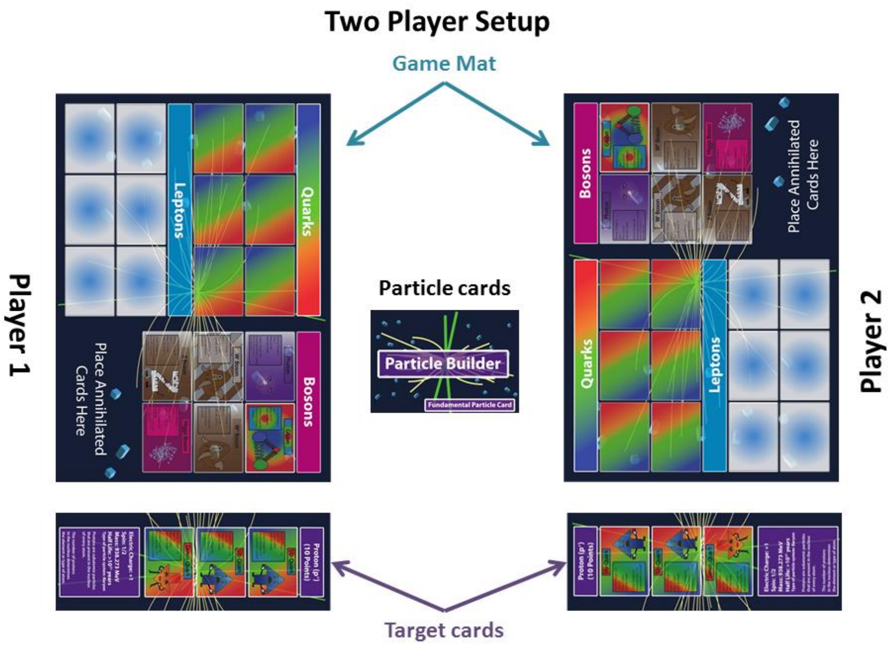
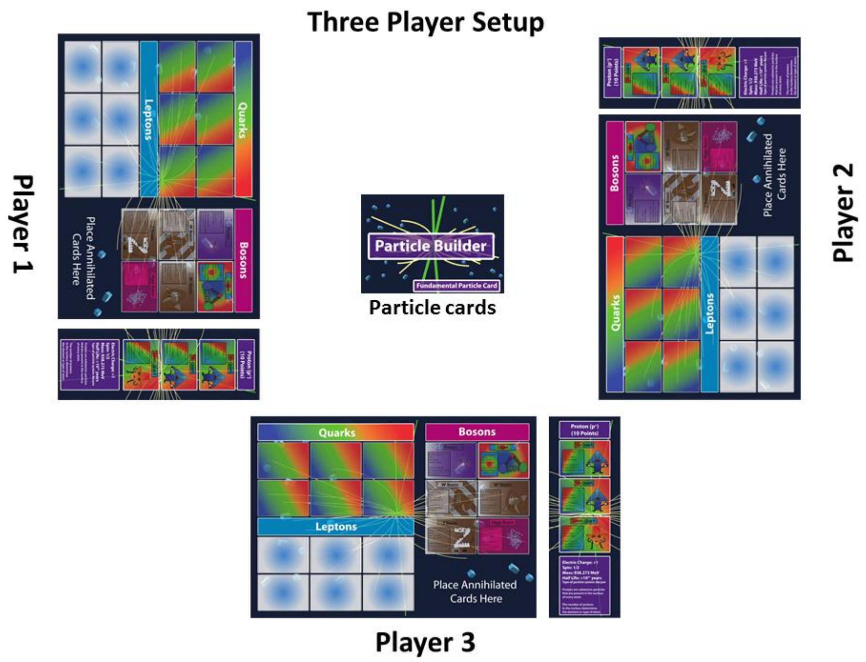
Particle Builder Board Game

This game is best played in pairs (or groups of 3 if there are odd numbers), where each player is competing against the others to get the most points.

Stage 1 (Getting to know the particles) – For beginners

1.) Each player gets a placemat and a target card. The mats, target cards and game cards are set up as shown below:



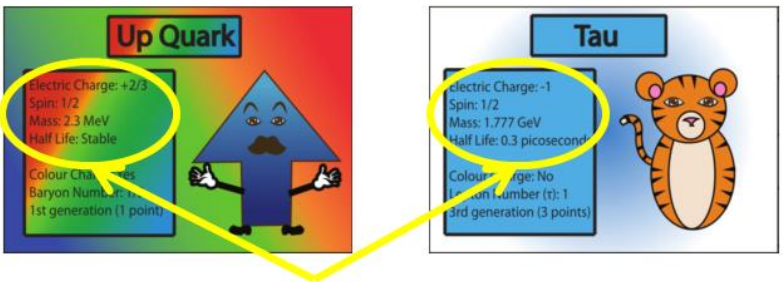


2.) Each player gets a large “Target” card. It is recommended in the first round that each player has the “proton” target card. The aim of the game is for a player to build their target by gathering all the required particles. Once a single player has obtained all the required cards the game is over. For example, for the proton target, when a player obtains two up quarks and one down quark, then the game is over. This player usually wins because the targets are worth a large number of points.

3.) The deck of particle of particle cards is placed in a face down pile in the middle of the table. Both players draw from this deck of cards.

4.) The game starts with the first player’s turn. Each player picks up a card but does not show it to the other players. The first player then chooses a statistic from the card, either charge, spin, mass or half-life. See diagram below:

Player 1’s Card **Player 2’s Card**



Statistics to be compared.

If it is player 1’s turn, player 1 must choose one of the statistics highlighted in yellow (before seeing player 2’s card). After the statistic is chosen the players must compare the statistic. If player 1 chose a statistic that is higher then he/she wins and may swap cards with player 2. If not both players keep their card.

If the first player’s statistic is higher than all the other players then they may choose to swap cards with another player of their choice. If not, they keep their card. Starting with the player whose turn it is and then going clockwise, the players put the (new) card in their hand onto the relevant area of the placemat (see instruction 5).

Note the following rules when comparing statistics:

- If there are 3 or more players then in order to win the player must beat every other player. Then they may choose to swap cards with any individual player.
- A tie always results in all players keeping their own card (same as losing).
- If the half-life is stable this count as infinity and beats all finite half-lives.
- If the half-life is unknown this is because the particle decays so quickly we cannot measure its half-life. Unknown automatically loses to all finite (and stable) half-lives and ties with other unknown half-lives.
- It is the highest charge that wins not the highest magnitude of charge. Therefore positive charges always beat negative charges.

5.) Placing the Cards on the Mat

When a player goes to put the card down on their mat, they must identify what type of particle they have.

Placing Quarks

If the card is a quark and is required to build the target, the player must place the particle in the appropriate place in target area.

Otherwise the player must place it in an empty space the quark section on the top left side of the mat. If there are no empty spaces in the quark section (they already have six quarks) the player then they must instead put their card on the bottom of the deck of particle cards.

Placing Leptons

If the card is a lepton and is required to build the target, the player must place the particle in the appropriate place in the target area.

Otherwise the player must place it in an empty space in the lepton section on the bottom left hand side of the mat. If there are no empty spaces in the lepton section (they already have six leptons) the player must instead put the card on the bottom of the deck of particle cards.

Placing Bosons

If the particle is a boson it must be placed in the corresponding position in the boson section on the right hand side of the mat. Players may multiple bosons in the same position. For example there is no limit to the number of photons a player may have, they simply stack them in the allocated position.

Particles with half-integer spin (leptons and quarks) are called leptons. Leptons obey a rule called the Pauli Exclusion Principle, which means they forbidden to be in the same state. Particles with integer spin do not obey this rule and are allowed to be in the same state.

6.) Next Player's Turn

It then becomes player 2's turn. Both players draw a card and player 2 chooses a statistic. If player 2's statistic is higher player two may choose to change cards with player 1.

It then becomes the next player's turn. This turn taking process continues and players build up a collection of particles until one player has enough particles to build their target card.

7.) Special Rule: Annihilation

In stage one the only special rule is annihilation of anti-particles. Anti-matter particles are represented with grey stripes in this game.

If a player has an anti-particle as their card rather than placing a card on the mat, they may choose to annihilate it with a corresponding antiparticle that is already on the mat (it may belong to them or another player). In this case the player takes both cards puts them in the annihilation area on the mat and adds the total points to their score at the end of the game.

Similarly, if there is already an anti-particle on the board and a player has the corresponding particle in their hand, they may choose to annihilate it and place both cards in their annihilation pile and receive two photons.

8.) Ending the Game

When a player has all the required particles for their the target they receive the given number of points and the game is over (if any plays still have cards in their hands they may put them down on their own mat, but they may not use them to stop the player from winning). Players then calculate their final score by adding the points for each particle on their placemat. The player with the most points wins.

The purpose of stage one is for students to see which particle belong to which category and learn some basic facts about them. Students will also be exposed to particle physics terminology.

You are now ready to stop reading a play Stage 1. If you are looking for something for advanced after you have finished playing, you can read on and play stage 2!

Stage 2 (Introduction to Interactions) – For players that have already played one or two rounds of stage 1.

The rules for stage two are the same as stage one, with the following exceptions:

- If a player has a particle with colour charge, instead of placing a gluon on the mat, the player may instead use the gluon to 'attract' (steal) a quark or gluon from another player. In this case the stolen quark or gluon is moved into the corresponding position on the new player's mat. The used gluon is 'absorbed' and placed on the bottom of the deck.
- If a player has an electrically charged particle, instead of placing a photon on the mat, the player may use a photon to 'attract' (steal) an electrically charged particle from another player. In this case the stolen electrically charged particle is moved into the corresponding position on the new player's mat. The used photon is 'absorbed' and placed on the bottom of the deck.
- As long as you have a particle, you may use a Z boson to 'attract' (steal) any particle from another player. In this case the stolen particle is moved into the corresponding position on the new player's mat. In this case the Z-boson is absorbed and placed on the bottom of the deck.

The purpose of stage two is to teach students about the strong force and the electromagnetic force and which particles they act on.

Stage 3 Introduction to Colour – For players that have already played one or two rounds of stage 1.

In order to play stage 3, players required colour tokens. These can simply be pieces of paper which have the colours blue, green, red, anti-blue, anti-green and anti-red written on them. Alternatively you can print the colour charge squares.

The rules for stage three are the same as stage two, with the following exceptions:

- There are colour tokens. Whenever a player puts down a quark card they must choose a colour for that quark card. The colour token is then placed on that quark. Whenever an anti-quark must also be allocated a colour (anti-blue, anti-green and anti-red).
- Gluons may be used to swap the colour of any two quarks (either a player's own quarks or their opponent's or one of each). In this case the gluon is 'absorbed' and is placed on the bottom of the deck.
- In order to win the game a player must obtain a colour neutral set for the target (this means they need a red, green and blue quark for a baryon target or a colour and its anti-colour for a meson target).

The purpose of stage 3 is to teach students about the colour charge and realise that all hadrons are colour neutral.

Stage 4 (Cross Sections) - For players that have already played one or two rounds of Stage 3.

In order to play stage four, dice are required.

The rules are the same as stage 3, with the following exceptions:

- Whenever a player attempts an annihilation they role a die. If they role an odd number the annihilation does not occur and instead they place the particle card on the relevant area on their own mat.
- Whenever a player attempts to use a boson card to change the colour charge or attract a particle, they roll they role a die. If they role an odd number the interaction does not occur.

The purpose of stage four is to introduce the idea that particles do not obey deterministic laws but are probabilistic by nature.

Warning: for Stage 5 and beyond the Rules become complicated! (And an extra set of cards is required)

Stage 5 (Transformations) - For players that have already played one or two rounds of stage 4.

In order to play stage five, a set of spare cards are required.

The rules are the same as stage 4, with the following exceptions. Instead of playing a W^+ or a W^- Boson on their mat, they can use it to transform a particle according to the rules below:

- Conservation of electric Charge. If a W+ is used to transform a particle then the product must have an electric charge 1 greater than the original. If a W- is used to transform a particle then the product must have electric charge 1 less than the original.
- Conservation of Baryon number. Quarks may only be transformed into other quarks. Anti-quarks may only be transformed into anti-quarks. Leptons may not be transformed into quarks.
- Conservation of Lepton Family Number – Leptons may only be transformed into other leptons of the same generation. For example a Tau may only be transformed into a Tau neutrino

A player may transform a particle that is on their own mat, or the mat of another player.

When a W+ or a W- is used to transform a particle it is absorbed and shuffled into the deck.

Special Rule Annihilation: When a player annihilates a charged lepton/anti-lepton pair they may put two photon cards onto the photon section of their mat. When a player annihilates a quark/anti-quarks they may put two photon cards or two gluon cards onto their mat. When a player annihilates a neutrino/anti-neutrino pair they place a single Z-boson on their mat.

Rather than rolling an even number, in order to annihilate a neutrino-anti-neutrino pair a player must role three 6s in a row.

The purpose of stage five is to introduce students to the types of transformations that are allowed by the standard model.

Stage 6 (Neutrino Oscillations) - For players that have already played one or two rounds of stage 5.

Warning: Although this level incorporates more modern physics, it makes the game more time consuming with almost no extra fun added.

At the start of a player's turn they roll a die for each neutrino and anti-neutrino on their mat. The neutrino then transforms according to the following rules:

- Roll a 1 or 2: Neutrino becomes (or remains) an electron neutrino
- Roll a 3 or 4: Neutrino becomes (or remains) a muon neutrino
- Roll a 5 or 6: Neutrino becomes (or remains) a tau neutrino

The purpose of stage 6 is to introduce students to phenomenon of neutrino oscillations. This occurs because the mass eigenstates of neutrinos are different to the flavour eigenstates of neutrinos.

Stage 7 (Decays or spontaneous transformations) – Too complicated, don't play it, run away while you still can and enjoy life!

For stage 7, players will need a large number of face up W^+ and W^- cards in addition to a spare set of cards, dice and a lot of patience.

When each player starts a new turn, they must role a die for each second or third generation particle, W^+, W^-, Z^0 and Higgs Boson on their mat. Depending on the number rolled the particle transforms as specified below.

Quark Decays (Spontaneous Transformations)

Quarks decay according to following rules which are summarised in the diagram below. Charge is always conserved in decays so the player also receives a W- or a W+ boson.

Top:

- if 3-6 is rolled it becomes a bottom quark
- if 2 is rolled it becomes a strange quark
- if a 1 is rolled it becomes a down quark

Bottom:

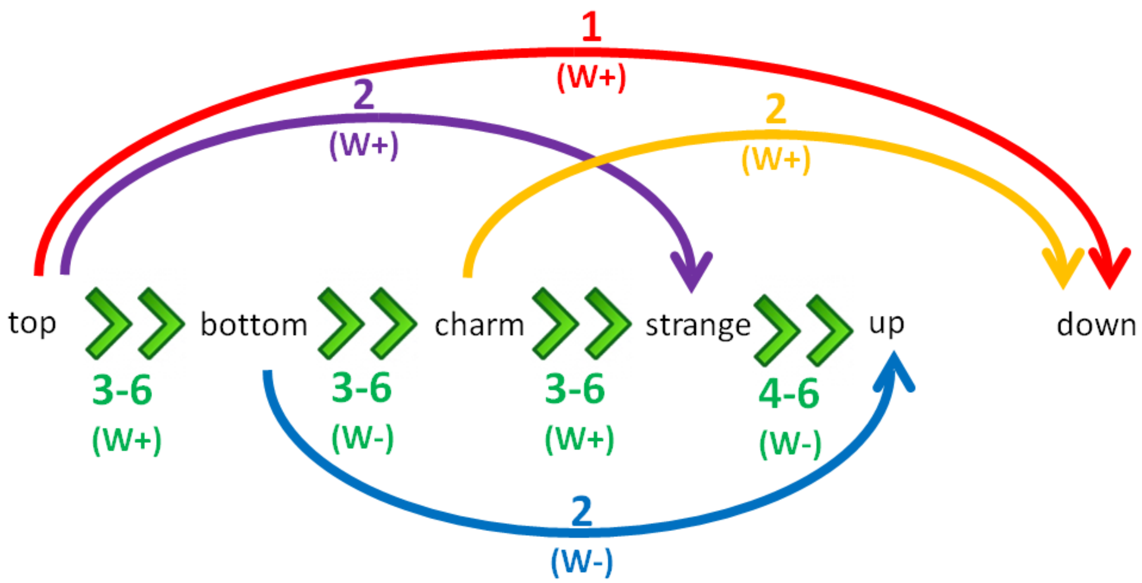
- if 3-6 is rolled it becomes a charm quark
- if 2 is rolled it becomes an up quark
- if a 1 is rolled it remains a bottom quark

Charm:

- if 3-6 is rolled it becomes a strange quark
- if 2 is rolled it becomes an down quark
- if a 1 is rolled it remains a charm quark

Strange:

- if 4-6 is rolled it becomes an up quark
- otherwise it remains a strange quark



Anti-particles decay according to the same rules, but the player should receive the corresponding anti-particle and a W boson with opposite charge.

Lepton Decays (Spontaneous Transformations)

Leptons decay according to following rules which are summarised in the diagram below. Charge is always conserved in decays so the player also receives a W- or a W+ boson.

Muon

- if 5 or 6 is rolled it becomes an electron , muon neutrino and electron antineutrino. All of these particles must be placed in the lepton area if there is space.
- otherwise it remains a muon

Tau

- if a 6 is rolled the Tau transforms into a Tau-neutrino, a muon and an anti-muon neutrino.
- if a 5 is rolled the Tau transforms into a Tau-neutrino, an electron and an anti-electron neutrino.
- If a 4 is rolled the Tau transforms into a Tau-neutrino, a down quark and an anti-up quark
- If a 3 is rolled the Tau transforms into a Tau-neutrino, a down quark, an anti-up quark and a neutral pion (player's choice of an up/anti-up pair, or a down/anti-down pair)
- If a 2 is rolled the Tau transforms into a Tau-neutrino, a down quark, an anti-up quark and two neutral pions (player's choice of an up/anti-up pair, or a down/anti-down pair)
- Otherwise it remains a Tau.

Anti-muons and anti-taus decay the same way except the corresponding anti-particles are created instead of the listed particles particles (and vice versa).

Higgs Decay

- if 4-6 is rolled it becomes a bottom/anti-bottom pair
- if a 3 is rolled it becomes a W+/ W- boson pair
- if a 2 is rolled, roll another die:
    - if a 4-6 is rolled it becomes two gluons
    - if a 2-3 is rolled it becomes a tau/anti-tau pair
    - if a 1 is rolled it becomes a charm/anti-charm pair
- if a 1 is rolled, it remains a Higgs Boson:

The decays here are the most probable decays to occur according to the standard model. However there are other possible decays. The probabilities when rolling a dice are somewhat indicative of actual Higgs decay.

W^+ and W^- Decay

W+ bosons decay according to the following rules (W^- Bosons decay to the corresponding antiparticles with the same probabilities)

- if a 5-6 is rolled a charm/anti-strange pair is produced
- if a 3-4 is rolled a down/anti-up pair is produced
- if a 1-2 is rolled, roll another die:
    - If a 5-6 is rolled a tau neutrino/anti-tau pair is produced
    - If a 3-4 is rolled a muon neutrino/anti-muon pair is produced
    - If a 1-2 is rolled an electron neutrino/positron pair is produced

Z^0 Decay

Z^0 bosons decay according to the following rules:

- if a 3-6 is rolled a roll another die:
    - if a 6 is rolled a bottom/anti-bottom pair is produced
    - if a 5 is rolled a charm/anti-charm pair is produced
    - if a 4 is rolled a strange/anti-strange pair is produced
    - if a 3 is rolled a down/anti-down pair is produced
    - if a 2 is rolled an up/anti-up pair is produced
    - if a 1 is rolled, roll again until you get a 2-6.
- if a 1-2 is rolled, roll another die:
    - If a 3-6 is rolled, role another die:
        - If a If a 5-6 is rolled a tau neutrino/ anti-tau neutrino pair is produced
        - If a 3-4 is rolled a muon neutrino/ anti-muon neutrino pair is produced
        - If a 1-2 is rolled an electron neutrino/anti-electron neutrino pair is produced
    - If a 1-2 is rolled, role another die:
        - If a If a 5-6 is rolled a tau neutrino/ anti-tau neutrino pair is produced
        - If a 3-4 is rolled a muon neutrino/ anti-muon neutrino pair is produced
        - If a 1-2 is rolled an electron neutrino/anti-electron neutrino pair is produced

Level 7 introduces students to particle decays and branching ratios. The reasons behind the branching ratios are complicated. However if students wish to learn more they can research some of the following terms: “Quantum Numbers”, “Branching Ratios”, “Decay Modes”, “Energy conservation in particle decays” “CKM matrix”, “Coupling constant”, “Chirality” (of leptons) and “Off mass shell”. Please note that because there are 3 different colour charges, decay through quark channels become 3 times as more likely for Z, W and Higgs Boson decays.