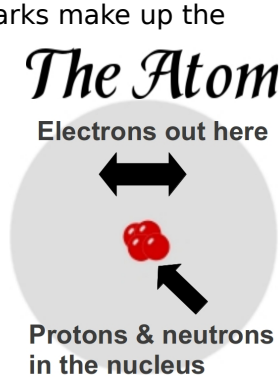
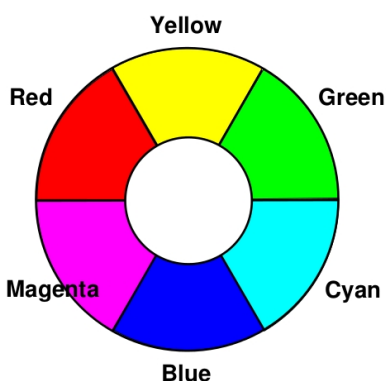
QCD ...The Game

QCD is a game based on the rules of how quarks combine to form particles of matter and anti-matter. Quarks make up the protons and neutrons found in the nucleus of every atom. They are different from the electrons that circulate outside the nucleus because they have <u>*two*</u> kinds of charge. Both electrons and quarks have *electric* charge, so they both can feel the electric force. But quarks alone have ***color*** charge, so they can feel the nuclear force that holds the nucleus together. Color charge is not the same as visible color, but the idea of color helps describe how quarks combine.



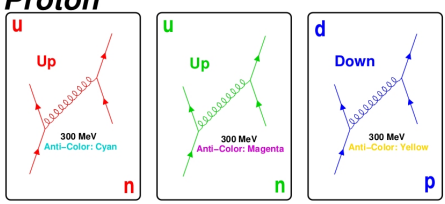
A QCD deck contains 24 quark cards and 24 *anti-quark* cards which are the anti-matter counterparts of the quarks. There are also four *wild* cards which we will come to later. Each quark card has one of the three primary colors (red,green or blue) while the *anti*-quarks each have one of the *anti*-colors (cyan, magenta or yellow). Many different games can be played with a QCD deck. In each game you will form card sets that represent the particles found in nature. The rule for forming a card set is the same rule quarks follow when combining to form a real particle: Every particle must be *color neutral,* meaning that the colors all *cancel out.* One way to do that is to combine three quarks, one of each color. Particles containing three quarks are known as *baryons*. Protons and neutrons are examples of baryons, but any particle with three different-colored quarks is a baryon. Another possibility is to combine three *anti*-quarks, each of a different *anti-color,* to form an *anti-baryon.* Finally, particles known as *mesons* consist of a quark/anti-quark pair, where the quark's and anti-quark's colors are opposite each other on the color wheel.



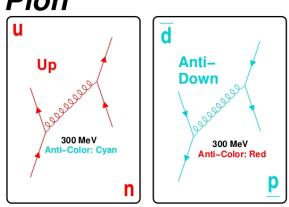
Quarks come in a variety of *flavors.* The QCD deck includes *up, down, strange* and *charm,* and their anti-quark partners. The value of a flavor is the energy, in Mega-Electronvolts (MeV), that it contributes to a color-neutral particle. Below are some examples of card sets. First is a baryon, which just happens to be a proton, followed by two mesons. When a meson contains only up and down quarks, it is called a *pion.* A *strange* quark paired with an up or down is called a *kaon*.

Quark/Anti-Quark	Energy
Up, Anti-Up	300 MeV
Down, Anti-Down	300 MeV
Strange, Anti-Strange	500 MeV
Charm, Anti-Charm	1500 MeV

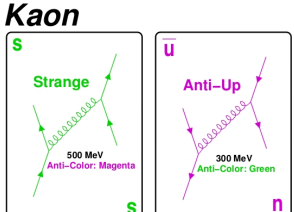
Proton



Pion



Kaon



Quark Rummy *(2 to 4 players)*

Shuffle the cards and deal five cards to each player in a clock-wise fashion. The remaining cards are placed in a stack, face down, and the top card placed face up beside it. This will become the discard pile. The player to the dealer's left takes the first turn, followed by the player to *his* left and so on. The responsibility of dealing will also advance clockwise around the table. On each turn, players will perform the following tasks, in order:

1. Draw one quark card from the draw stack, or take the top card from the discard pile.
2. Disintegrate <u>one</u> unstable particle that was played on a previous turn (see rules below). Cards from a disintegrated particle are placed face down in a stack in front of the player. This is referred to as the *energy stack,* and contributes to the player's score at the end of the hand.
3. Try to form new particles, observing the rule that particles must be color neutral. If a player can form a particle, he must do so on his turn and lay the card set face up in front of him.
4. Attempt to annihilate as many of his particles as possible with any of his own or his opponent's particles (see rules below).

5. Draw cards from the draw stack to maintain 5 cards in his hand. If a player was unable to form a particle on his turn, he must discard one card, face up, onto the discard pile. Otherwise, a new card is turned up if the discard pile is empty.

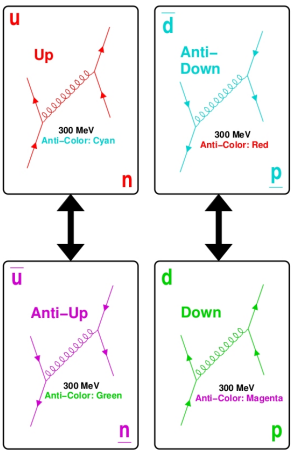
If a player forgets to draw a card prior to making any other play, he may not draw a card on that turn. If a player forgets to disintegrate a particle before performing any of steps 3, 4 or 5, he must wait until his next turn to disintegrate a particle.

When the draw stack is exhausted, each player takes one additional turn, optionally drawing the top card from the discard pile, and making whatever plays are possible before passing to the next player. Finally, each player disintegrates all of his remaining particles, including protons and neutrons, as explained in the *Disintegration* section below. Players then sum the energy of all cards in their energy stacks, subtract the value of cards remaining in their hands, and report the results to the score keeper. The winner is the first player to accumulate 10,000 MeV, or the player with the most energy if two or more players reach 10,000 MeV on the same hand. Players may agree to play to a different energy total for a longer or shorter game.

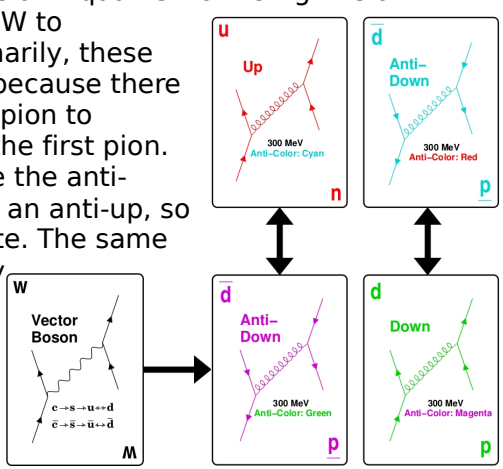
Disintegration: Baryons, anti-baryons and mesons may spontaneously disintegrate in a process called *radioactive decay.* Players may disintegrate <u>one</u> particle per turn that contains a strange or charm quark (or anti-strange or anti-charm). For kaons (a strange quark plus an up or down), only the strange quark is added to the energy stack. The up or down quark is placed in a *dead-card* pile off to one side, and is not considered in the score. Particles called *Deltas* (up-up-up or down-down-down) and anti-Deltas are ten-billion times more unstable than most other particles, and so may be disintegrated as soon as they are played, without waiting for the next turn. Protons (up-up-down), neutrons (down-down-up) and their anti-matter counterparts are *stable*, and may only be disintegrated at the end of the hand. Pions (mesons containing only up and down quarks) may <u>*never*</u> be disintegrated.

Annihilation: When real quarks encounter their anti-quark counterparts, matter-antimatter annihilation occurs. Both particles are destroyed, and all of their energy is released as gamma radiation. Players may annihilate as many particles as possible during their turn. To do this, each quark in one particle

must have its anti-quark partner present in the other particle. Color is not considered in annihilation. When two particles annihilate, both card sets are placed face down in the player's energy stack. For pions, only one up or down is placed in the energy stack, the other three going to the *dead-card* pile. For kaons, only the strange quarks go in the energy stack. Annihilation between two pions is shown to the left. The up quark in the first pion annihilates the anti-up in the second pion, while the anti-down in the first pion annihilates the down quark in the second.



Wild Cards: *One* Vector Boson card (W) may be played during an annihilation to change a quark or anti-quark from one flavor to another. This is called ***transmutation***. W cards can transmute *charm* to *strange, strange* to *up, up* to *down* or *down* to *up,* and the same transmutations apply to the anti-quarks. To the right is an example of how to use the W to annihilate two pions. Ordinarily, these pions could not annihilate because there is no anti-up in the second pion to annihilate the up quark in the first pion. The W is used to transmute the anti-down in the second pion to an anti-up, so that the pions can annihilate. The same result could be achieved by using the W to transmute the up to a down in the first pion. The transmuted quark card is placed in the dead-card pile, and will not contribute toward the score. When annihilating pions or kaons, the transmuted quark will be among those cards already going to the dead-card pile if its final flavor is up or down.



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