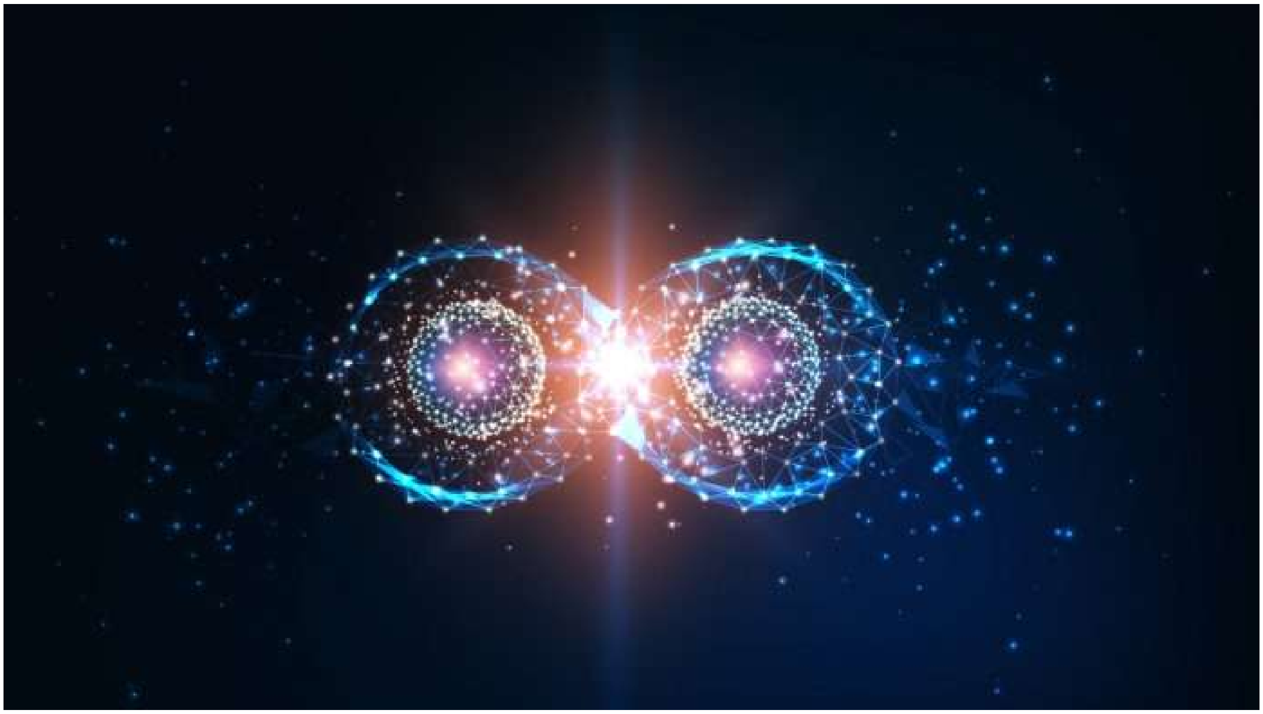
Physics Newsletter

April 2021



Hi guys,

Welcome to the 11th edition of the Physics Newsletter. This edition's theme is recent quantum discoveries, since there have been a few very significant ones. We hope you get entangled reading our articles for this month!

In this edition we will discuss:

- The Muon G-2 Experiment - Vanshika Gupta (15guptav699@kechg.org.uk)
- The Leptoquark Hypothesis - Maheen Abir (15abir780@kechg.org.uk)

If you have any questions about our articles or would like to contribute to the next edition of the newsletter, feel free to email us :)

The Muon G-2 Experiment

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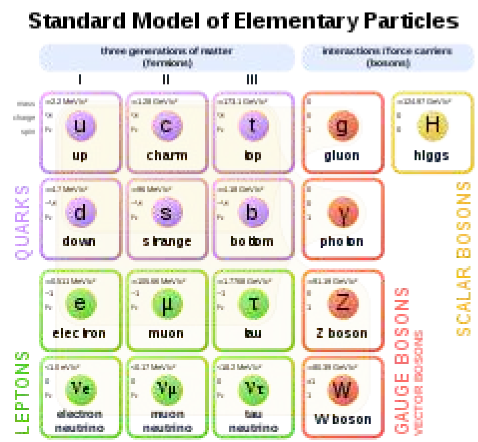
Intro



The standard model is all that particle physicists have known and developed ideas, theories based on it like a base- something that is a surety and cannot be wrong. However, this experiment at fermilab has raised doubts and has highlighted the dangers of having a false sense of security in the field of physics, *the* ever changing field. Results from the muon g-2 experiment have shown that there may be other forces or another particle at play that we still need to discover.

As I said, the standard model was insanely accurate. It helped us make many predictions about particles precisely. For example, there was the Higgs boson. It was theorised to exist before it was discovered. However, this possible particle has shown evidence to exist, but it came out of nowhere.

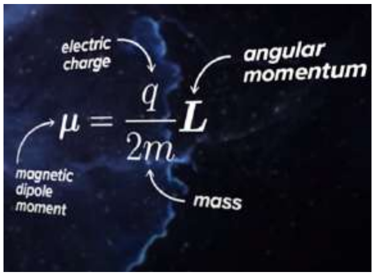
If you simply just want a summary and not confuse yourself more please go down to the summary

The Theory

<u>Magnetic Dipole Moment</u>

Moving charges generate a magnetic field around them (just accept it for now) just like current going through a wire or particles. If you have a background magnetic field and you place a smaller thing with a magnetic field, the fields of both the objects will align with the north and south, like a magnet. The strength or pull of one of the fields to align with their own magnetic field is called torque and is dependent on how much the thing with a magnetic field is spinning. Because if it's spinning it will be way harder for it to align with the primary magnetic field- the spinning is called angular momentum.

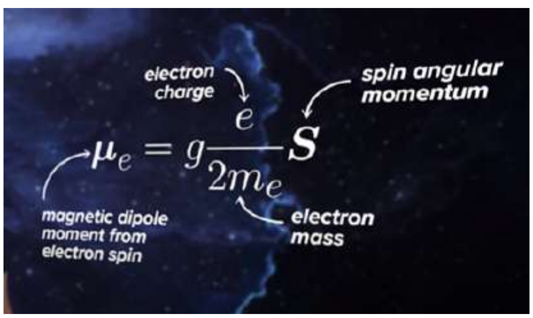
● ‘ Like a compass needle, the magnetic moment (μ) will seek to align with an externally applied magnetic field (Bo).’



If you really think about it in terms of the formula it does make sense for a spinning thing with a magnetic field to align with the external magnetic field it came into- It needs to do some work. The moment it would have to go through (how much it turns to align) would depend on how much the particle or object is spinning in the first place, it’s mass because if it’s heavier you would need it to spin more and it’s charge because if it has a higher electric charge, its own magnetic field would be stronger so it would be attracted to the external magnetic field and would want to align more.

<u>G-factor</u>

In layman terms it’s ‘how much a particle wobbles’



The electron is special though, its magnetic dipole moment depends on a factor, it doesn’t exactly obey the formula. So for all electrons and particles similar to the electron **cough the muon* the strength of the magnetic dipole moment is dependent on this factor aka the g factor.*
For the electron, g is around 2 so the magnetic dipole moment is 2 times bigger than your average particle.

● g= how strongly particle interacts with magnetic field/ Interaction strength= the sum of all the possible ways an interaction can take place (feynman diagrams can depict these interactions)

<u>Anomalous Dipole Moment</u>

The anomalous is the bit left over, all the decimals.. And also what the experiment is all about

For example, for the electron anomalous, the scientist Paul Dirac calculated the simplest g factor (which is always for an electron) which was g=2 . Over time more people added to the interactions and stuff to adjust the g factor for more complicated interactions. Now because of nice computers we have a very accurate g factor. The anomalous is calculated by doing the value of g that we have calculated (G) minus the basic value of g=2 .

anomalous= G - 2
This is where the muon g-2 name comes from

This will give a bunch of digits left over.
The theoretical value of this anomalous matched the experimental value of the electron which was nice, so then we decided to measure the anomalous for other particles...that's the point of the experiment.

So physicists continued on their journey. The muon is a particle similar to the electron, it's heavier cousin, so we decided to start from there to measure its g factor. The muon would have a different g factor to the electron because they're still different particles and they would have different set of possible interactions. Now what the main talk of this experiment is and why it's so groundbreaking is that its g factor is different to its theoretical g factor.

I understand that his discovery may seem a bit pedantic but i'll explain. Some physicists did theoretical calculations of the value of the g factor, the roundabouts or the probability of where it should be. However after running the experiment it turned out all our calculations were wrong. What's really shocking is that our very accurate standard model couldn't predict muon g2 glitch. So the implications are quite exciting, something i'll explain a paragraph down.

What's physically happening in the experiment ?
What is happening in the experiment is that loads of muons are spinning around a round magnet at almost the speed of light and physicists are measuring the wobble of the particle. When they're in the giant magnet spinning around (like in CERN), the muon particles are in a vacuum but the wobble (g factor) of the particle is affected by 'quantum foam'. Now that really paints a picture… no not literal foam but just these virtual particles that pop in and out of existence anywhere including a vacuum- so you never really have emptiness. These particles interact with the muons and affect the g factor. In the calculations these virtual particles were accounted for… so there shouldn't be a difference between the calculated value and experimental but there is.

Why should I care?
If the theory does not fit with the result then there is something we haven't found yet to explain the experiment being weird.
Before the experiment the g factor of the muon was predicted to be g= 2.00233183620
And it was actually g= 2.00233184080

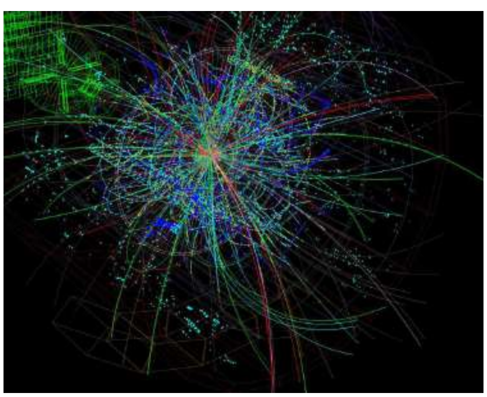
Why this is exciting is because there is something that we have found that cannot be explained by us through or current theories alone. We'll either need to adjust them or create an entirely new area of physics. This experiment is literally like a pearl found after loads of barren oysters for theoretical physicists. It's funny because I think only physicists can relish in the idea of knowing less.

So these results could lead to:
- New theories because our very accurate one is wrong
- A new particle
- New forces
- Disappointment because something went wrong in the experiment (highly unlikely though)

What will happen in the future?

The aim is now for this result to be declared as an official discovery in physics. Now for something to be called a discovery, it needs to have a probability of coming up in 1 in 3,500,000 (aka 5σ) and this g factor was INCREDIBLY close so it looks like we have a new particle to discover for it. However, currently, the experiment wasn't accurate enough (surprisingly) and the bump had the chance of happening in 1 in 100,000 (4.2σ). With a higher accuracy this value should move more towards the rare side.

Summary



Muons are the 'heavier cousins' of the electron, they're literally the same except that the muon is heavier .Particles with an electric charge that move also have a magnetic field around them. Scientists experimented with putting a muon and testing it under a magnetic field. The muon's own magnetic field and spin interact with the magnetic field applied in the actual experiment. This interaction that takes place is called a magnetic dipole moment. The formula of a magnetic dipole moment relates a constant called *g (aka g factor)* and other quantities. 'g' was predicted to be 2, but with the help of the standard model we got a more precise value.The addition of the small amount after the two is the anomalous dipole moment (or formulaically 9-2 *which is in the title of the experiment btw*). So after the experiment, the g factor for the muon experimentally was different to the theoretical value of the g factor. The experimental g factor value had a little more added to it, something that we hadn't accounted for .This means there is stuff that we still don't know about. But for this to be counted as a discovery, the chance of it happening needs to be 1 in 3.5 million (5 σ) but is currently 4.2σ. Future experiments and reruns hope to get a higher precision so that this value can get to 5σ.

In the end, it is most probable that there is still more we don't know and we might have to ditch/ add to the standard model which is quite an exciting thought :D

Bibliography

If you struggled to understand what I said, don't worry I don't even know what I said so you're good to go.
I basically just watched a bunch of youtube videos because I wouldn't understand it just by reading (funny how i made an article huh)

- https://www.youtube.com/watch?v=O4Ko7NW2yQo&t=76s
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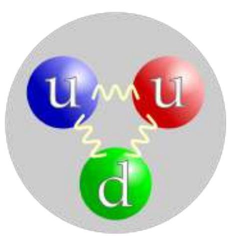
Vanshika Gupta 12P :D

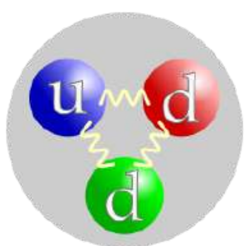
The Leptoquark Hypothesis

The world of physics is rich, diverse and characterised by groundbreaking discoveries. It comes as no surprise, then, that researchers at CERN have potentially made an incredible find: a new particle dubbed a ‘leptoquark’. Its existence was hypothesised by physicists working on the Large Hadron Collider (LHC) and has forced reevaluations to be made about the behaviour of certain particles.

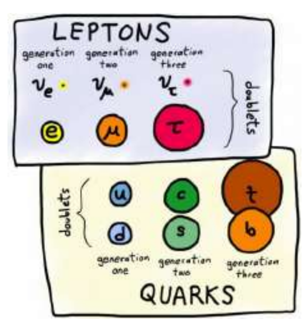
But before I discuss this, it is crucial to provide some background on particles.

One of the first things we are taught in science is that all matter is composed of atoms, which are supposedly the smallest possible particles. Then, later on, we find out that atoms can actually be broken down further into protons, neutrons and electrons. And finally, if you’re brave enough to take A level physics, you’ll learn that protons and neutrons fall into a class of particles named hadrons, which are made up of quarks. Here, at last, are the true holders of the ‘smallest particle’ title, along with other elementary particles like electrons and muons. Quarks and electrons are fundamental in the composition of all commonly observed matter. There are many different types of quark, like the charm quark, strange quark, top quark and bottom quark. However, the only stable types are the up and down quarks, which are responsible for the formation of composite particles like hadrons. Depending on their arrangements, they can form different particles. For example, two up quarks and a down quark make a proton, and two down quarks and an up quark make a neutron.





In this article, we’ll be focusing on the bottom quark, also known as the beauty quark. It is a third generation heavy particle, significant for its low rate of transition into lower mass quarks (which is unusual, given its size). The Standard Model of particle physics, which, despite limitations like being unable to explain theories like dark matter, is generally accepted as the best theory explaining particle physics, states that generation 3 particles should decay into muons and electrons at equal rates. However, as we have come to expect with the notoriously fickle field of particle physics, this might not actually be the case.



The LHC is a particle accelerator which makes high-energy protons collide at the speed of light. This creates many unstable exotic particles[1], which decay rapidly. Beauty quarks are no exception, but they follow a different decay path. Electrons are produced more frequently than muons in beauty quark decay, which seemingly violates the Standard Model. This is because the model states that interactions producing the two particles do not discriminate between either type as they are identical save for their masses (with muons being around 200 times more massive).

This anomaly was first noted in 2014. Now, after extensive study on data from 2011-18, it has been discovered that the electron decay chain is favoured over the muon decay chain. But what does this have to do with a new particle?

Since the actual decay path of the beauty quark defies what is expected, it is possible that a different type of interaction could be at play other than the ones that we already know about. This would be our leptoquark, a massive exchange particle[2]. If this is true, which it certainly could be, as the uncertainty of the experiment is over 'three sigma' (meaning that the chance of the result being a fluke is only one in a thousand) then it means that there could be a whole new world of particles and interactions far beyond what is theorised in the Standard Model .

We might be a long way away from definitively finding out if the leptoquark theory is true (we need an uncertainty of 5 sigma for this), but, needless to say, the research that has been compiled over the past ten years has helped us to potentially find a new type of particle and, by extension, many hitherto unknown interactions and particles. As I iterated earlier, physics as a subject is all about finding new possibilities and challenging what we already know in order to gain a better understanding of the universe around us.

I hope you enjoyed this article. Look forward to the next edition of the physics newsletter!

~ Maheen :)

1: https://en.wikipedia.org/wiki/Exotic_matter

2: During particle interaction there is a change in the energy state of each particle e.g. one gains energy and the other loses it. As seen in the equation $E=mc^2$, mass and energy are interchangeable, so an 'exchange particle' simply goes from one particle to another.

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