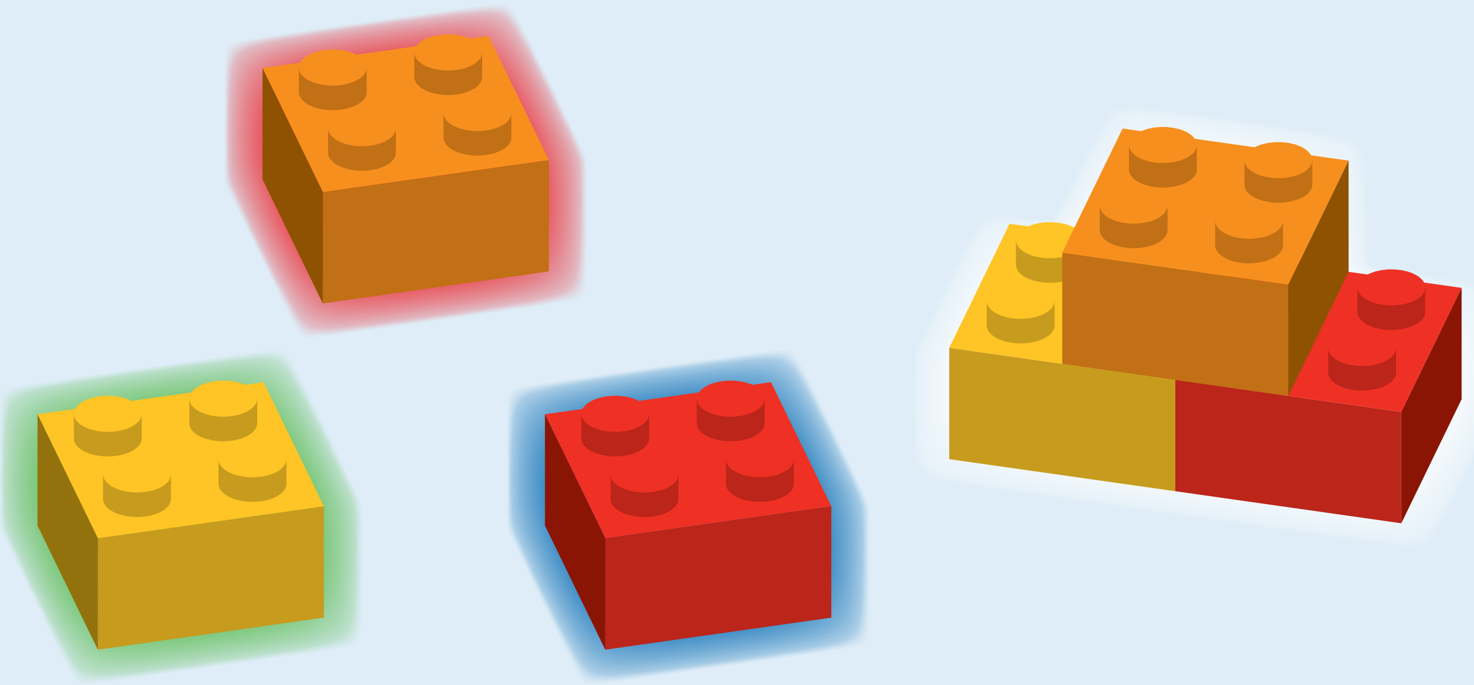
FORCE SUMMARY

Force	Conserves charge?	Conserves baryon number?	Conserves strangeness?	Conserves lepton number?	Range	Force carrier particle
Strong	Yes	Yes	Yes	Yes	Short range: attraction up to 3fm. Below 0.5fm, it is repulsive.	Gluon
Weak	Yes	Yes	No	Yes	*Very* short range: about 10^{-18}m.	W or Z boson
Electromagnetic	Yes	Yes	Yes	Yes	Infinite in range, although it gets weaker as things move apart.	Photon



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SEPnet South East Physics Network **Outreach**

Queen Mary University of London

Design: Lydia Thornley Design www.thornley.co.uk Illustrations: Roger Taylor

PARTICLE PHYSICS: A PHYSICS KIT

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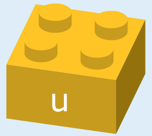
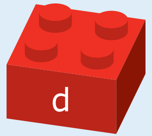
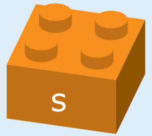
THE SMALLEST THINGS



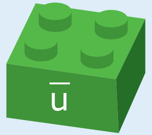
Up quark.
Charge $+{}^{2}/_{3}$



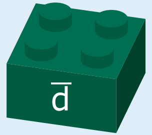
Down quark.
Charge $-{}^{1}/_{3}$



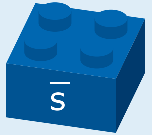
Strange quark.
Charge $-{}^{1}/_{3}$



Antiup quark.
Charge $-{}^{2}/_{3}$



Antidown quark.
Charge $+{}^{1}/_{3}$

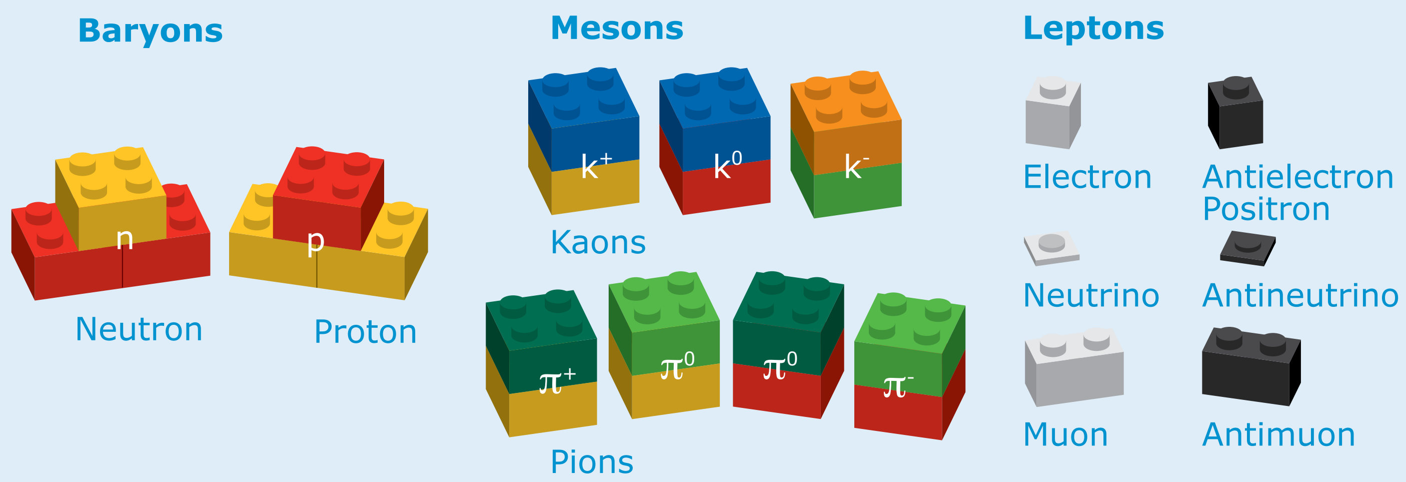


Antistrange quark.
Charge $+{}^{1}/_{3}$

As science has evolved, we have been able to look deeper and deeper into the heart of matter, finding ever smaller things – first atoms, then protons and neutrons, and finally quarks. These particles combine in different ways to make everything around us. All of the matter we see every day is made of two types of quark: up quarks and down quarks. However, there are 6 types of quark in total, some of which are only seen inside particle accelerators and other physics experiments, like the LHC. The other types of quark form particles which decay – turn into other particles, made of up and down quarks – very quickly.

Here are the lightest three quarks: up, down and strange, along with their antiparticles. Antiquarks (represented by a bar above the letter denoting the type of quark) are particles which are the exact opposite of their partner particle: they have the same mass, but they interact with the world in the opposite way to ordinary matter, as they have the opposite electric charge. If antimatter meets with its matter twin, they annihilate, disappearing in a flash of energy. There are also three other types of quark – charm, top and bottom. Charm and bottom can also combine with up, down and strange to make particles, but top is too heavy, decaying into other things before it has time to combine with other quarks.

SLIGHTLY BIGGER THINGS

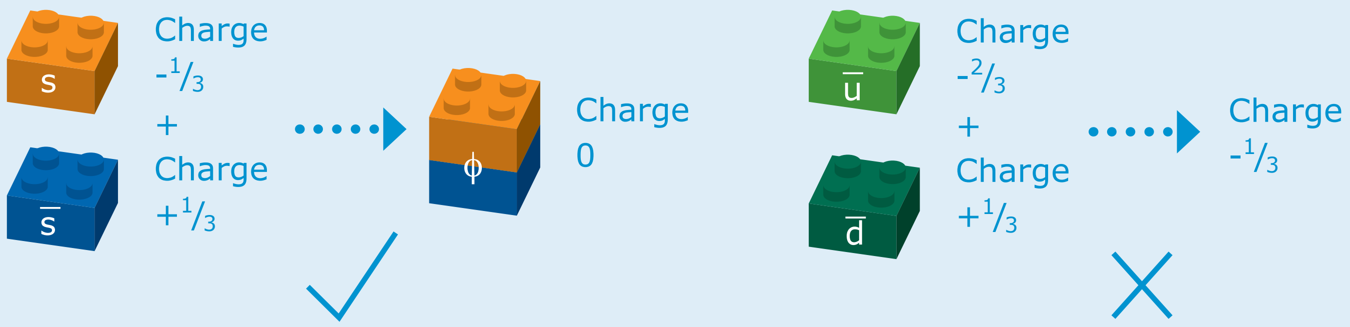


Any particle made of quarks is called a hadron. They come in two types:

Baryons. These are made of three quarks. A proton, made of two up quarks and a down quark, is a baryon. Its antiparticle is the antiproton, made up of two antiup quarks and an antidown quark.
Mesons. These are made of one quark and one antiquark. The π+ (a positively charged pion) contains an up and an antidown quark. The antiparticle is the opposite of the particle – swapping quarks for antiquarks and vice versa.

There is also a class of particles called leptons. These include the electron, and are not made up of quarks – in fact we don't think they are made up of anything smaller at all. The muon is like a heavy electron, and the neutrino is a ghostly particle which is very light, and doesn't often interact with normal matter.

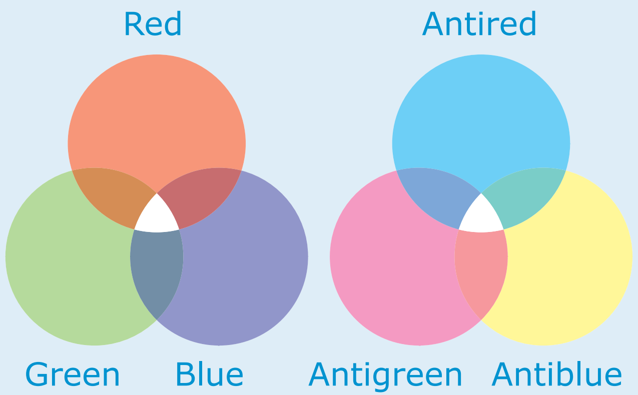
RULES FOR COMBINATIONS: CHARGE

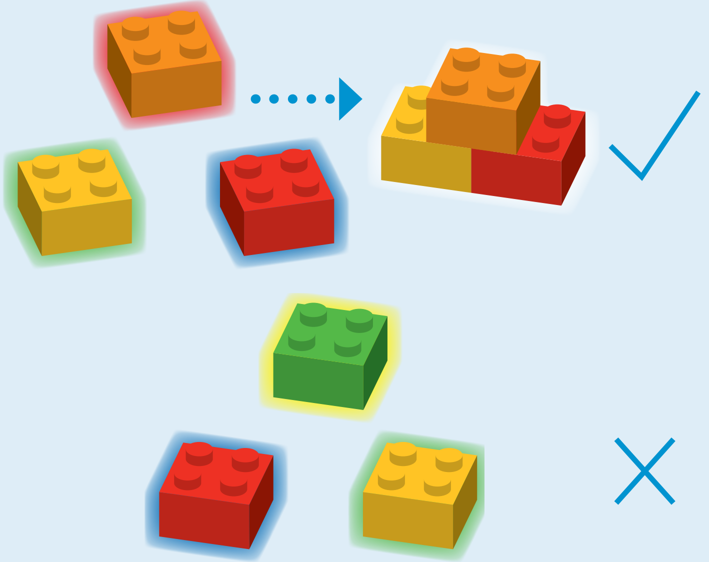


We can't just stick any combinations of particles together to make whatever we like. Quarks combine according to certain rules.

Electric Charge. To make a particle, the charges of the individual quarks must add up to make a whole number. Particles cannot have fractional charge. So a particle with just two up quarks is impossible, because it would have a charge of $^4/_3$.

RULES FOR COMBINATIONS: COLOUR

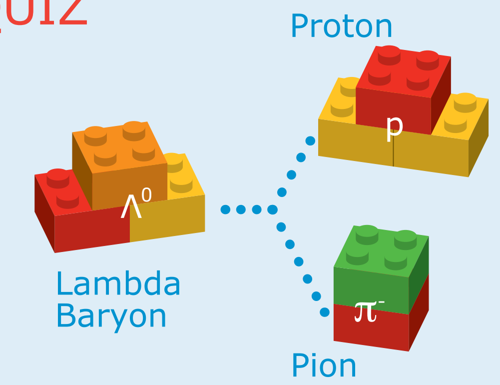




Quarks have a strange property called colour - they can be red, green or blue, whilst anitquarks are antired, antigreen or antiblue. Any quark can have any colour, although antiquarks must have anticolours. This doesn't refer to a real colour, it's just a (rather odd) name for a property, like charge or baryon number. Particles must be colour neutral: that is the colours of the quarks must combine to make white. So a particle with three quarks is fine, as one quark will be red, one blue and one green. A particle with a quark and an antiquark is fine too, as the quark can be red, and the antiquark antired. But if you try to make a particle with two quarks and an antiquark, you won't be able to combine the colours to make white, so it isn't a possible real particle.

INTERACTIONS QUIZ

Charge
Baryon number
Lepton number
Strangeness

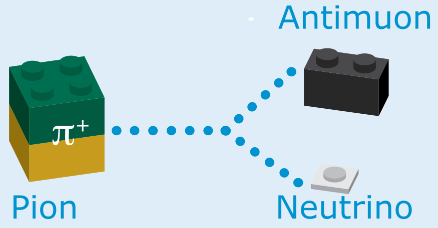


Charge
Baryon number
Lepton number
Strangeness

Charge
Baryon number
Lepton number
Strangeness

What force is it? ____________

Charge
Baryon number
Lepton number
Strangeness



Charge
Baryon number
Lepton number
Strangeness

Charge
Baryon number
Lepton number
Strangeness

What force is it? ____________

Here are some interactions between particles. Work out the strangeness, charge and forces involved.

CONSERVATIONS

When particles interact, they can't just do anything they want. Just like quarks can't combine in any way they like, particle interactions must obey certain rules. Particle physicists call these 'conservations' and there are a lot of them - but here are a few that will be helpful to you now.

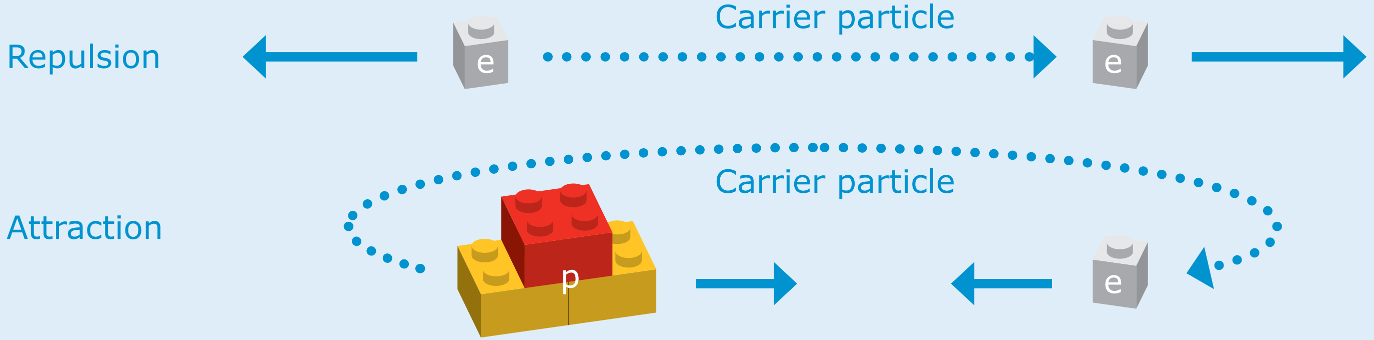
Electric Charge. The charge at the beginning must be the same as the charge at the end. So if the particle which decays has a charge of +1, then the charges of whatever it decays into must add up to +1.

Baryon number. This basically says that the number of baryons (particles made of three quarks) must stay the same. Baryons have a baryon number of +1, whereas antibaryons (made of three antiquarks) have a baryon number of -1. This does mean that you can add a baryon-antibaryon pair to one side of a reaction, as their baryon numbers combine to make 0.

Lepton number. Similar to baryon number, but for leptons. Electrons, muons and neutrinos have lepton number +1 and their antiparticles have lepton number -1.

Strangeness. This is like a 'strange quark number', like baryon or lepton number, except backwards: if a particle has one strange quark in it, it has a 'strangeness' of -1. A particle with an antistrange has a strangeness of +1. What this is saying is that most of the time, if you start off with a strange quark in the particle before it decays, you will end up with one at the end. It's like a chemical reaction: if you start off with 4 oxygens, whatever you get at the end must contain 4 oxygens. However, there is one big exception to this: the weak force. This force has the weird ability to change one quark into another, an effect which is very important in everyday life (see page 10!). If you have a strange quark at the beginning but not the end, you can be sure that the weak force is responsible!

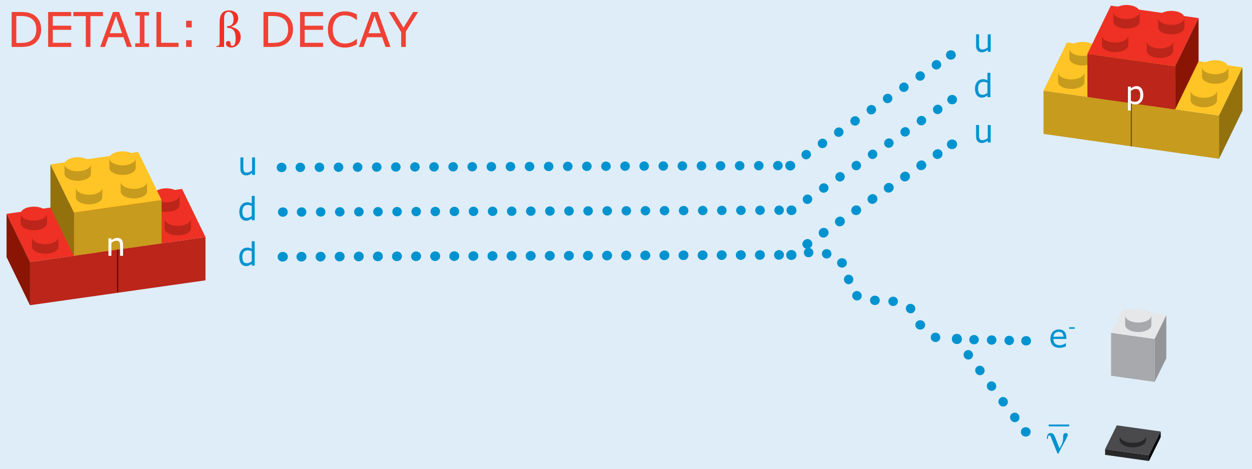
HOW FORCES WORK



There are four types of force that we know about. The one that is the most familiar to you – gravity – isn't actually very important in particle physics, because it is very weak compared to the other three. The three important forces are: **Electromagnetism**. This will be very familiar to you – it's why you can stick things to the fridge and watch tv. **The strong force**. This is the strongest force (unsurprisingly), and is what sticks quarks together inside particles. If the quarks get too close together, the force becomes repulsive, so that the quarks don't collapse in on one another. **The weak force**. This is the only force that can change one type of quark into another, and only works over very very small distances. Gravity doesn't seem all that weak, but the strong and weak forces are very short range, so we don't really notice them, and things tend to have no overall electric charge, so electromagnetism doesn't make us all stick together.

Forces work through the exchange of particles. Imagine throwing a ball to someone. As you throw the ball, you have to move backwards a little – and when they catch it, they will move backwards too. This is how repulsion works. To imagine attraction, think about throwing the ball with your back to the person, over your head. If you both move backwards, you will end up closer together.

IN DETAIL: ß DECAY



Earlier, we said that the weak force has the ability to change one quark into a totally different type of quark, a bit like changing an oxygen atom into something totally different. This might seem a bit strange – but in reality, it causes a very well known effect, and one that you have studied a lot. Radioactivity is where one element turns into another element, by emitting radiation, and the most common type – beta decay – is controlled by the weak force.

In beta decay, a neutron turns into a proton, shooting out an electron in the process. To conserve lepton number, it must also emit an antineutrino at the same time. But what is actually happening? Take a look at the Feynman diagram – a handy way of writing down what is going on in particle interactions. One of the down quarks in the neutron is turned into an up quark and becomes a proton. In order to do this, one of the force carrier particles mentioned earlier is released, which quickly turns into an electron and an antineutrino. This type of decay is called ‘Beta Minus’ decay, because it emits a negatively charged electron.