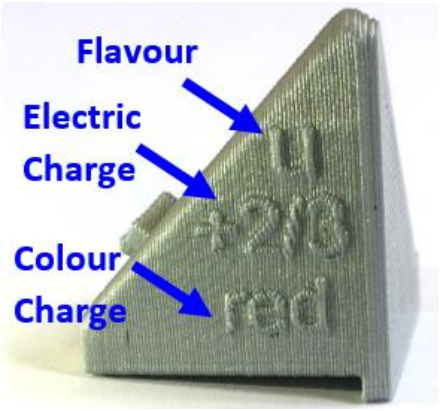
The Quark Puzzle

Each piece is a model that represents a tiny particle that is too small to see, called a "**quark**". Every quark has a flavour, an electric charge and a colour charge. You can find these properties printed on the side of the quark.



F**lavours** include up (u), down (d), anti-up ($\overline{u}$) or anti down ($\overline{d}$).

+2/3 is an example of **electric charge**.

Examples of **colour charge** are red and anti-blue ($\overline{blue}$).

Making Groups of Quarks

Quarks form groups. There are two groups with special names, they are '**baryons**' and '**mesons**'. In this model baryons and mesons have special shapes.

Baryon

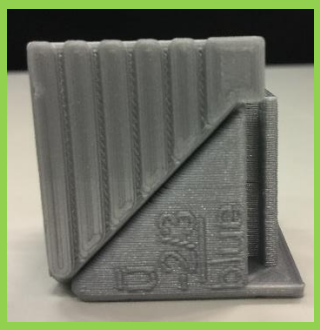
Three quarks that form a cube are called '**baryons**'.

Meson

Two quarks that form a double pyramid are called '**Mesons**'.

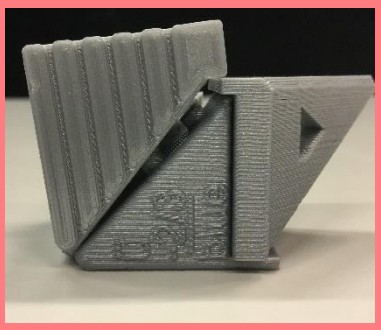
Some combinations fit together nicely, others ones do not. See diagrams below.

Good Joint



Here the pieces fit together nicely.

Bad Joint



Here the pieces do not fit together nicely.

Using groups that fit together nicely complete the tasks on the following pages.

Hint: If it is difficult to build a group, try sorting the quarks by colour charge first and try one from each pile.

Activity 1 – Building a Proton

A **proton** is a **baryon** made of two **up (u) quarks** and one **down (d) quark**.

There are many possible colour charge combinations. Put the pieces together to find what combinations are possible. Record the colour combinations and electrical charges in the table below. One row has been filled out as an example for you.

Once you put the pieces together, you can find the **electric charge** by adding the electric charge of each quark piece together.

Table of Colour Combinations for Protons

Particle Name and symbol	Baryon or Meson?	Up Quark Colour Charge	Up Quark Colour Charge	Down Quark Charge Colour	Electric Charge
Proton (p)	Baryon	red (r)	blue (b)	green (g)	2/3 + 2/3 - 1/3 = +1
Proton (p)	Baryon				
Proton (p)	Baryon				
Proton (p)	Baryon				

Questions:

1.) How many different colour charge combinations of the proton did you find? _____

2.) Challenge Question: Is it possible there are other colour charge combinations that you have not found? How can you be sure?

_____

_____

_____

Activity 2 – Building Anti-Protons

An **anti-proton** is a baryon made of two $\overline{\mathbf{u}}$ **quarks** and one $\overline{\mathbf{d}}$ **quark**.

Put the anti-quark pieces together to find what combinations are possible. Record the colour charge combinations and electrical charges in the table below.

Table of Colour Combinations for Anti-Protons

Particle Name and symbol	Baryon or Meson?	Anti-Up Quark Colour	Anti-Up Quark Colour	Anti-Down Quark Colour	Electric Charge
Anti-Proton ($\overline{p}$)	Baryon	anti-red ($\overline{r}$)	anti-blue ($\overline{b}$)	anti-green **(** $\overline{g}$ **)**	

3.) How many different colour charge combinations of the anti-proton did you find? _____

4.) How does this compare to the colour charge combinations for protons from activity 1?

_____

_____

Activity 3 – Building Neutrons and Anti-Neutrons

A **neutron (n)** is a baryon made of one **u quark** and two **d quarks**.

An anti-**neutron ($\overline{n}$)** is a baryon that contains one $\overline{u}$ **quark** and two $\overline{d}$ **quarks**.

Put the quark and anti-quark pieces together to build neutrons and anti-neutrons. Record the colour combinations and electrical charges in the table below.

Particle Name and symbol	Baryon or Meson?	Up/Anti-Up Quark Colour	Down/Anti-Down Quark Colour	Down/Anti-Down Quark Colour	Electric Charge

5.) How many different colour charge combinations of the anti-neutron did you find? _____

6.) How does this compare to the colour charge combinations for protons and anti-protons from activity 1 and 2?

_____

_____

7.) What electric charges are possible? Is this the same as for protons and anti-protons?

_____

_____

Activity 4 – Building Pions

A **pion** is a **meson** made of **u, d**, $\overline{\mathbf{u}}$ and $\overline{\mathbf{d}}$ **quarks**.

For **pions** there are many different flavours, values for the colour charge and electric charge.

Build **pions** out of the pieces and fill in the combinations you find in the table below:

Table of Colour Combinations for Pions

Particle Name	Baryon or Meson?	Flavour Combination	Colour Charge Combinations	Electric Charge
Pion (π)	Meson	$u\,\overline{d}$		+1

4.) What are the different possible values of electric charge for pions? _____

5.) (Challenge) Are there any other possible values for electric charge for pions? How can you be sure?

_____

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Activity 5 - Claims, Evidence and Reasoning

Using the combinations you have found in the tables (or using the pieces to explore other combinations if necessary) state whether the following claims are supported or not. After this, write down the evidence and reasoning that led you to this conclusion.

The first claim is completed for you as an example.

Claim 1: Neutrons can have an electric charge of +1.

True or False ___False_____

Evidence and Reasoning: _A neutron is made of two down quarks and one up quark. The provided_ _down quarks always have an electric charge of -1/3 and the up quarks have charge +2/3. Therefore_ _when these are combined the net charge is always 0. Therefore it is not possible to have a neutron_ _with charge +1._ _____

Claim 2: Protons can have an electric charge of +1.

True or False _____

Evidence and Reasoning: _____

_____

_____

Claim 3: Mesons must have one blue and one anti-blue quark.

True or False _____

Evidence and Reasoning: _____

_____

_____

Claim 4: It is possible for a baryon to have an overall electric charge of -2.

True or False _____

Evidence and Reasoning: _____

_____

_____

Claim 5 (Challenge): It is possible for a meson to have an overall electric charge of +1/3.

True or False _____

Evidence and Reasoning: _____

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Claim 6 (Challenge): All particle systems (mesons or baryons) can only have whole number electric charge.

True or False _____

Evidence and Reasoning: _____

_____

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Activity 6 – Comparing the Puzzle to Real Particles (Research Task)

The puzzle provided is only a model and it does not show what real quarks look like. Do some research and in the table below write down the differences and similarities between the puzzle and real quarks. One row has been completed for you an example:

Category	Quark Puzzle	Real Particles
Shape and size	In this puzzle, a proton has a cube shape. Pions have a double pyramid shape.	Real protons and pions have no well-defined shape that humans can see or even imagine.
Empty Space		
Colour Charge		
Anti-particles (Challenge)		
Difference between up and down quark (Challenge)		