

Hadron Mesons	Symbol	Quarks	Charge	Color	Mass (MeV/c <sup>2</sup> )	Spin
Pion <sup>+</sup>	$\Pi^+$	u anti-d	+1	white	140.	Boson 0
Pion <sup>-</sup>	$\Pi^-$	anti-u d	-1	white	140	Boson 0
Kaon <sup>+</sup>	$\kappa^+$	u anti-s	+1	white	494	Boson 0
Kaon <sup>0</sup>	$\kappa^0$	d anti-s	0	white	498.	Boson 0
Kaon <sup>-</sup>	$\kappa^-$	s anti-u	-1	white	494	Boson 0
Rho <sup>+</sup>	$\rho^+$	u anti-d	+1	white	776	Boson 1
Rho <sup>-</sup>	$\rho^-$	d anti-u	-1	white	776	Boson 1
J/Psi <sup>0</sup>	eta-c	c anti-c	0	white	2980	Boson 0
Upsilon <sup>0</sup>	$\Upsilon^0$	b anti-b	0	white	9400	Boson 1
B-zero	B0	d anti-b	0	white	5280	Boson 0

†Information taken from "Matter & Forces" poster published by Stokes Publishing Co., 1995.

Quark	Charge	Color	Spin
u	2/3	R, G, B	1/2
d	-1/3	R, G, B	1/2
s	-1/3	R, G, B	1/2
c	2/3	R, G, B	1/2
b	-1/3	R, G, B	1/2

Hadron	Symbol	Quarks	Charge	Color	Mass (MeV/c <sup>2</sup> )	Spin
Proton	p	u u d	1	white	938	Fermion 1/2
Neutron	n	u d d	0	white	940	Fermion 1/2
Lambda	$\Lambda$	u d s	0	white	1115	Fermion 1/2
Sigma	$\Sigma$	u u s	1	white	1189	Fermion 1/2
Sigma	$\Sigma$	d d s	-1	white	1192	Fermion 1/2
$\Sigma^+$	$\Sigma^+$	d s s	-1	white	1325	Fermion 1/2
$\Sigma^-$	$\Sigma^-$	u s s	0	white	1315	Fermion 1/2
Omega	$\Omega$	s s s	-1	white	1675	Fermion 3/2
Delta	$\Delta$	u u u	1	white	1232	Fermion 3/2
Delta	$\Delta$	u d d	0	white	1232	Fermion 3/2
Delta	$\Delta$	d d d	-1	white	1232	Fermion 3/2

# The Quark Game – Score Card

Investigator: \_\_\_\_\_

<i>Quark Manuscript</i>			
Name	Symbol	Charge	Color
Up	u	+2/3	R G B
Anti Up	$\bar{u}$	-2/3	$\bar{R}$ $\bar{G}$ $\bar{B}$
Down	d	-1/3	R G B
Anti Down			
Strange	s	-1/3	$\bar{R}$ $\bar{G}$ $\bar{B}$
Charm		+2/3	
Anti Charm	$\bar{c}$		
Top	t	+2/3	
Bottom			
Anti Bottom	$\bar{b}$	+1/3	

<i>Research Costs</i> (2 points per card)	
<b>Total Costs</b>	

Quark Combination Quark symbols eg. d-w (white), t-g (green), etc.			Quark Charge Quarks      Net			Meson or Baryon?	Subatomic Particle Name	Source for Name	Points
<b>Total Points</b>									