CONTAINING ANTIMATTER

The antimatter trap from "Angels & Demons"

From Star Trek (The Original Series)
Season 3 episode "That Which Survives" (1969)

"…and I'm not even sure a man can live in a crawlway in the energy stream of the magnetic field that bottles up the antimatter!..."

Can we really “bottle up” antimatter?

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**Antimatter HAS been successfully contained,
but only in very small amounts
and on relatively short time scales.**

As you saw in one of the examples in the lesson *"Boys With Toys"*, the Enterprise would have had to contain 15 thousand tons of antimatter (just to propel it at one-half the speed of light).

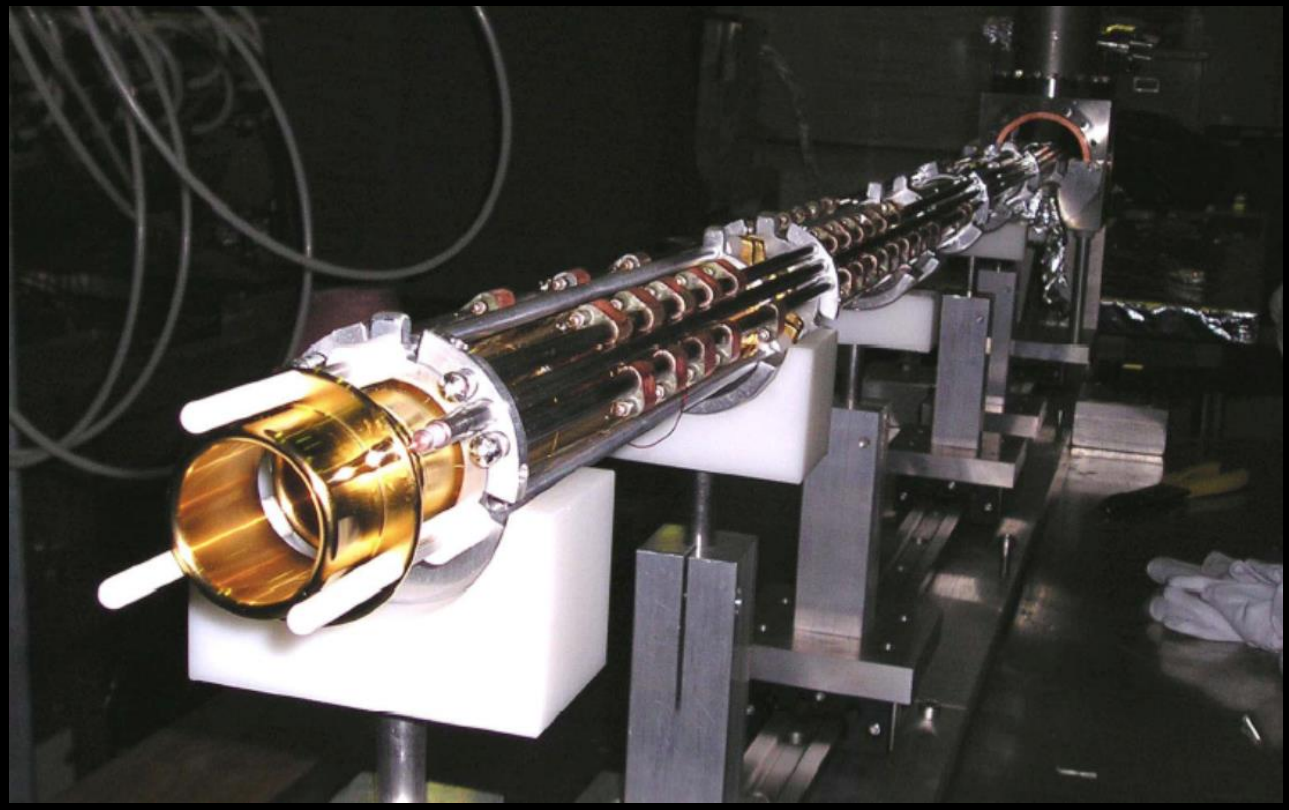
As you discovered in the lesson *"Operation: Annihilate"*,
the portable antimatter trap in the *Angel & Demons* movie
contained a seemingly "reasonable" amount (0.12 grams) of antimatter.

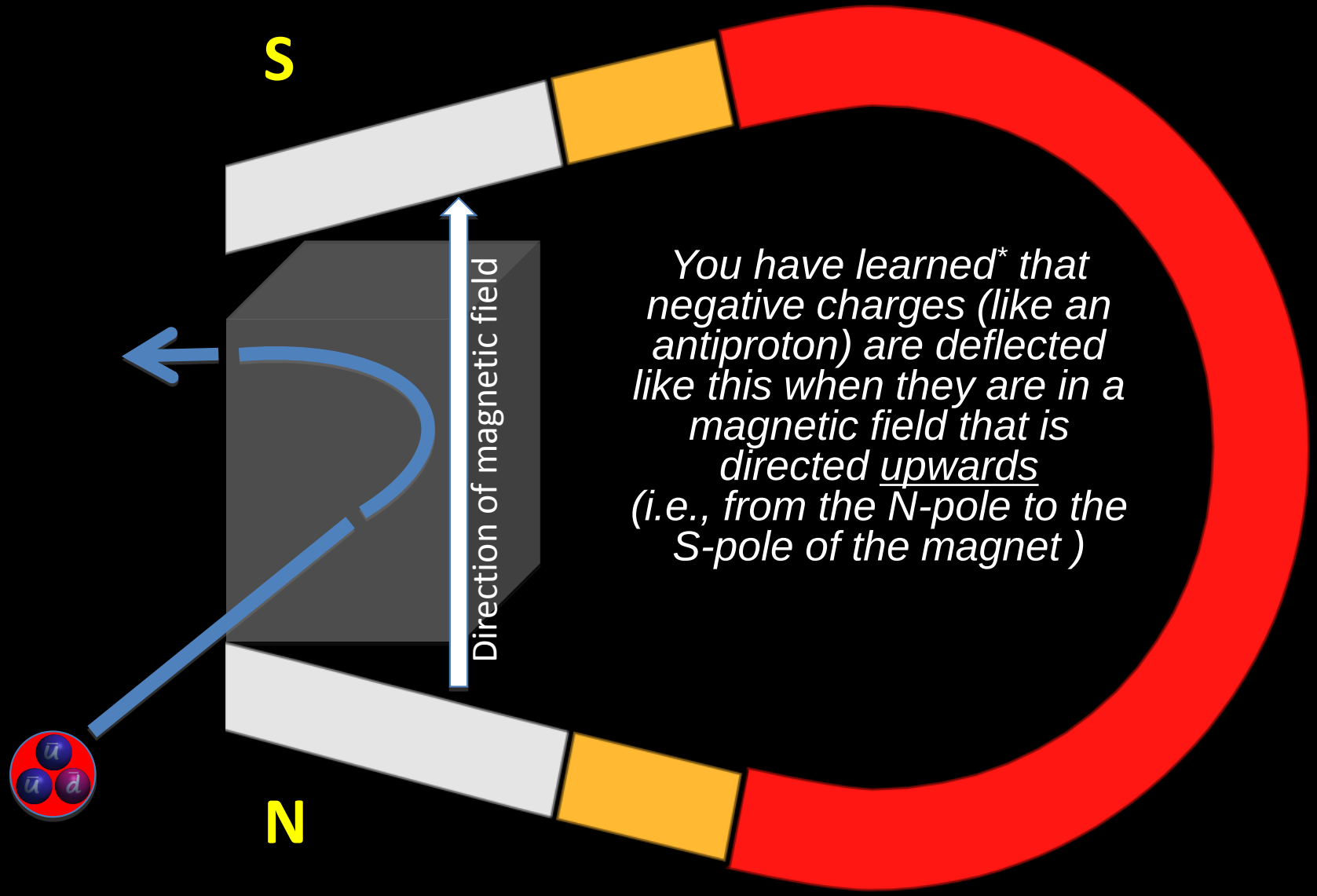
But even this small amount would have required the containment of
around 7.2×10^{22} antihydrogen atoms.

If magnetic fields are to be used
to contain antimatter,
the particles must be *electrically charged*.

An atom of antihydrogen,
(composed of an antiproton and a positron)
is *electrically neutral*.

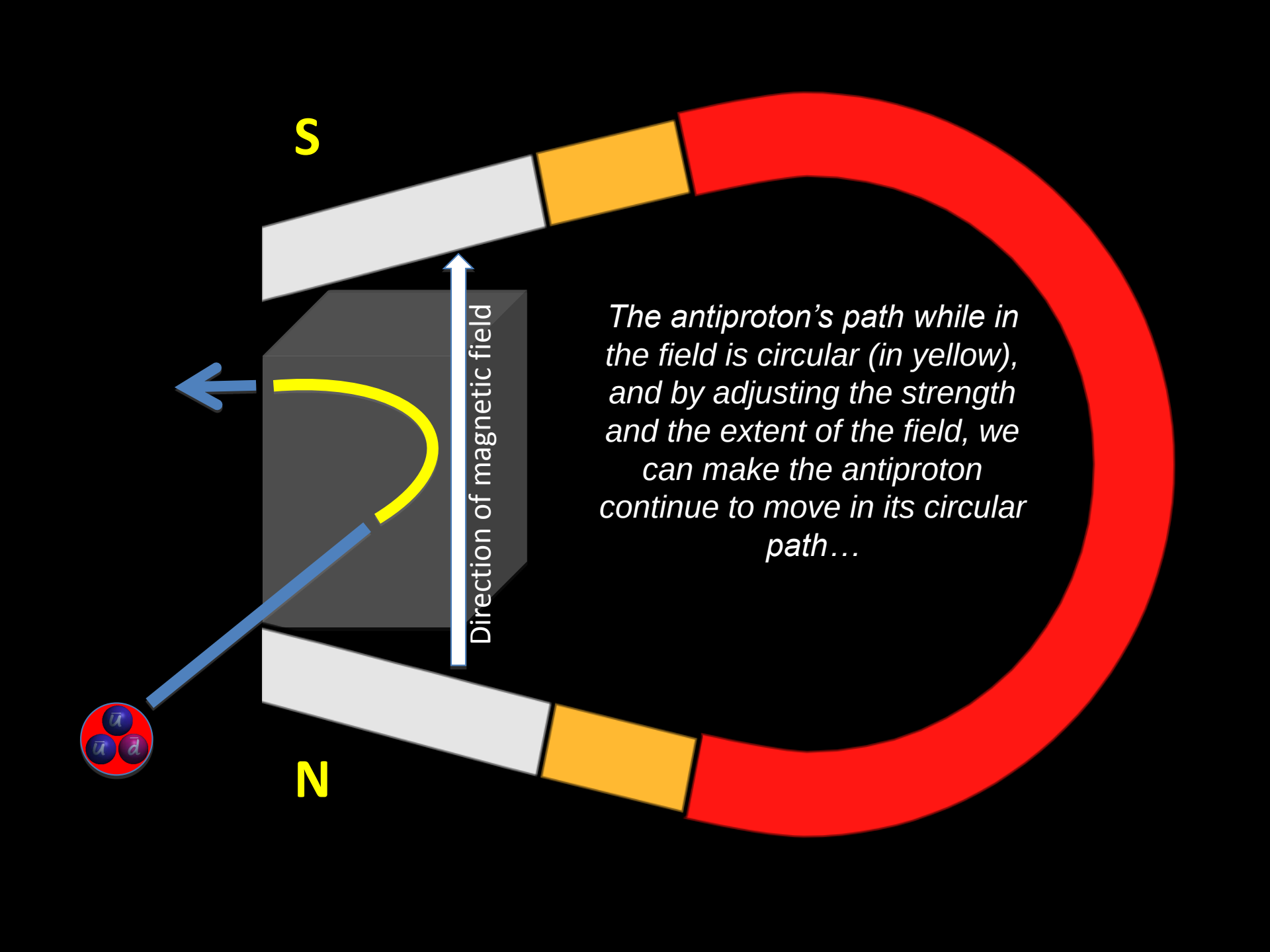
However, charged particles of antimatter such as positrons and antiprotons can be contained in a containment apparatus called a "Penning Trap". We shall take a look at how a *simplified* version of this cylindrical-shaped container can trap antimatter…





You have learned that negative charges (like an antiproton) are deflected like this when they are in a magnetic field that is directed upwards (i.e., from the N-pole to the S-pole of the magnet)*

**See "Will You Be Charging That?" in the Background Materials*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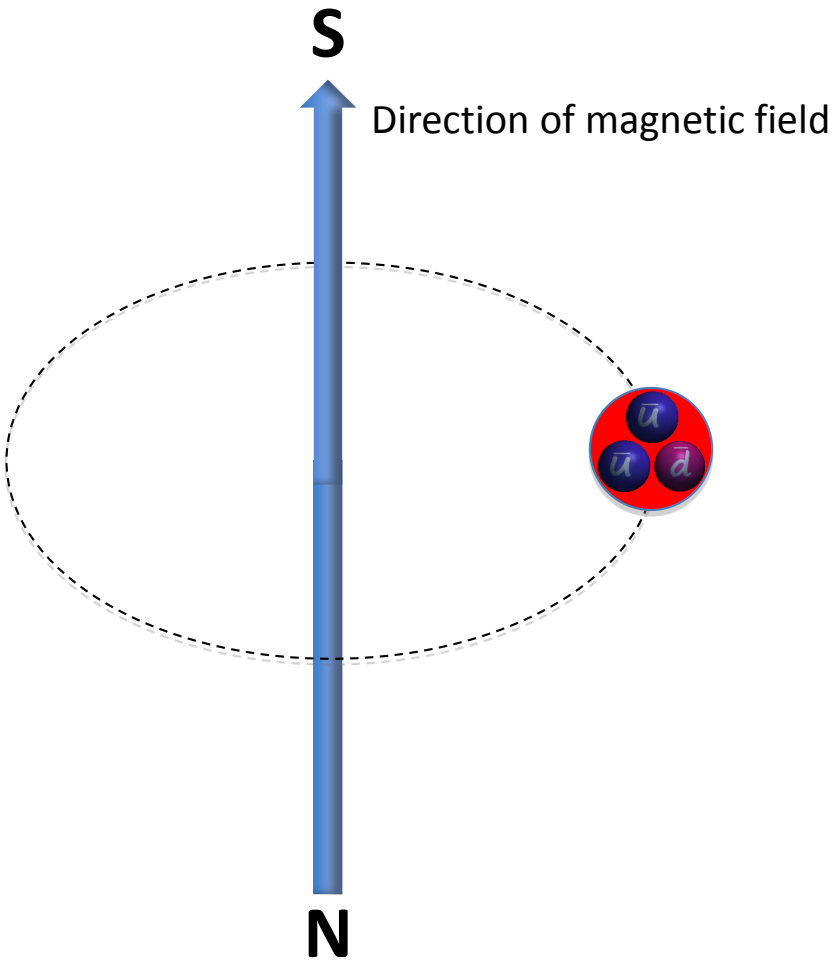
The antiproton's path while in the field is circular (in yellow), and by adjusting the strength and the extent of the field, we can make the antiproton continue to move in its circular path…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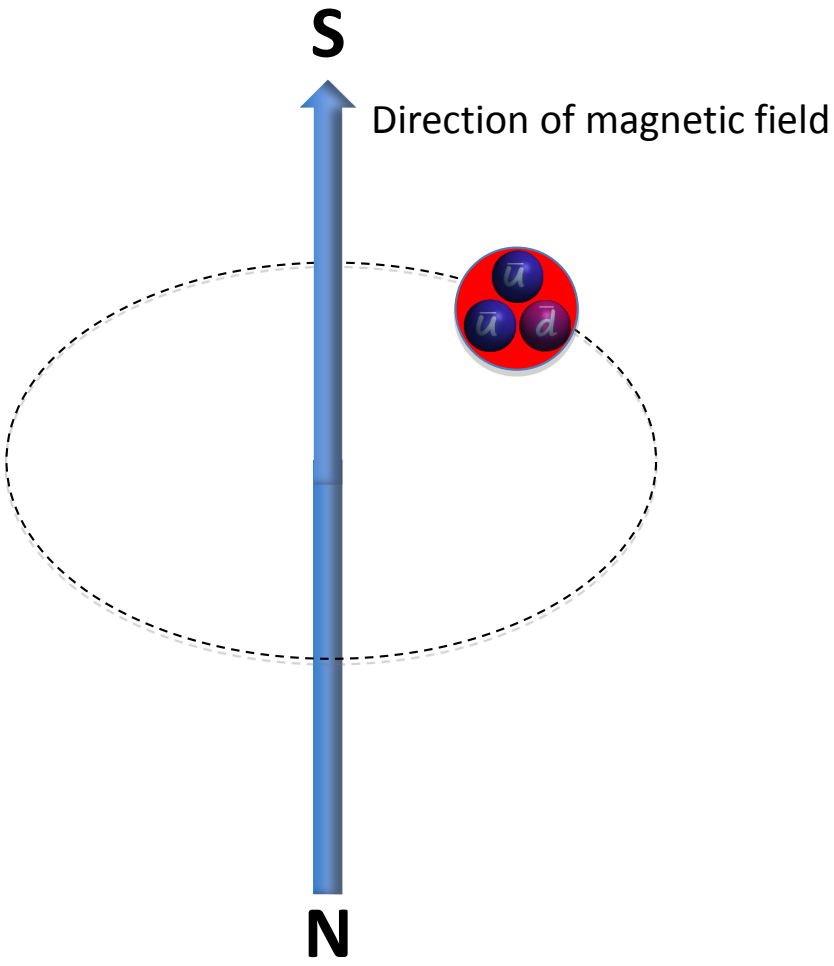
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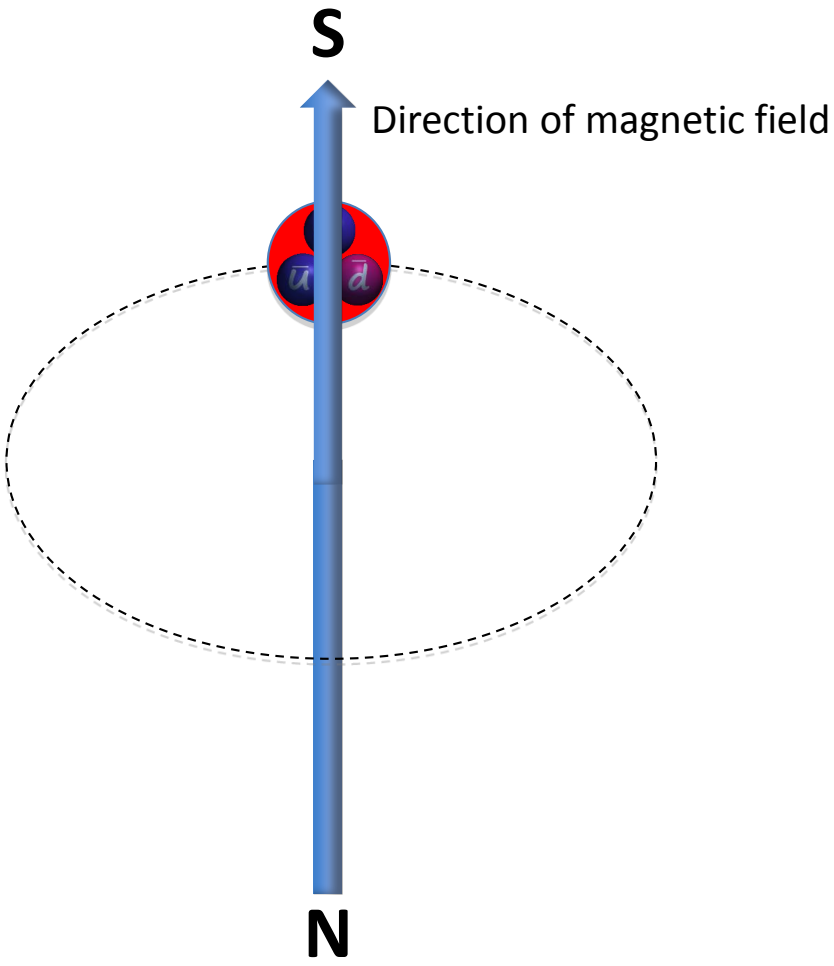
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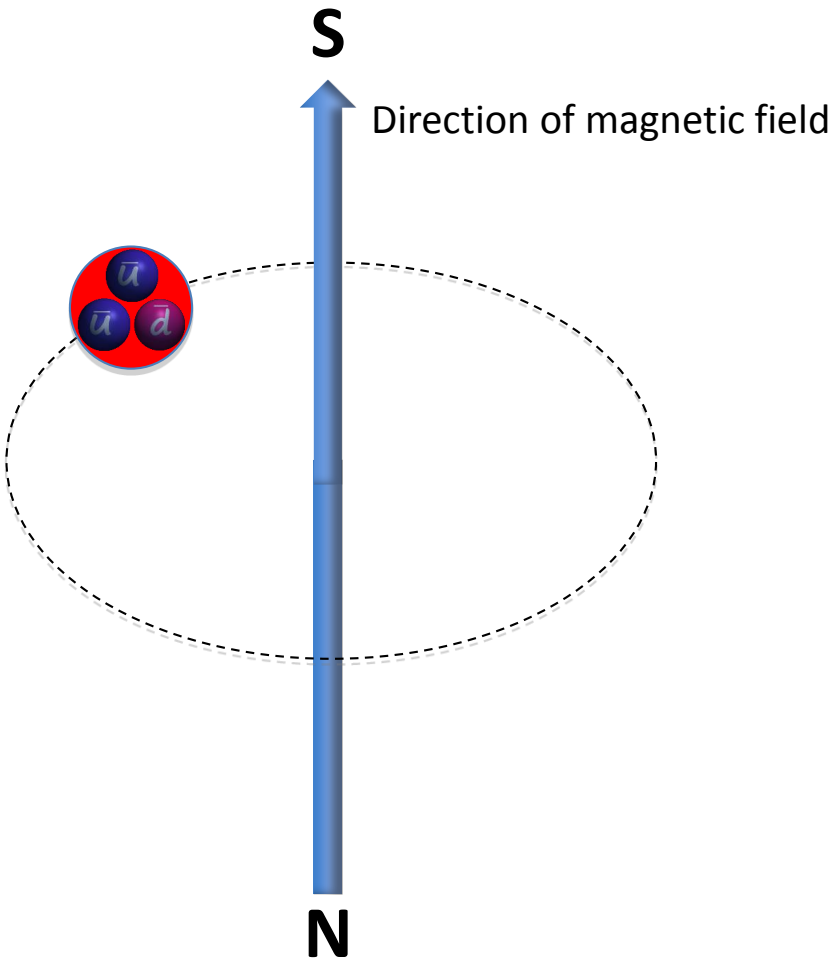
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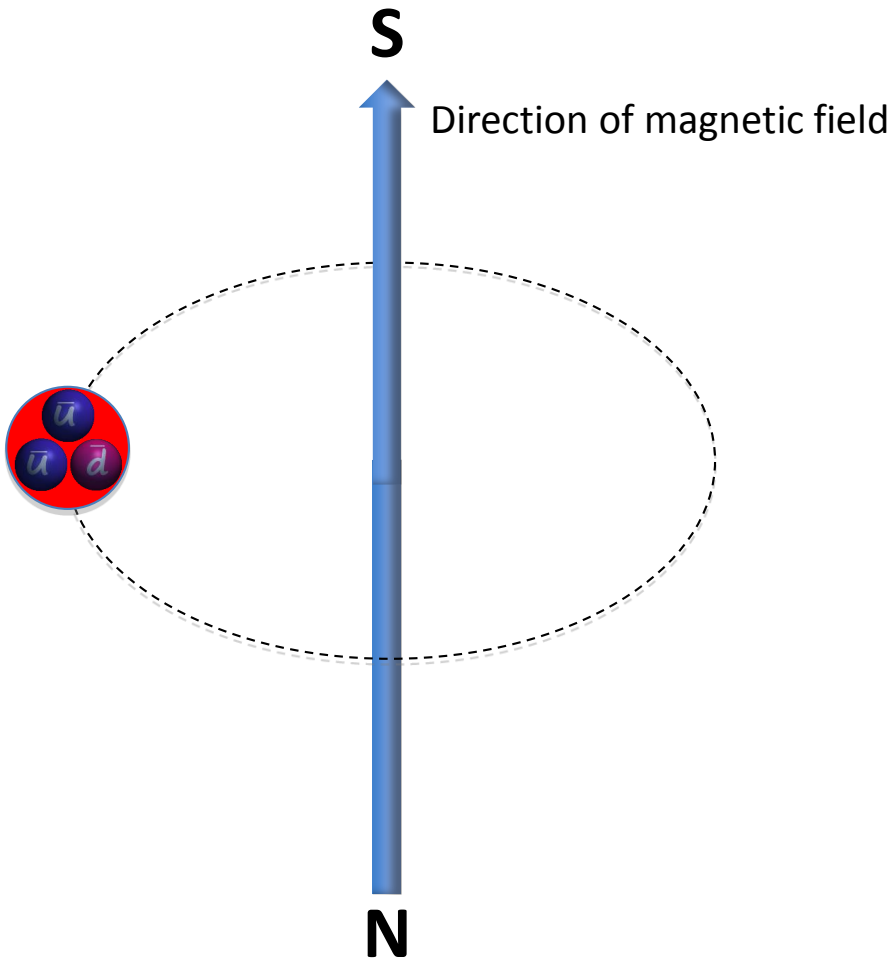
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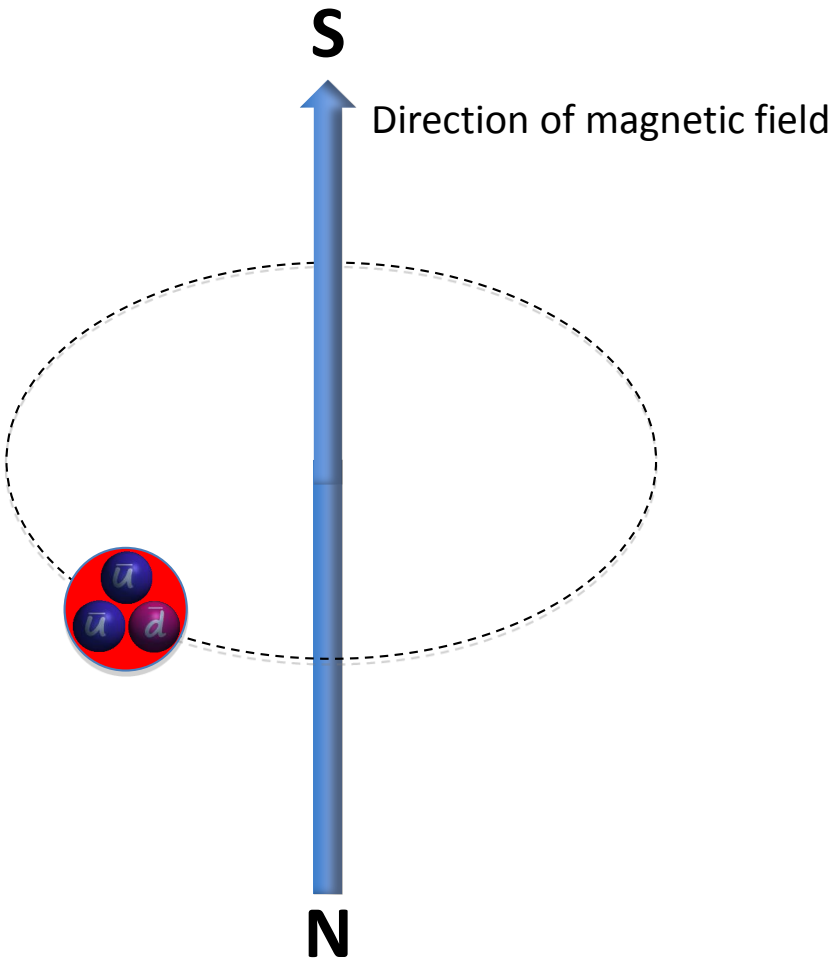
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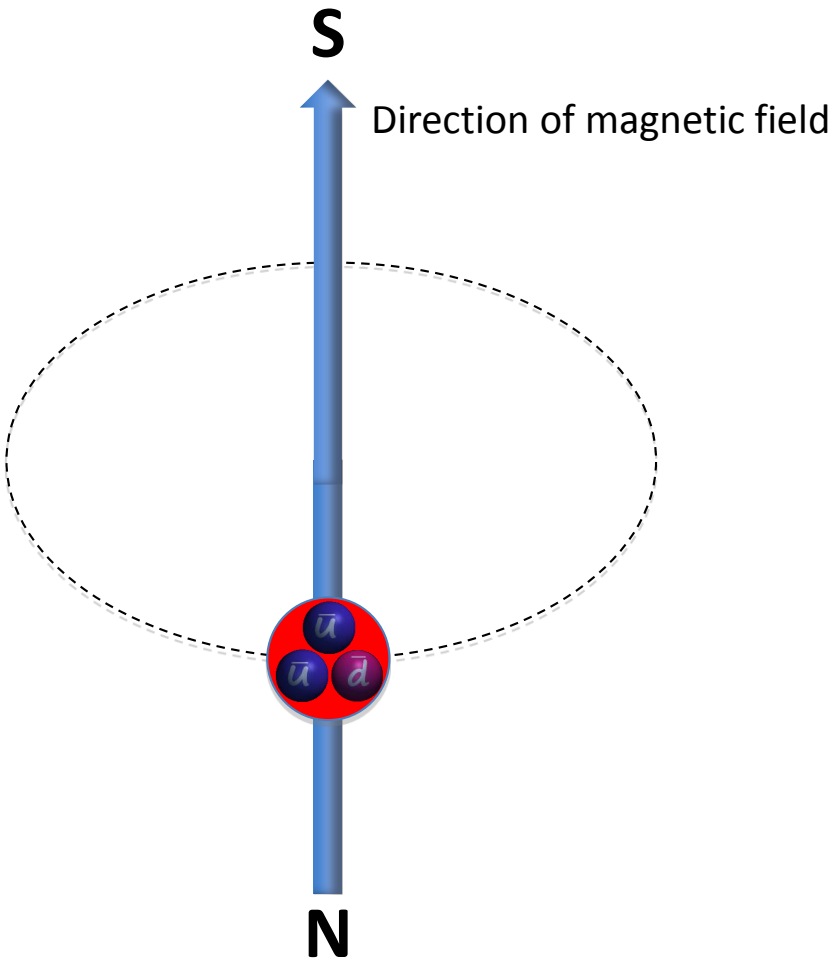
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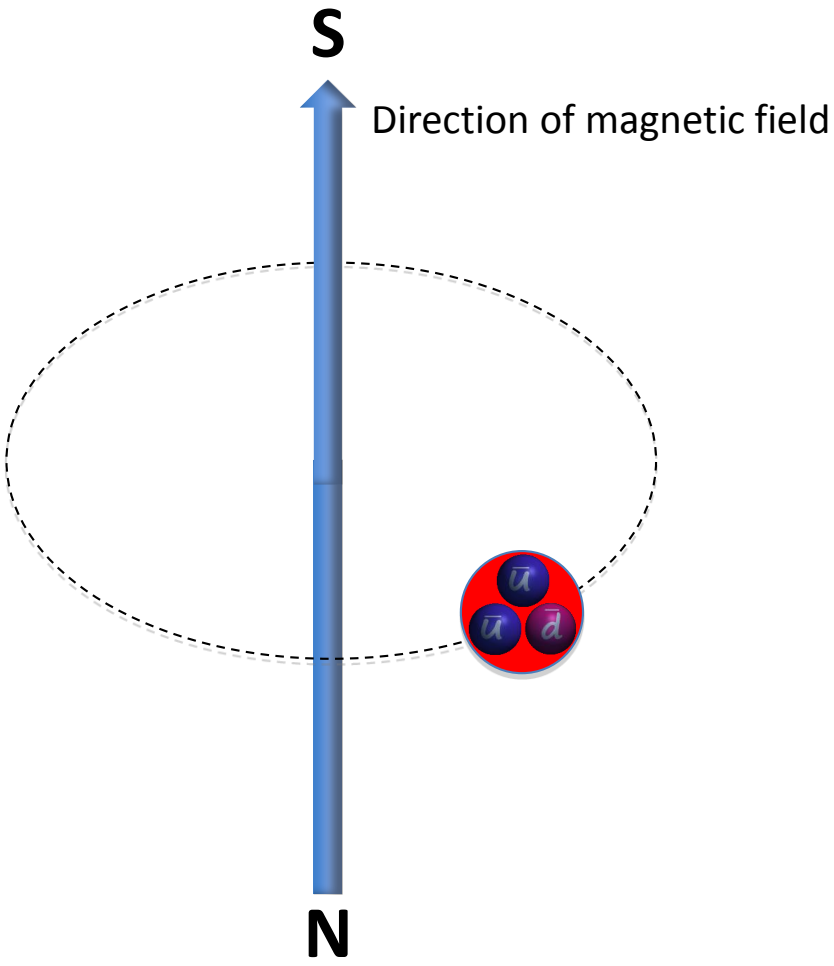
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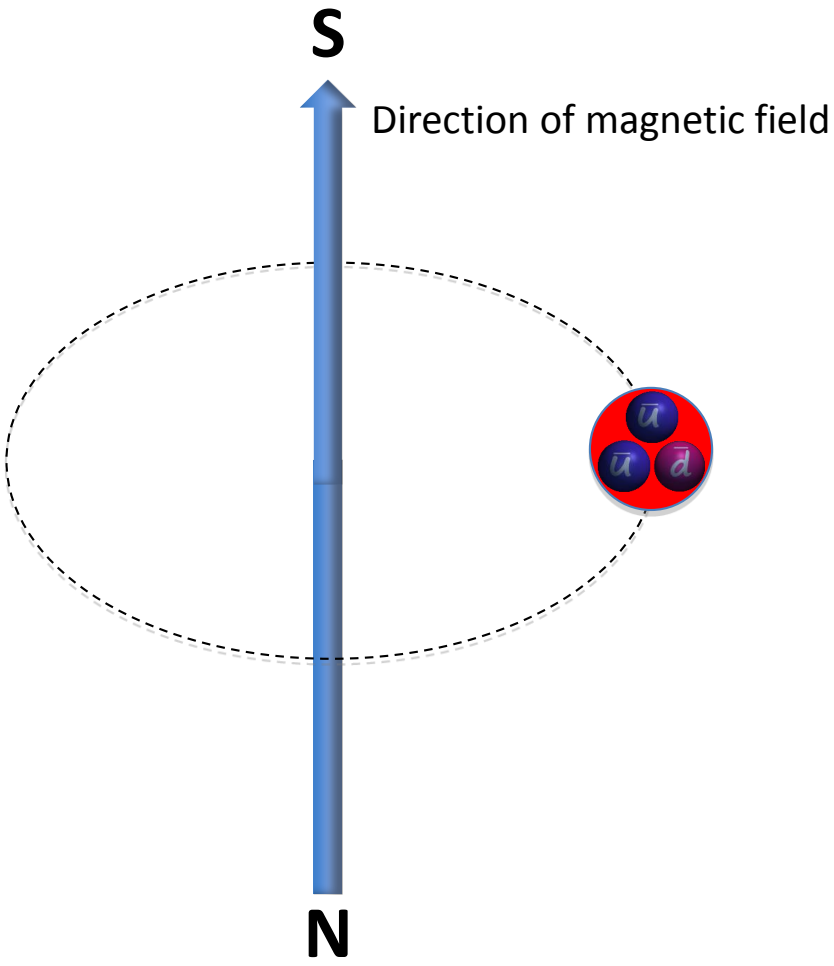
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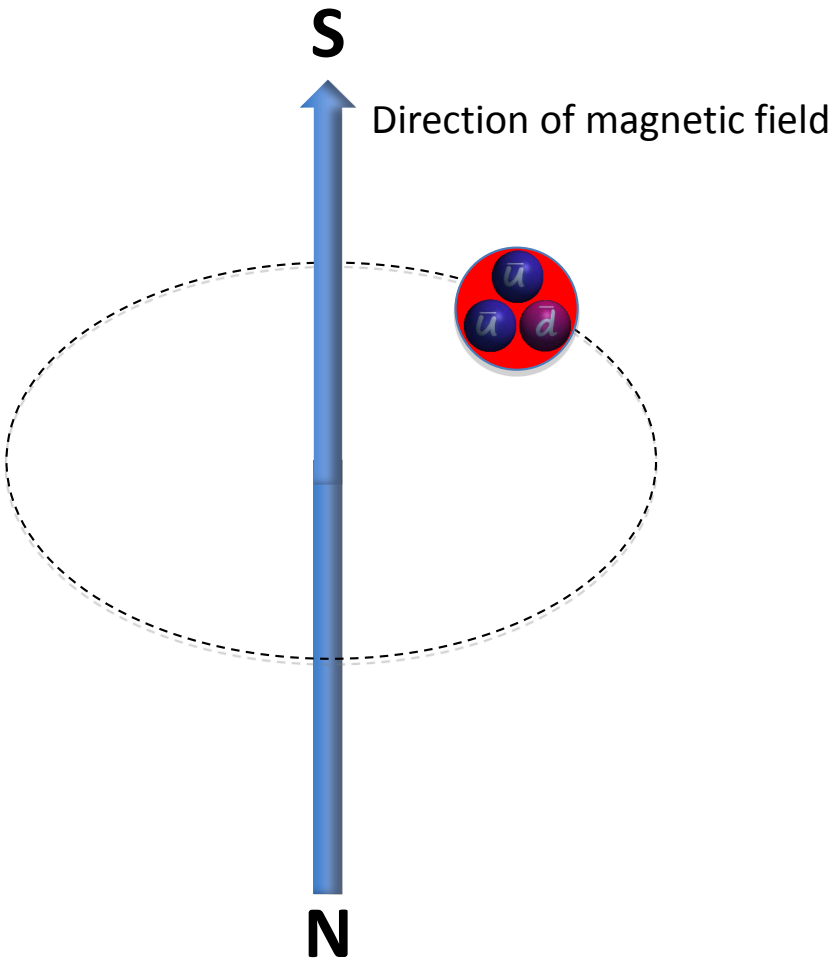
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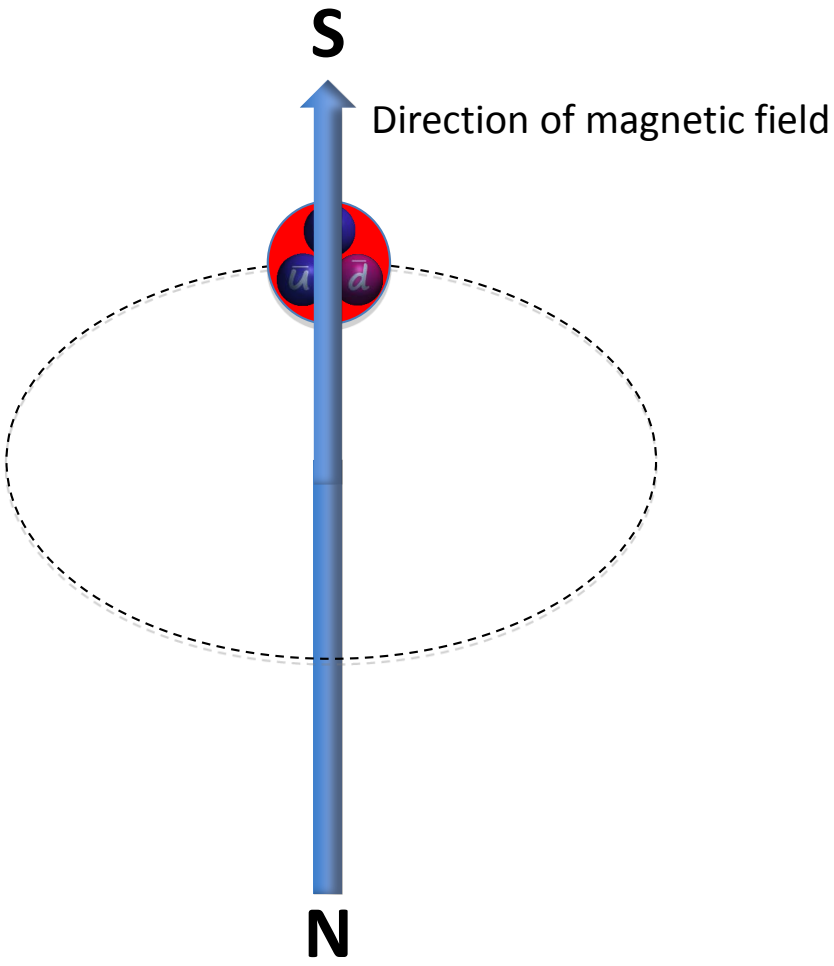
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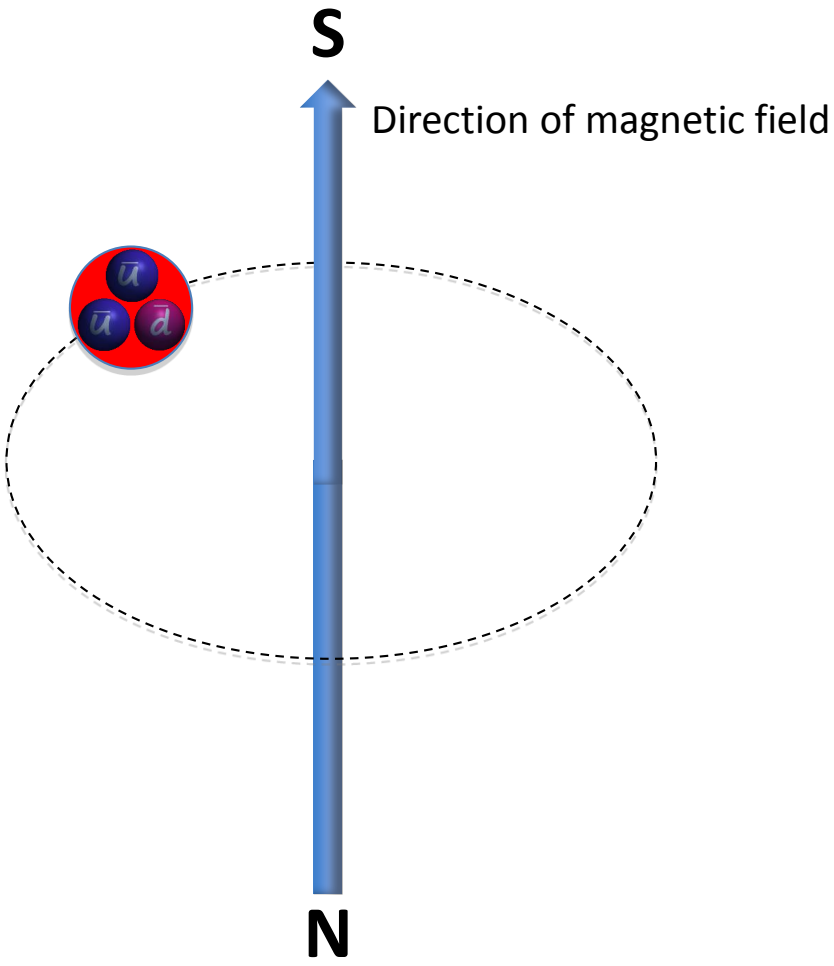
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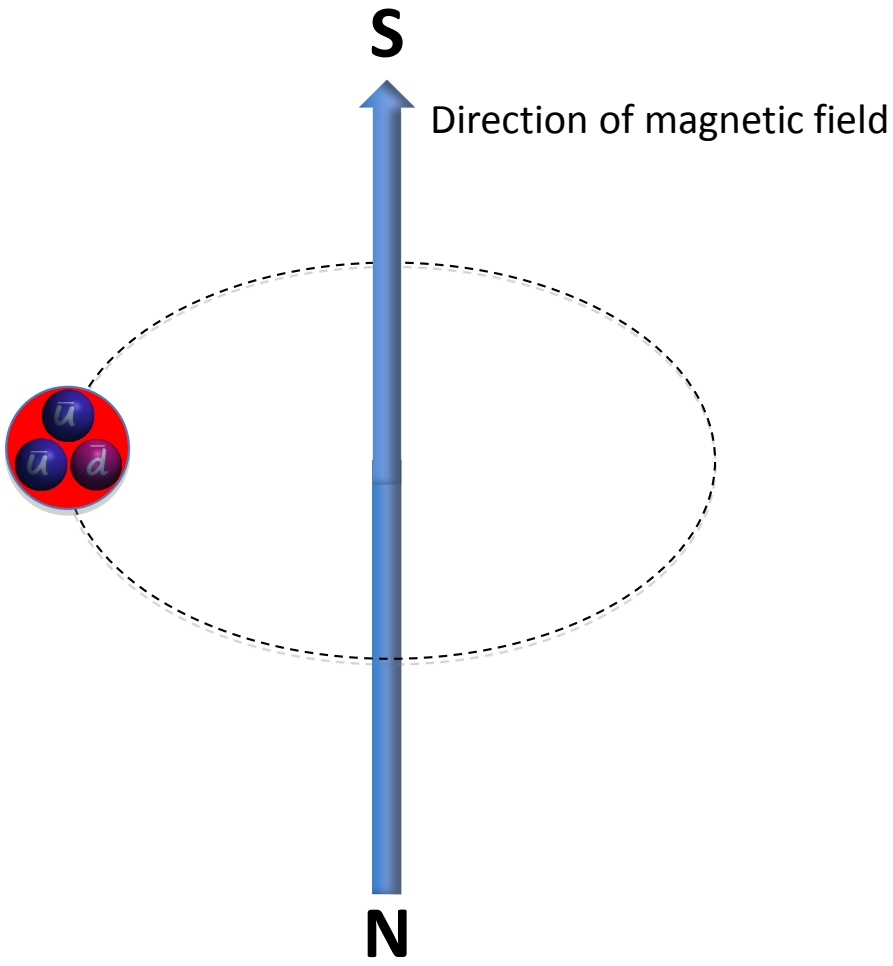
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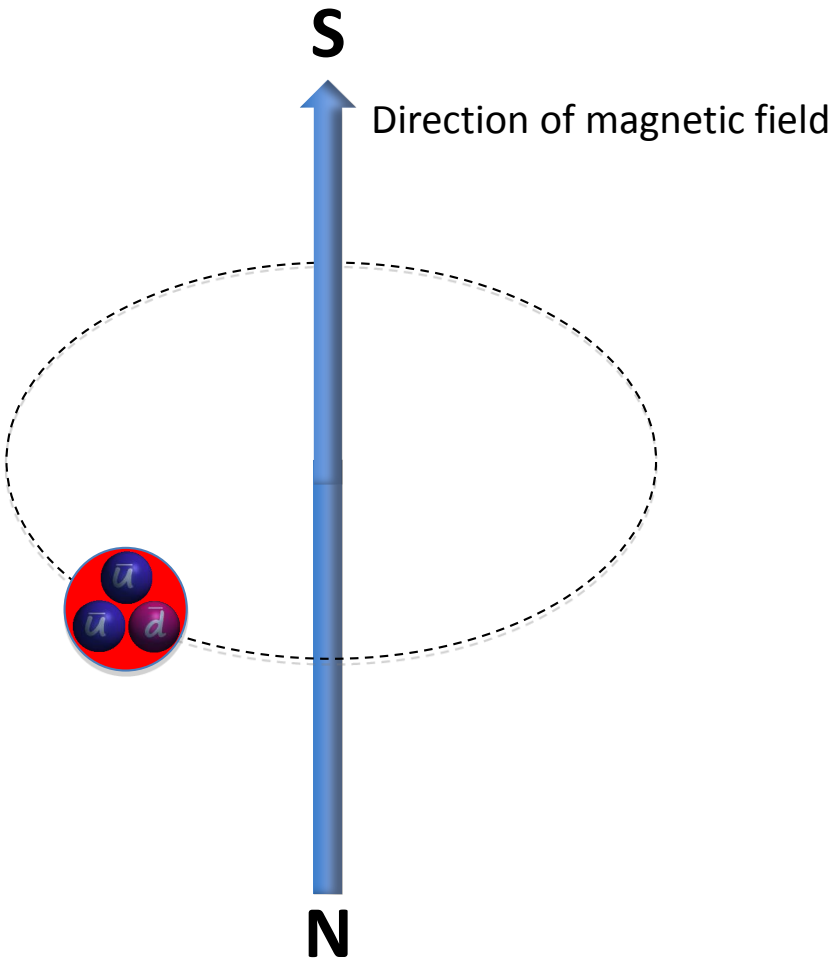
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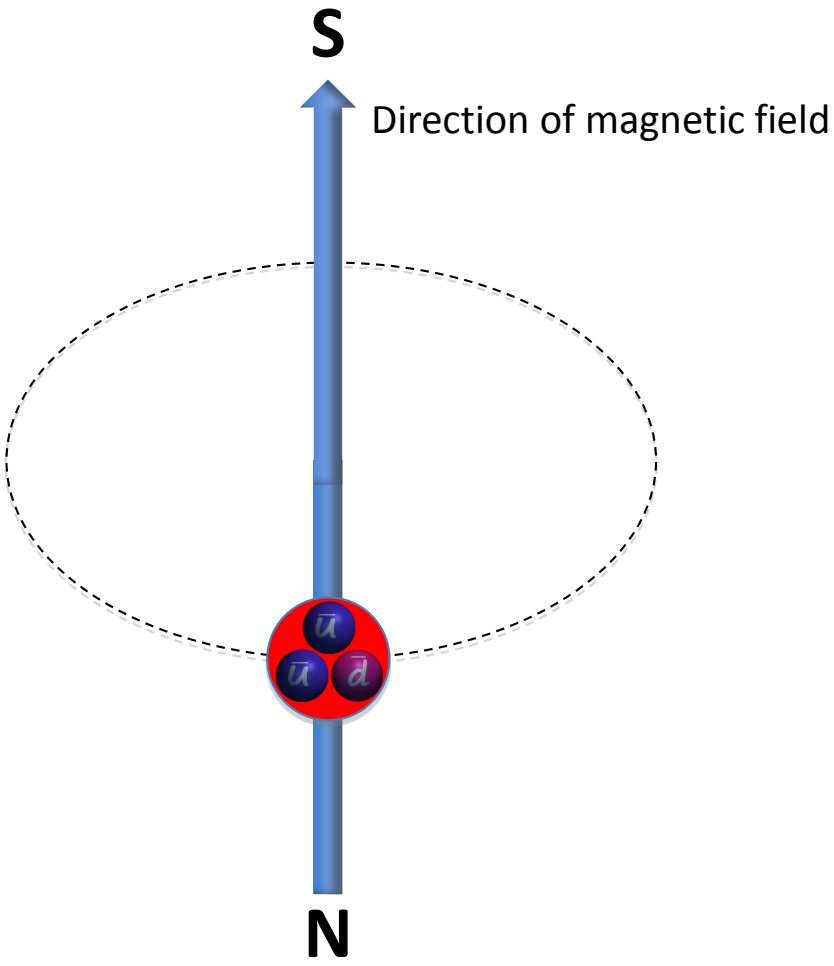
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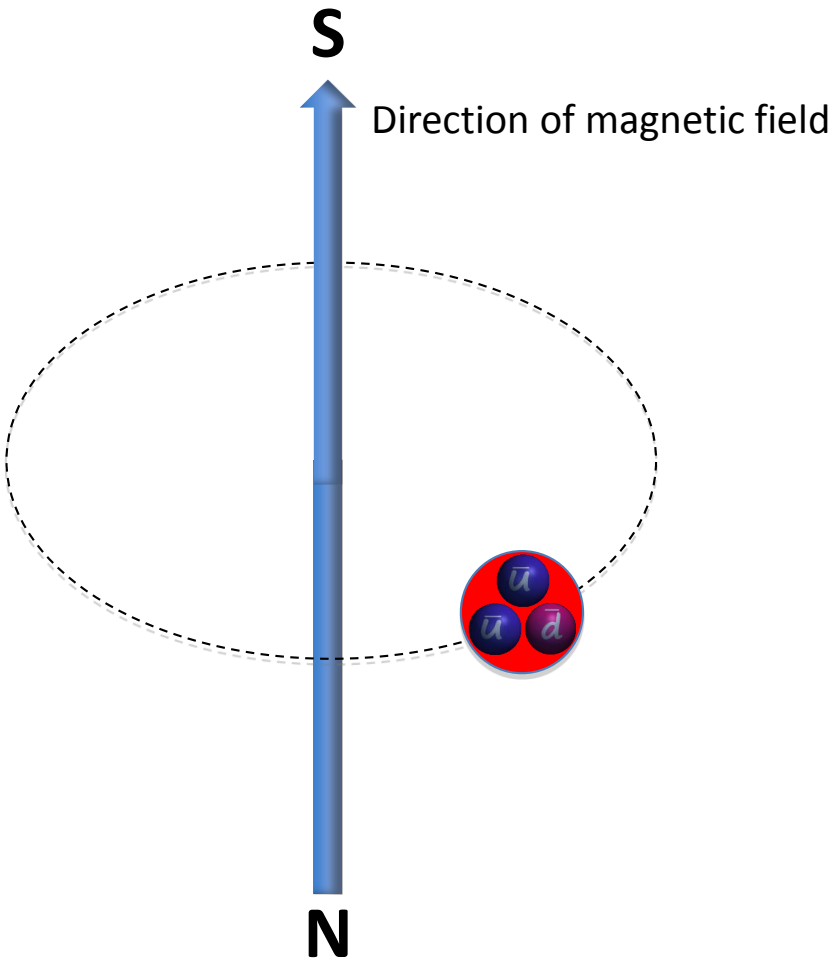
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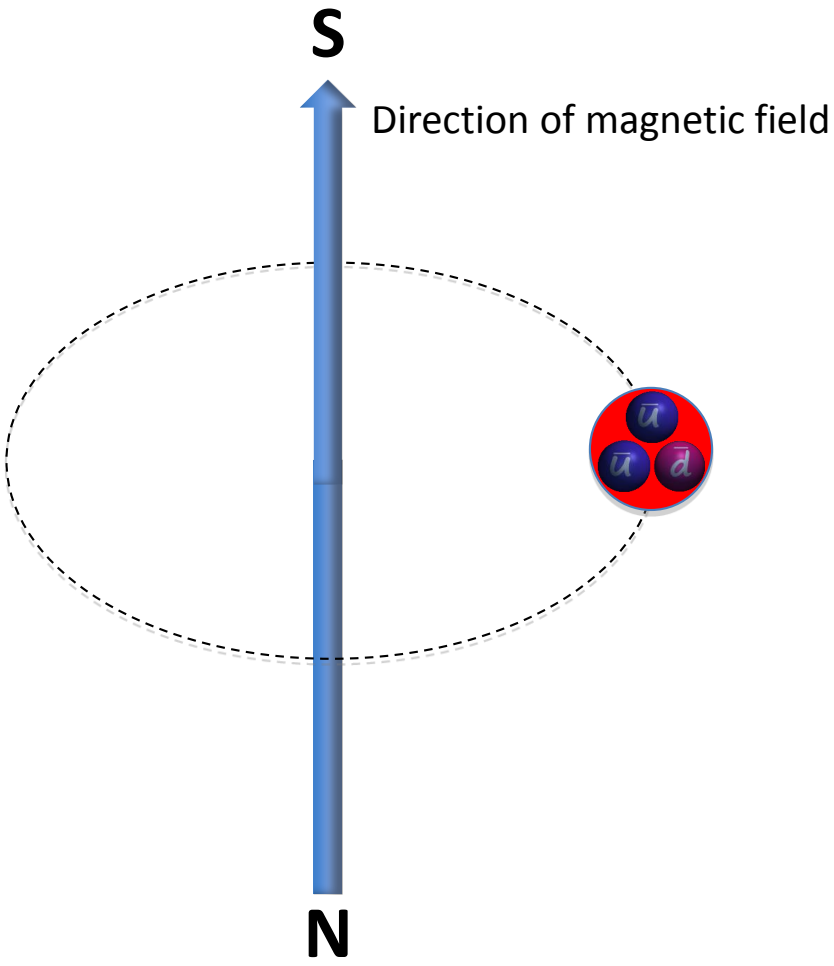
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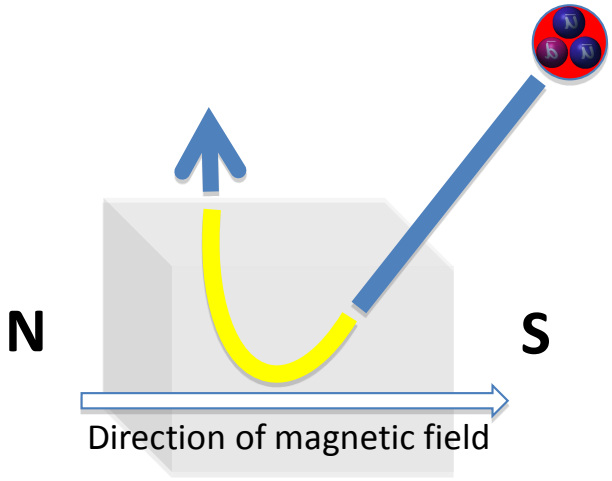
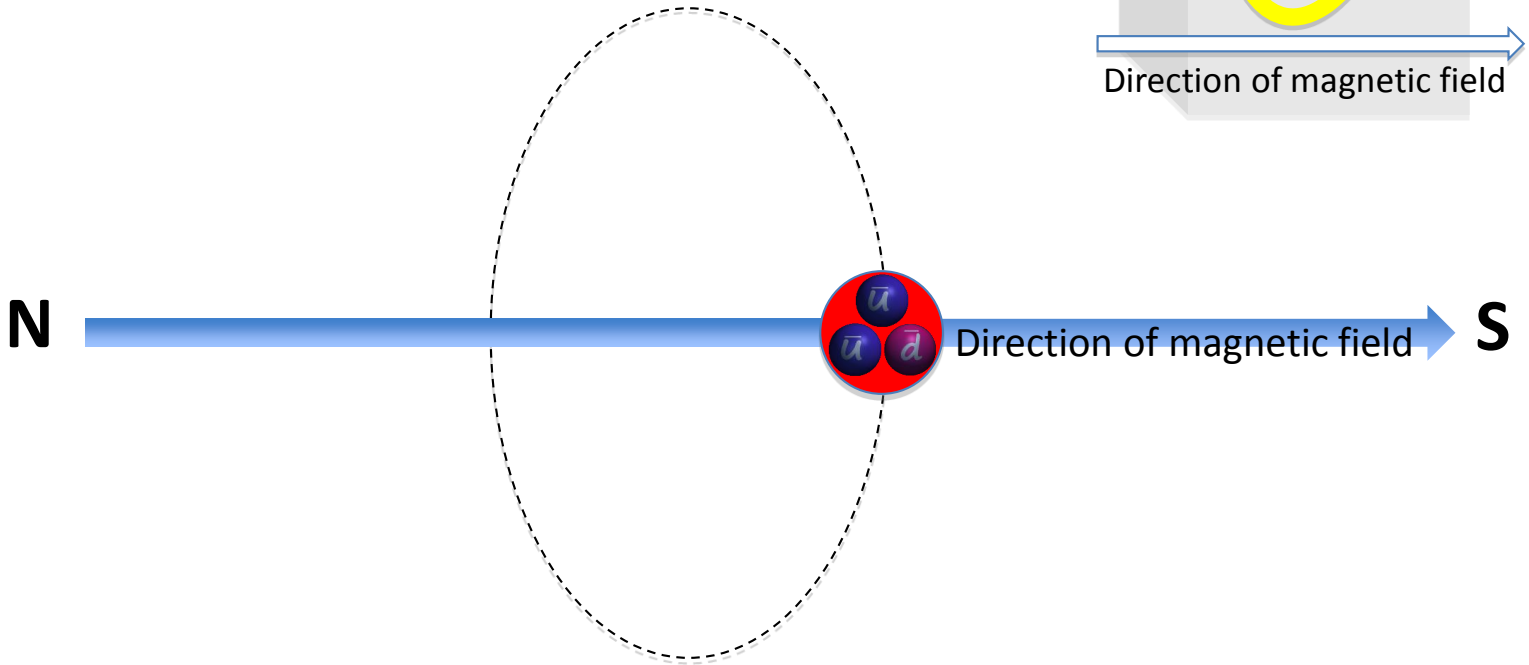
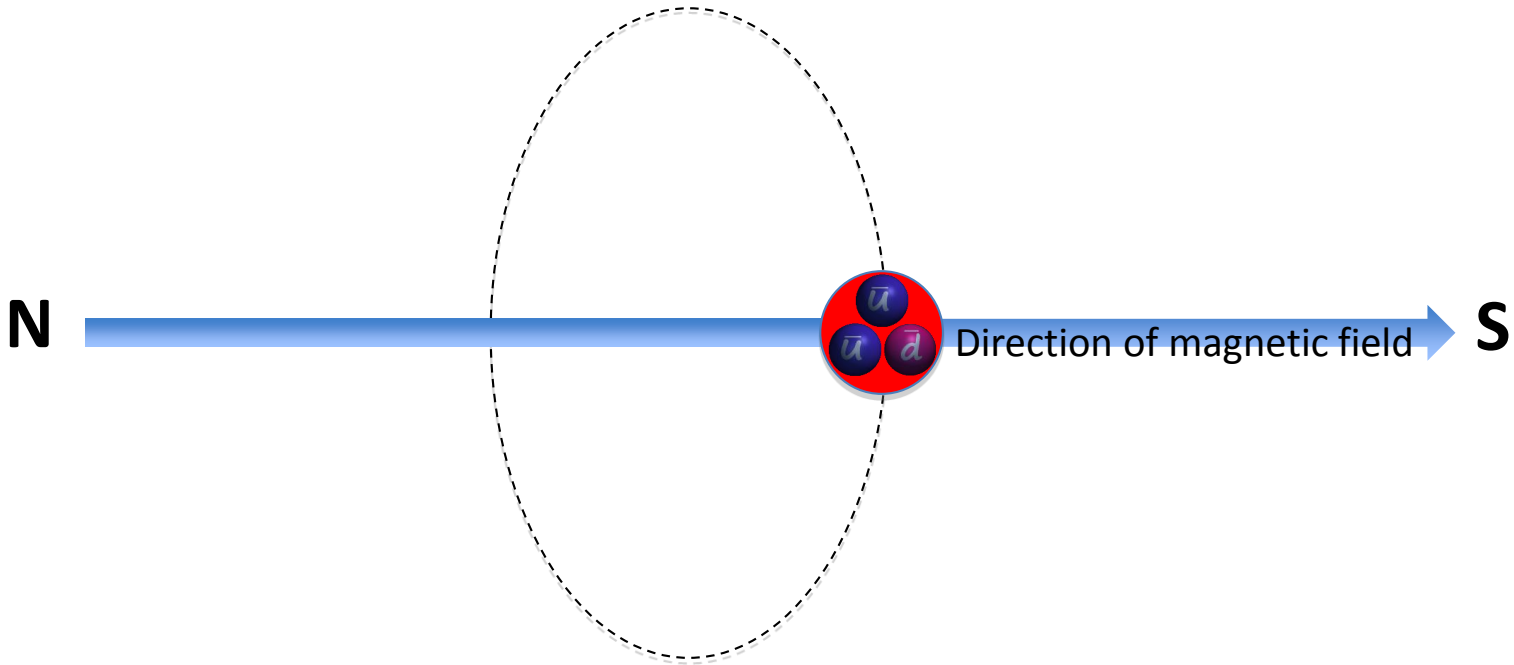
*In the next sequence, we have changed the perspective so that the direction of the field is now to the **right** (and points slightly **into** the page).*
As an exercise, convince yourself that the motion of the particle is consistent with the previous sequence.



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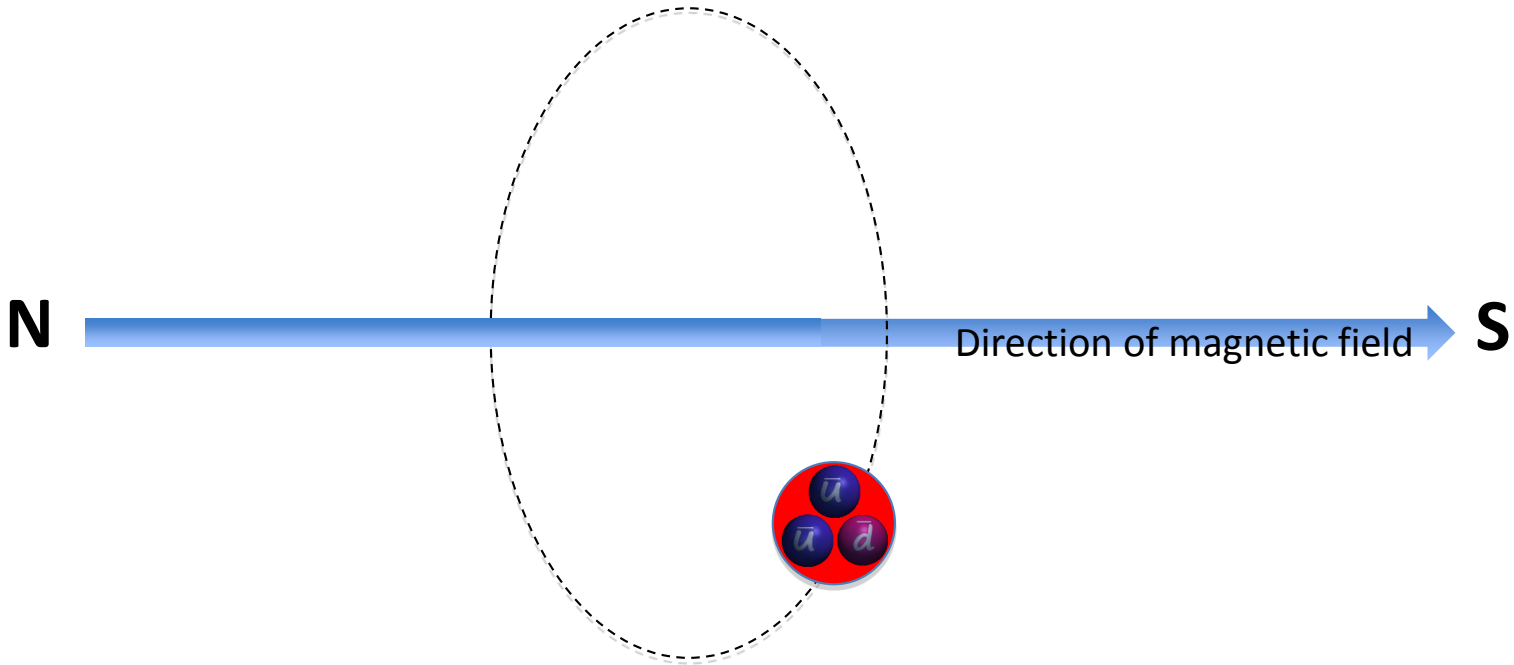
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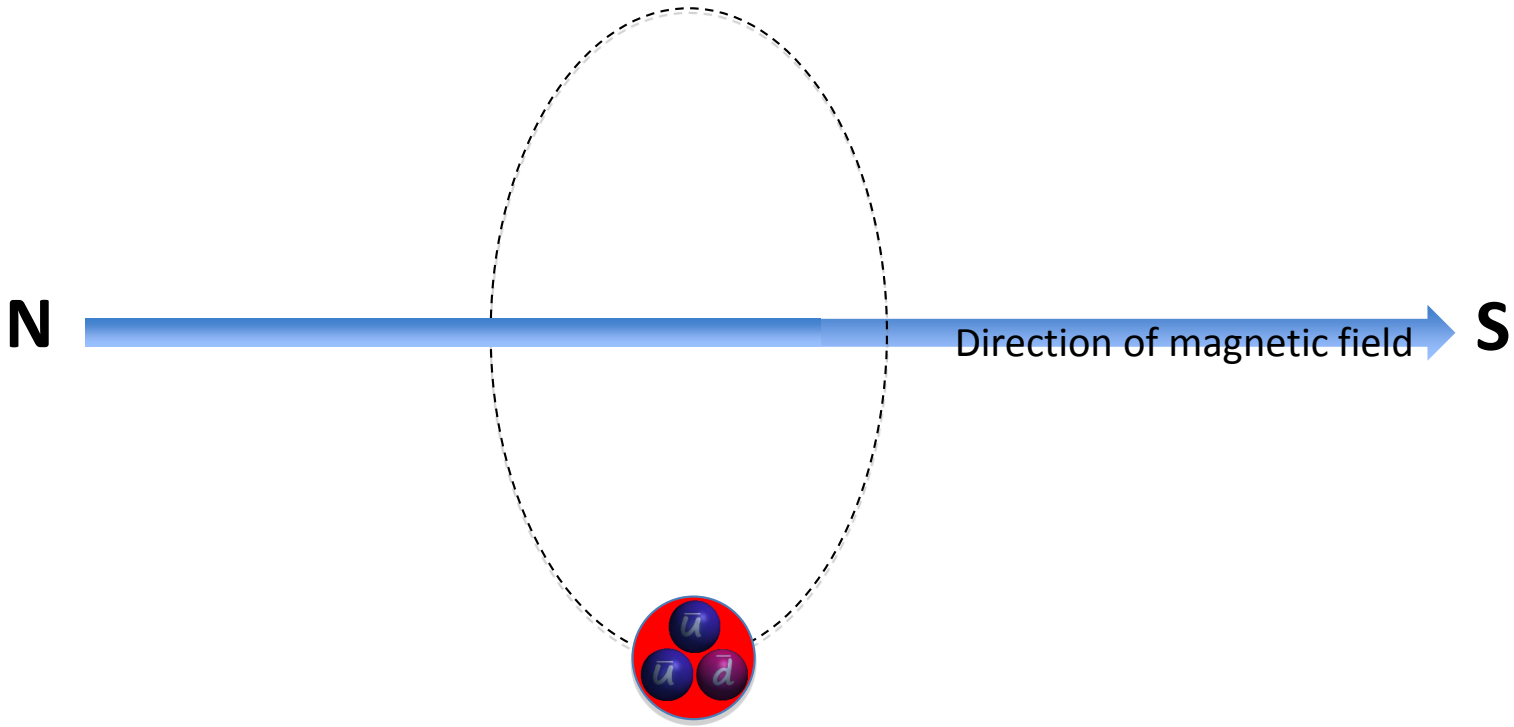
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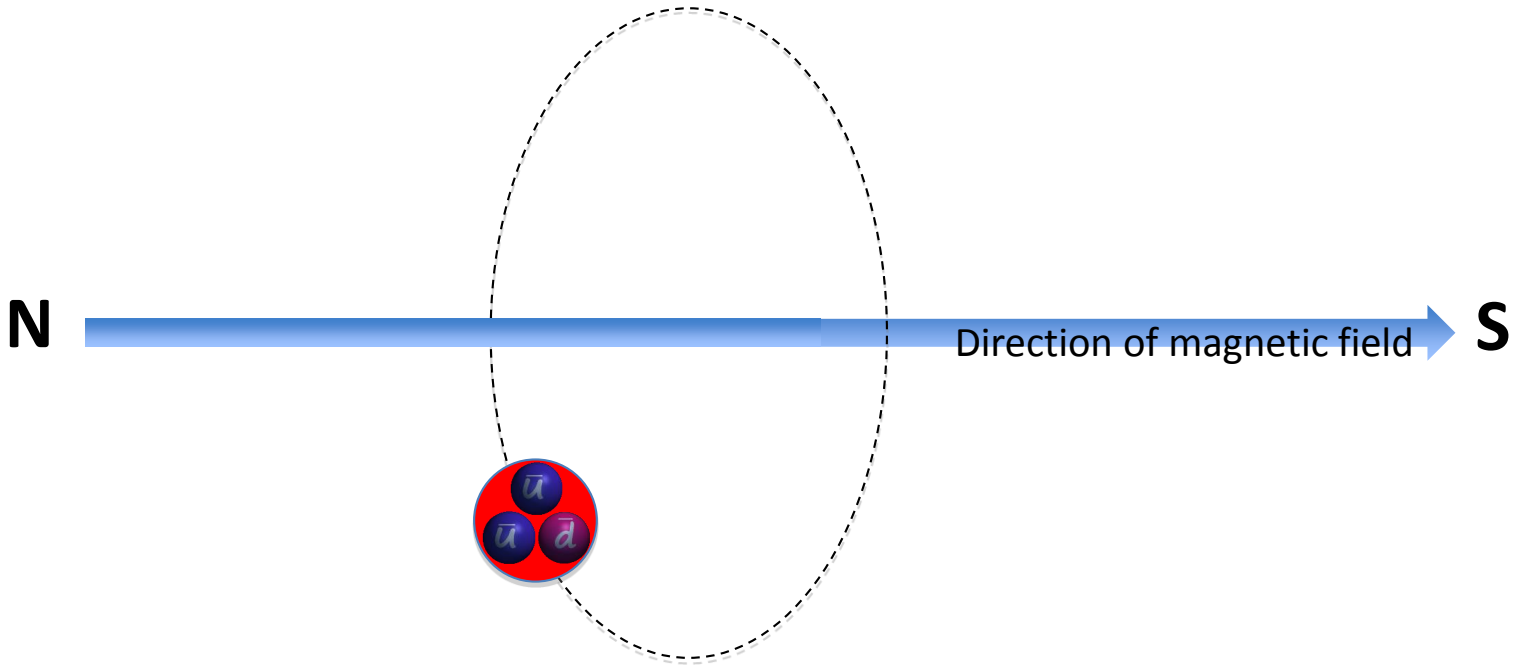
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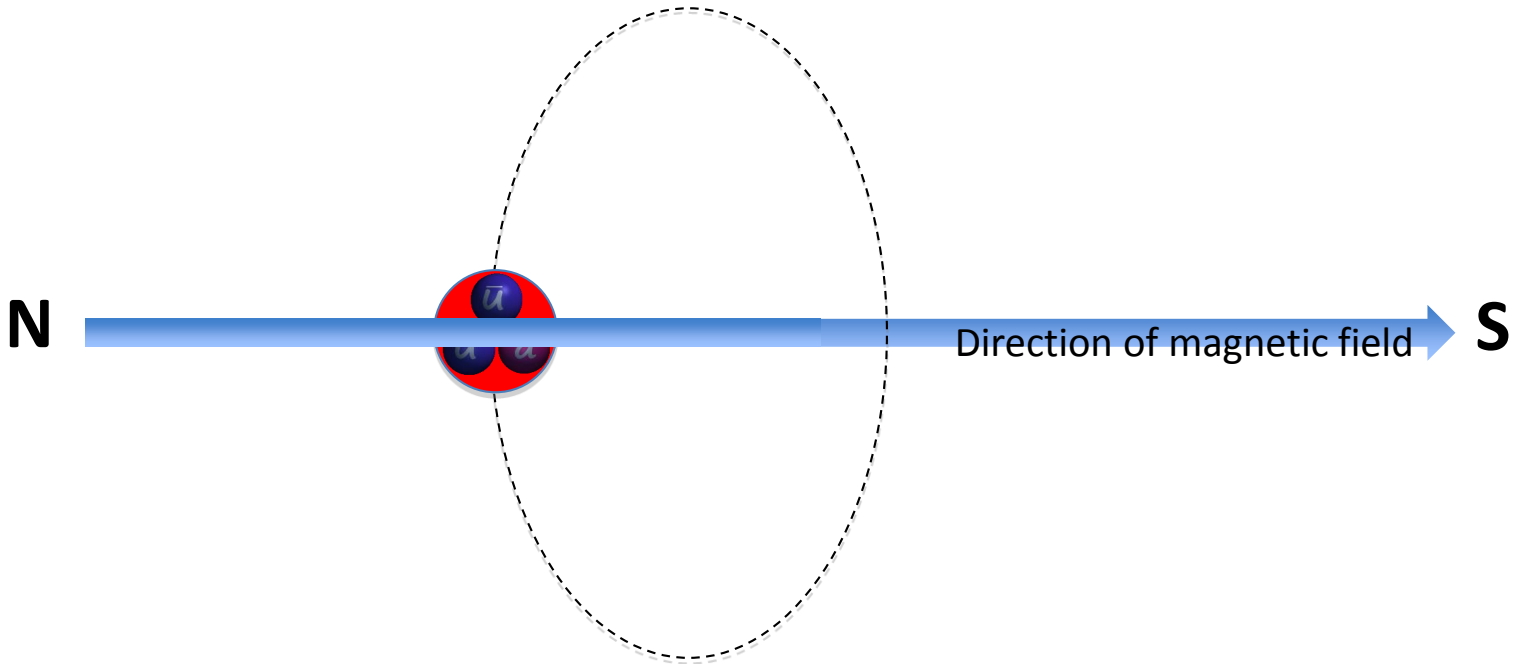
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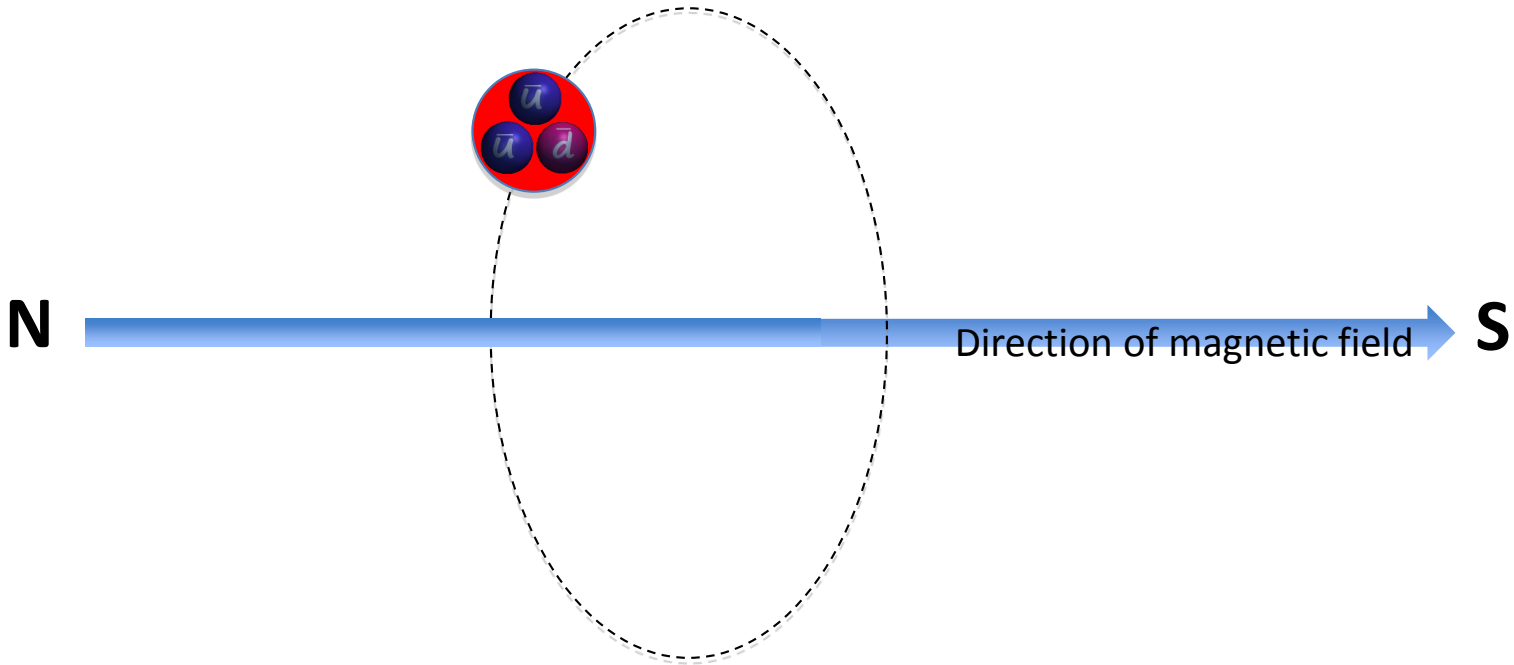
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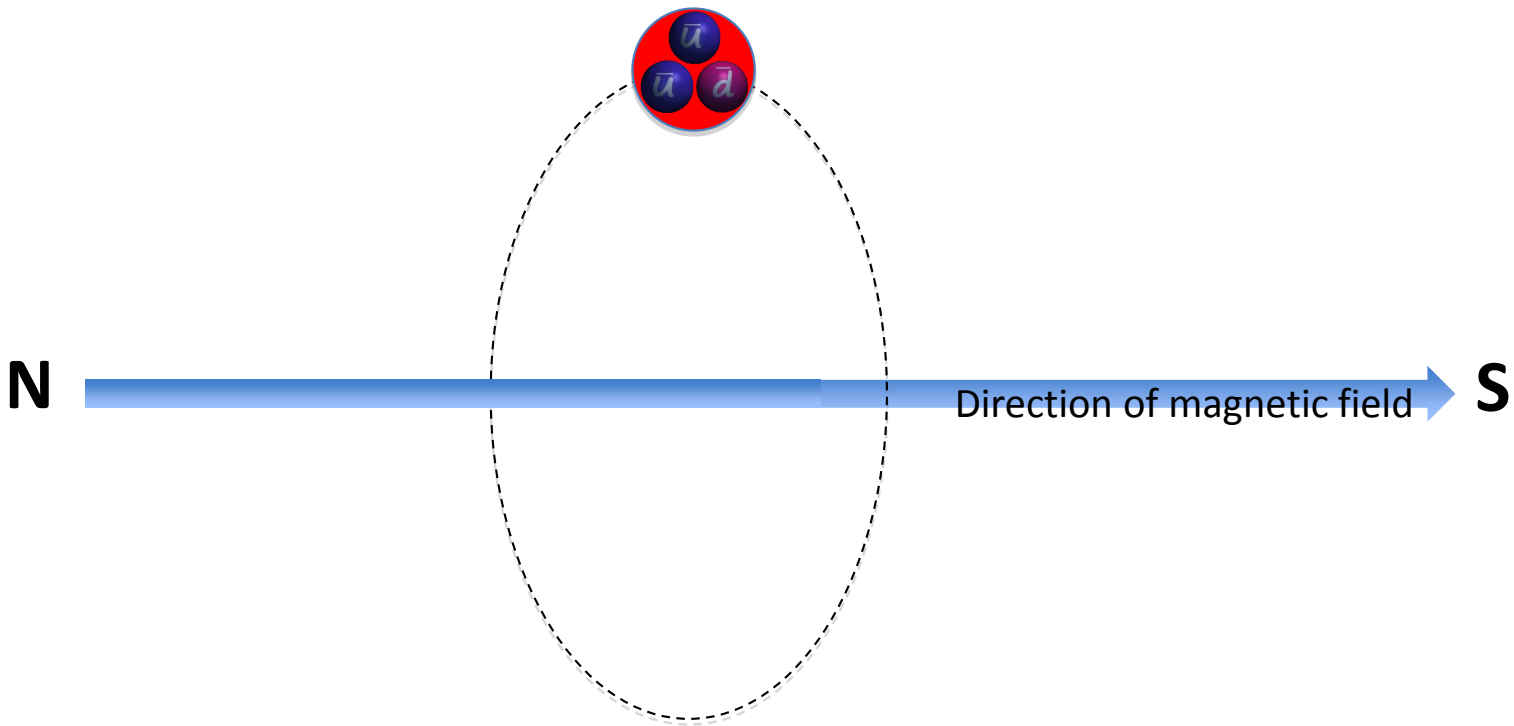
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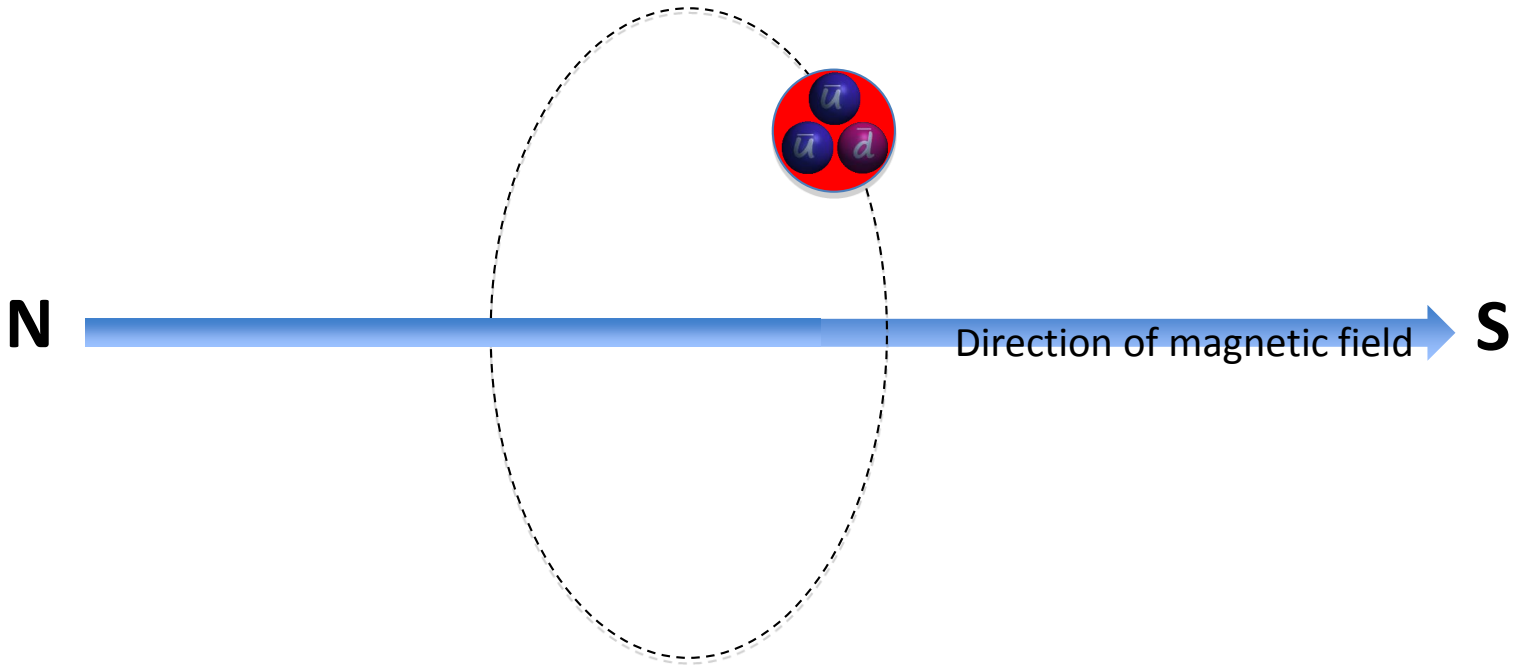
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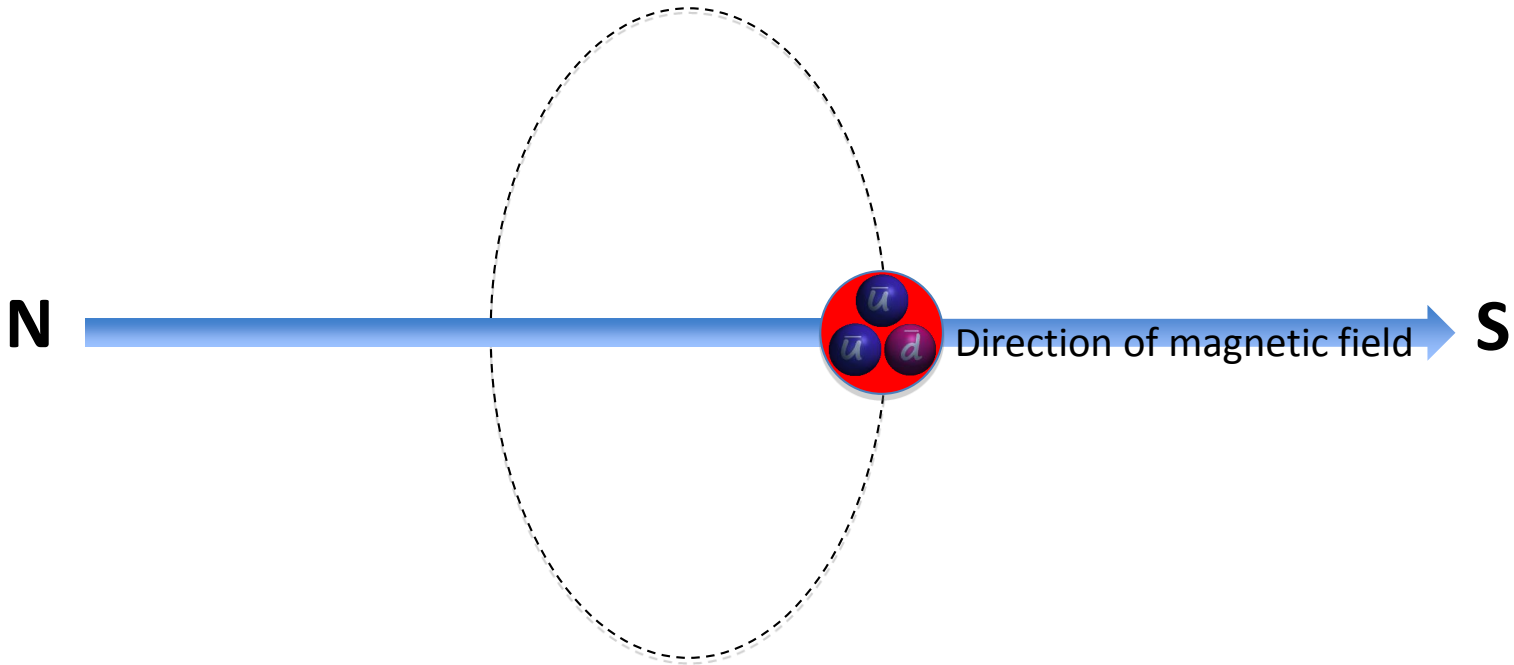
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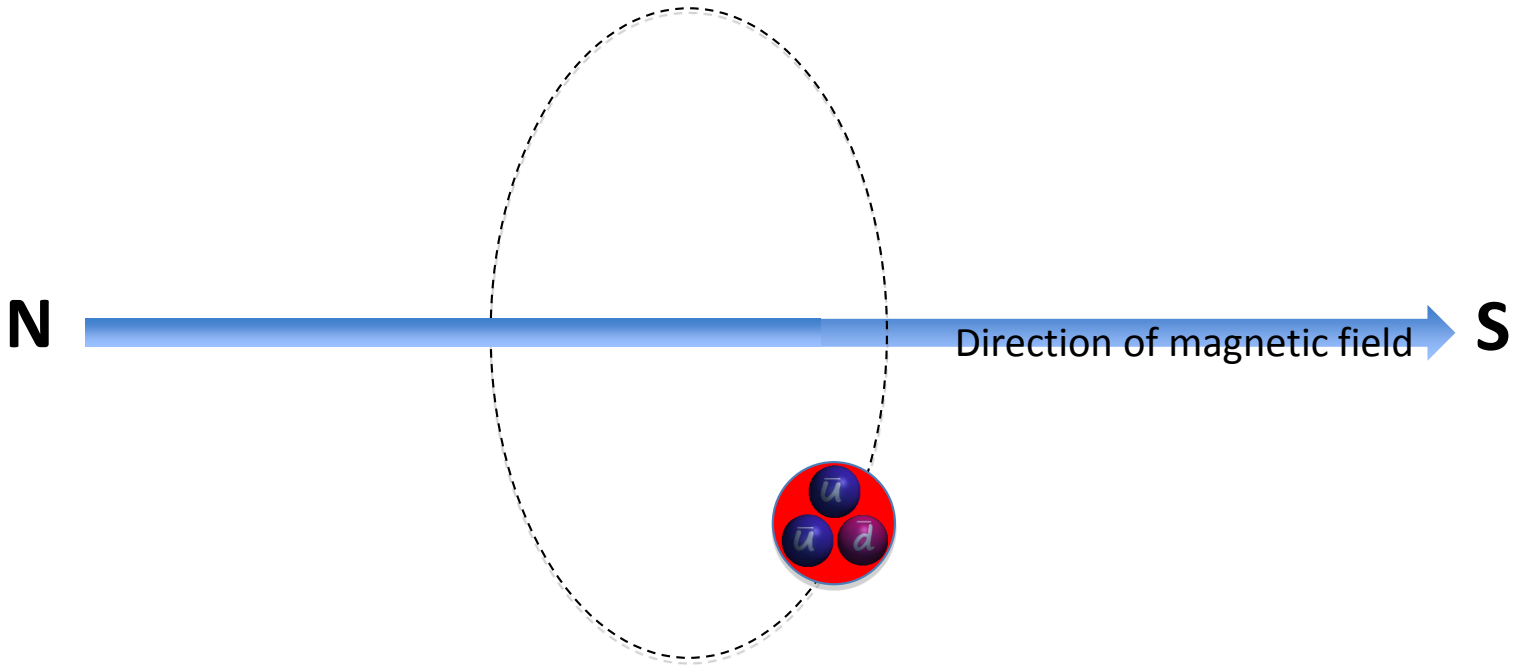
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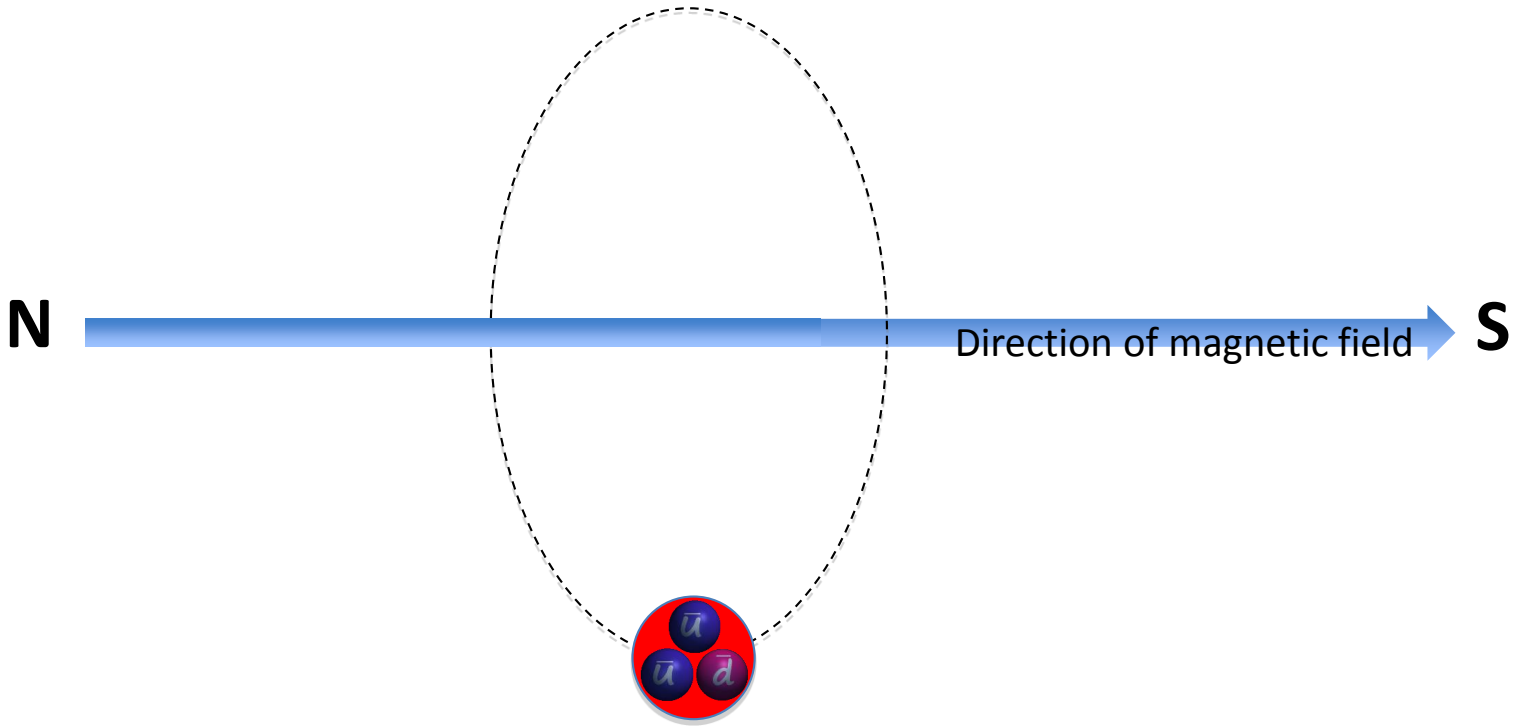
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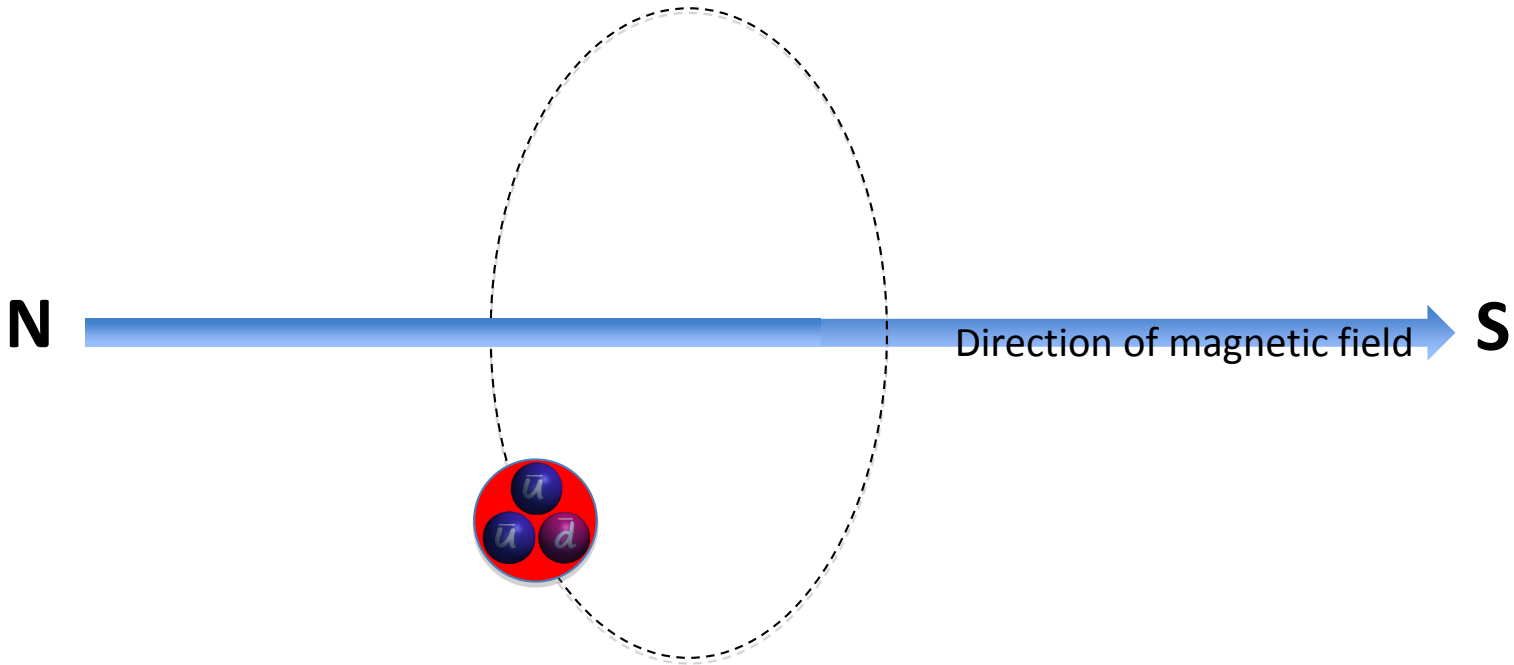
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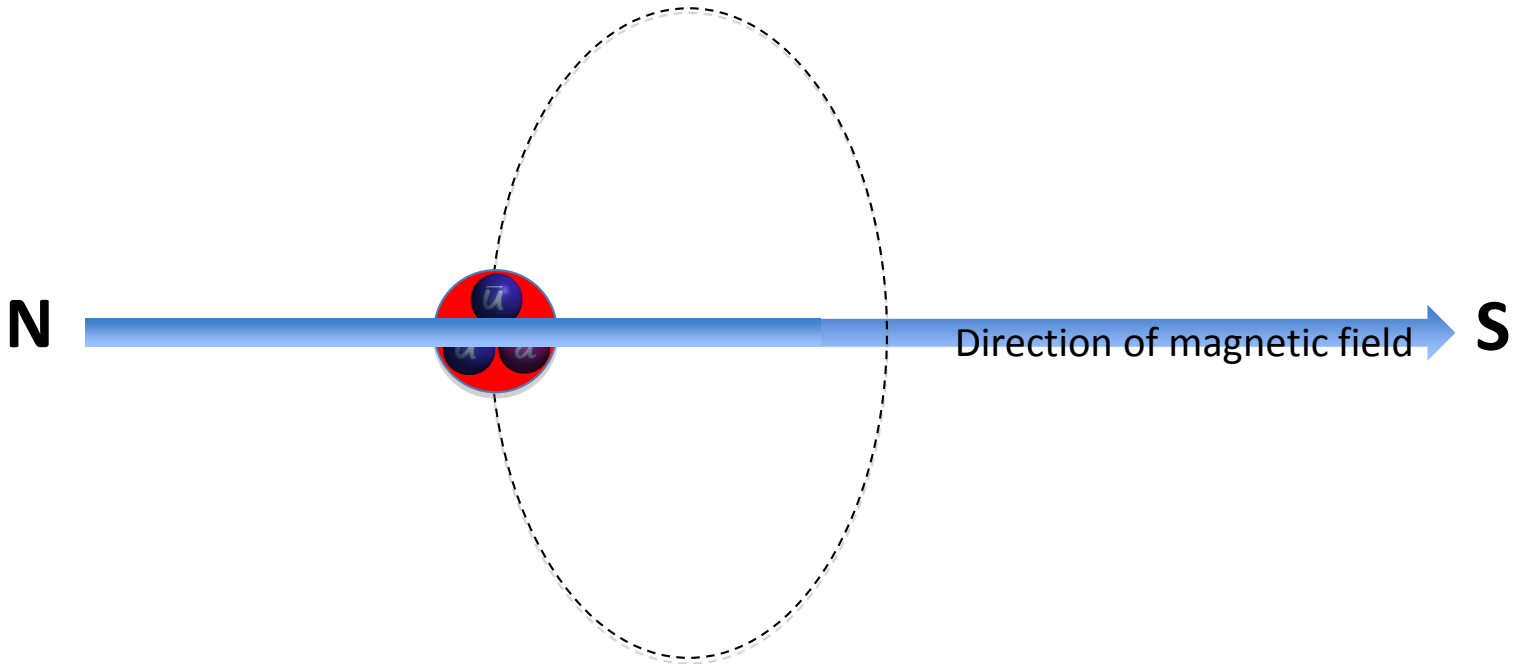
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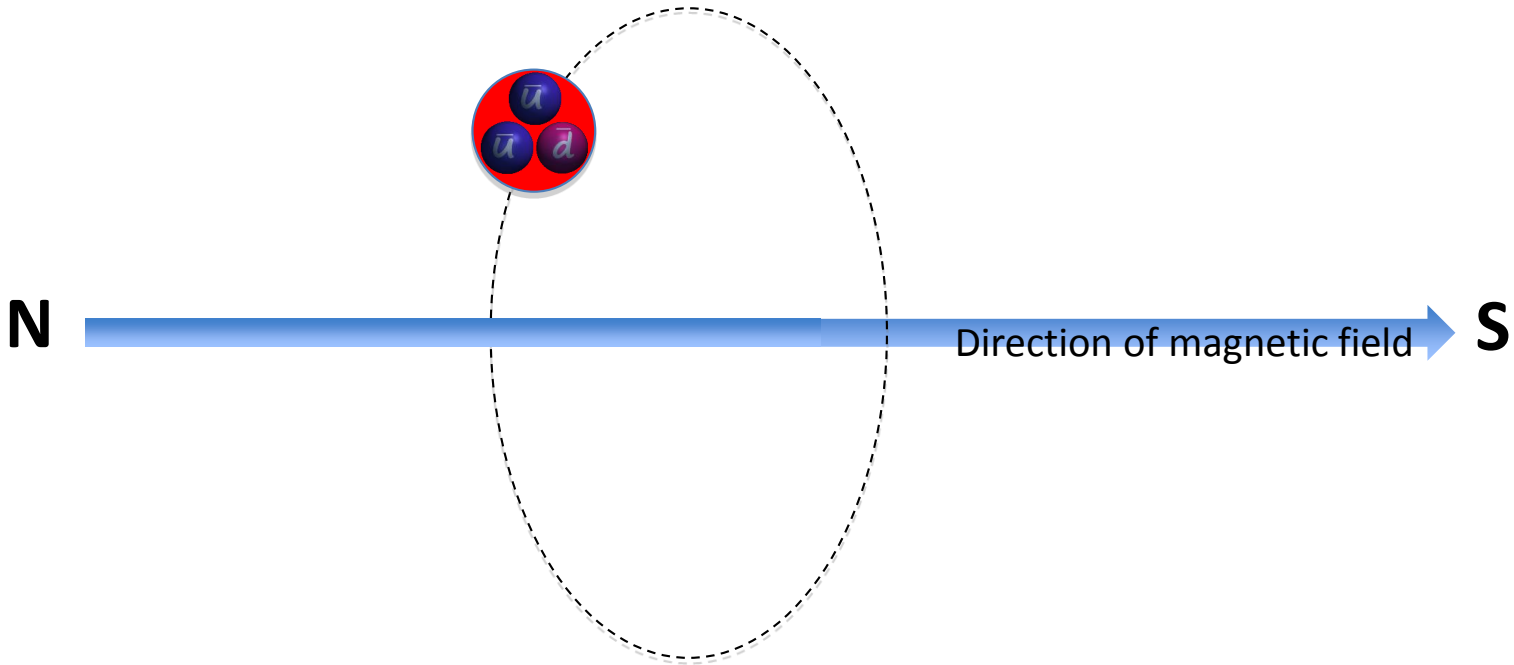
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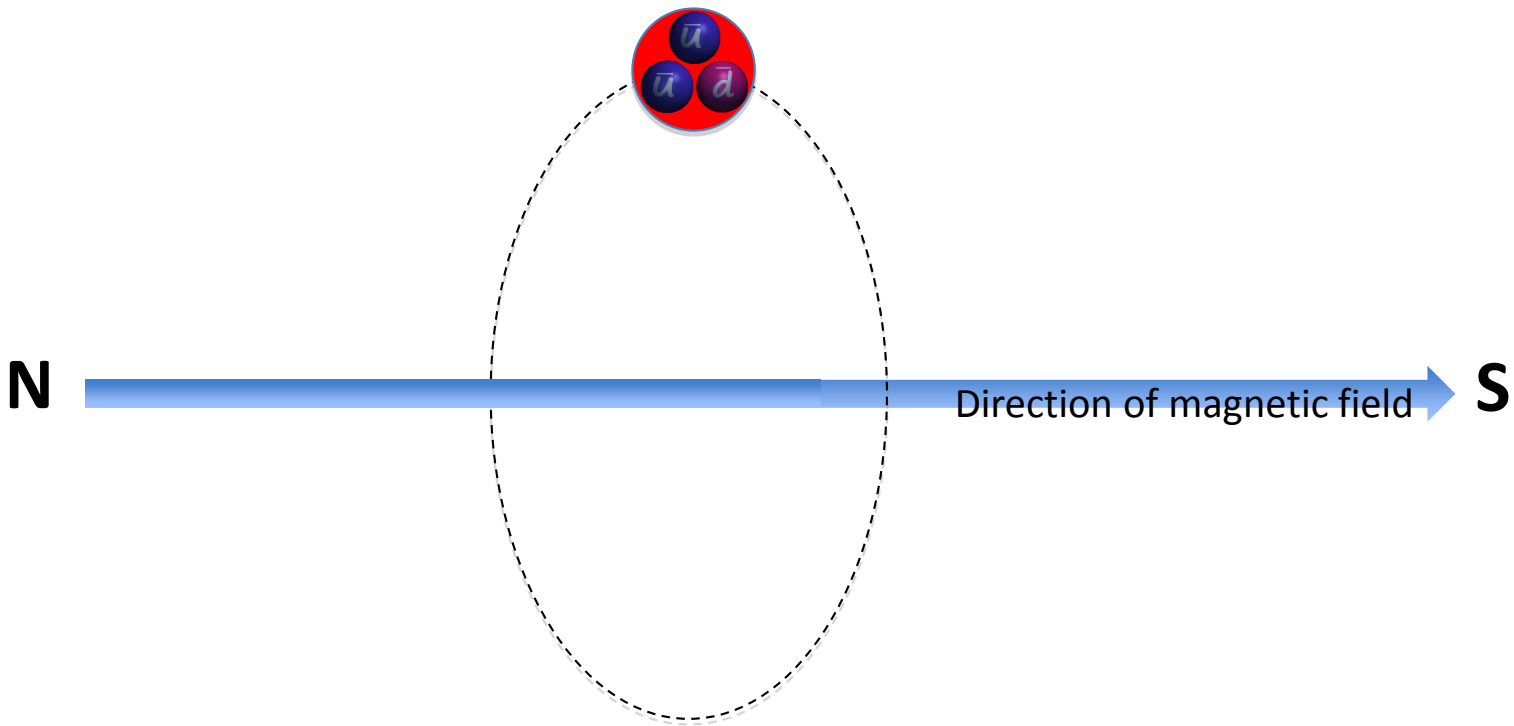
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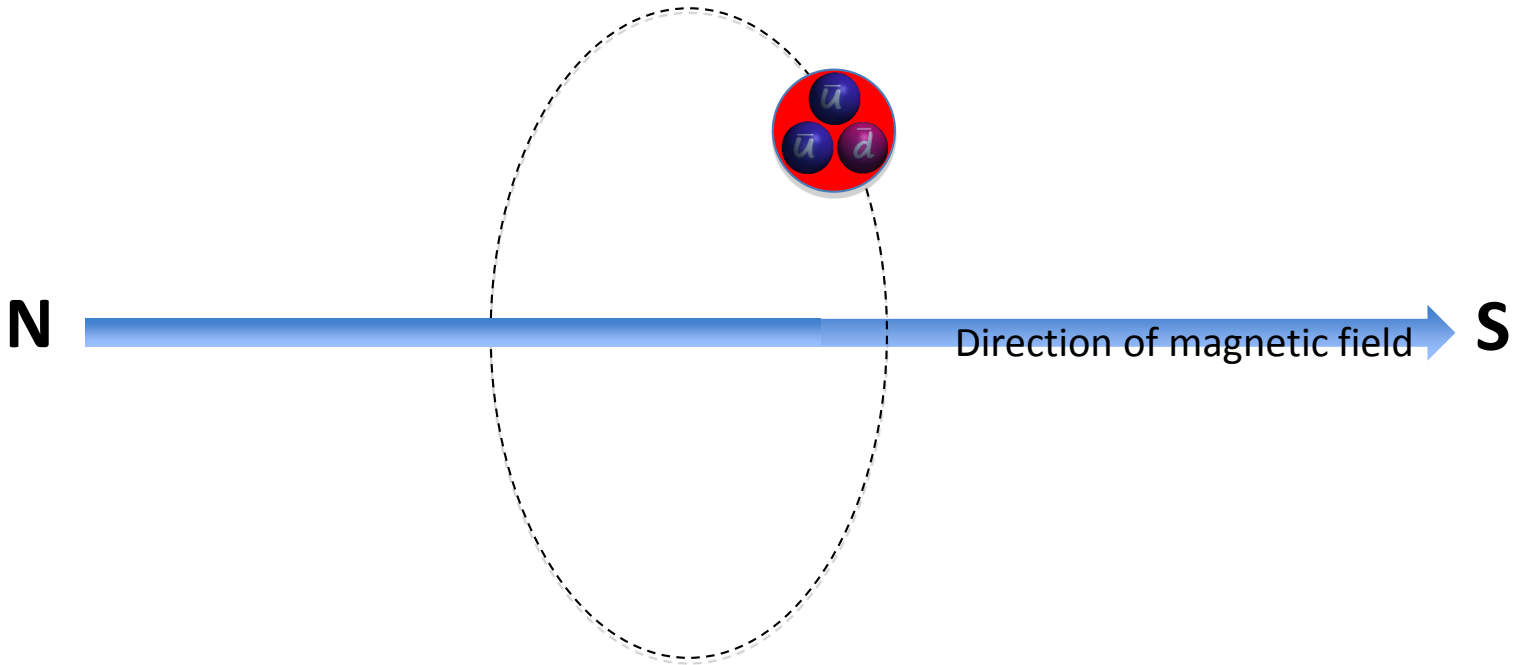
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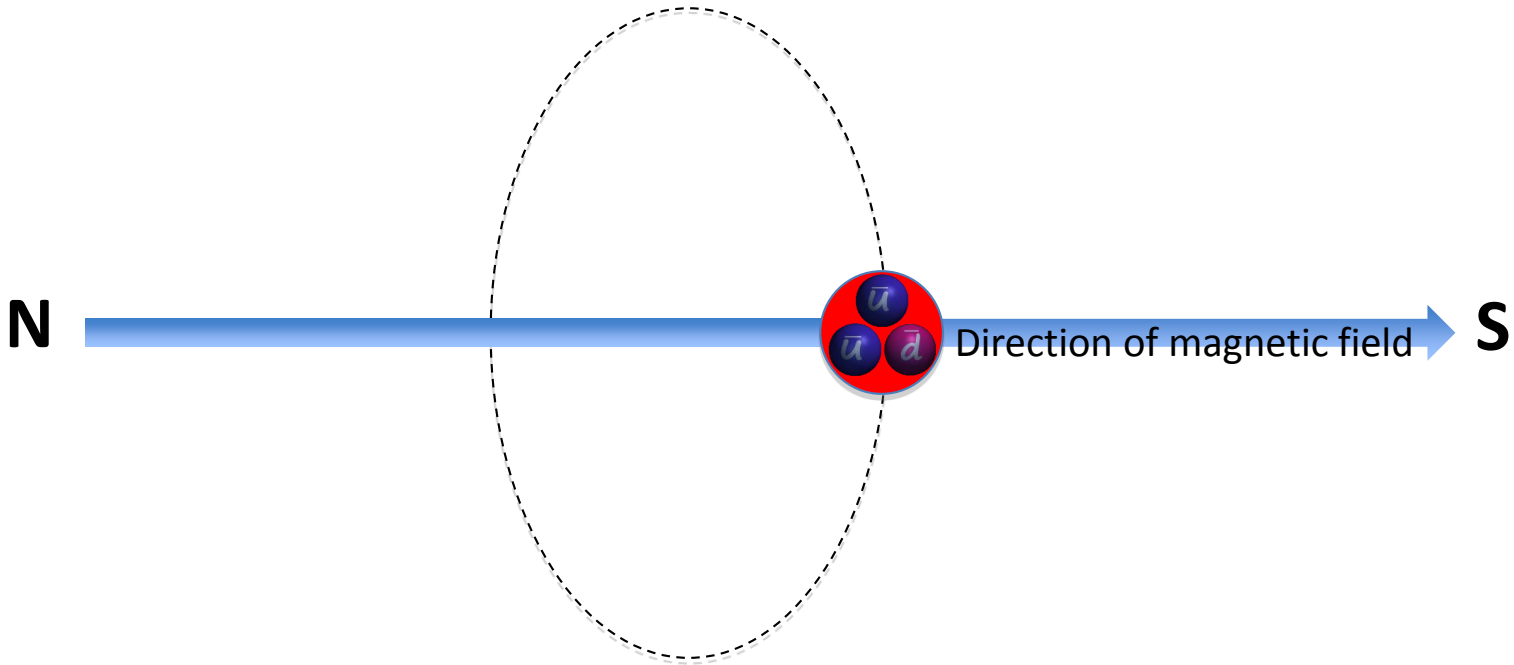
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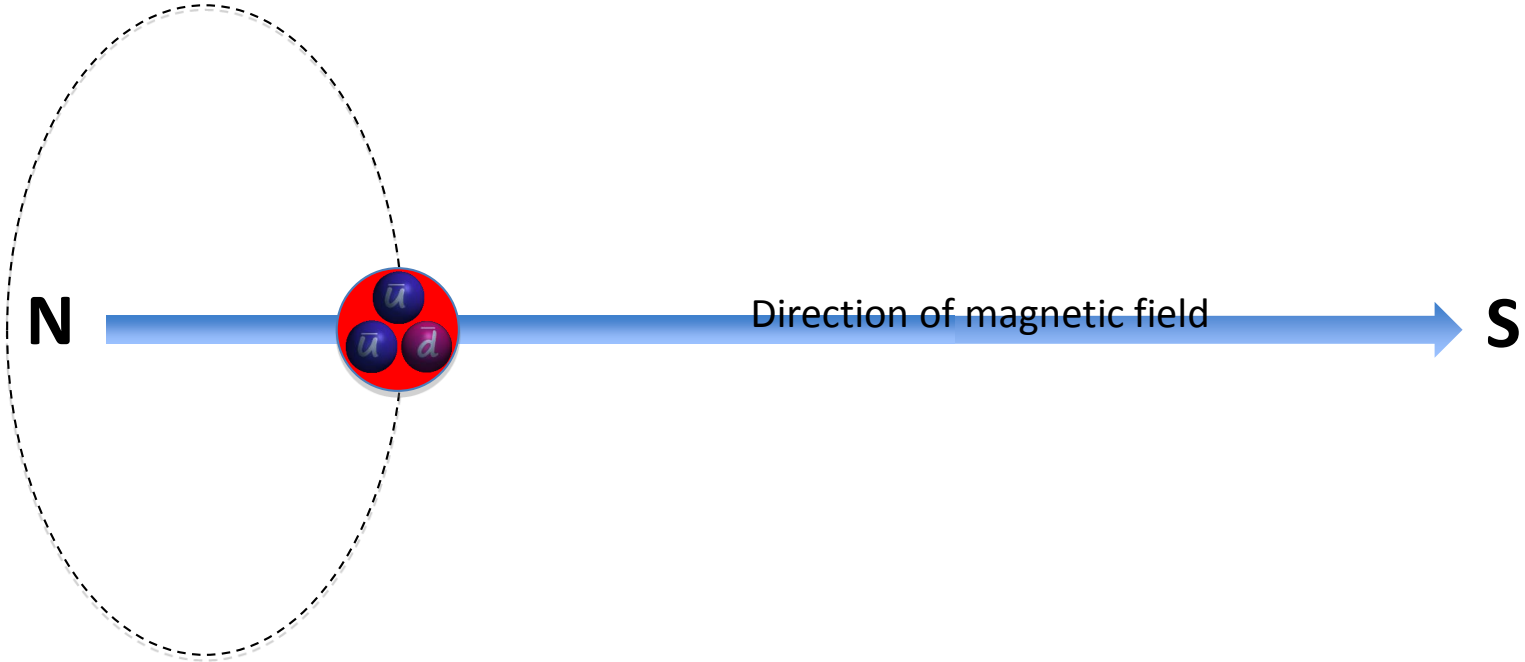
In addition to this circular movement, the particle will at the same time move along the direction that it had when it first entered the magnetic field. So, if the antiproton initially entered from the left, the motion would look like this…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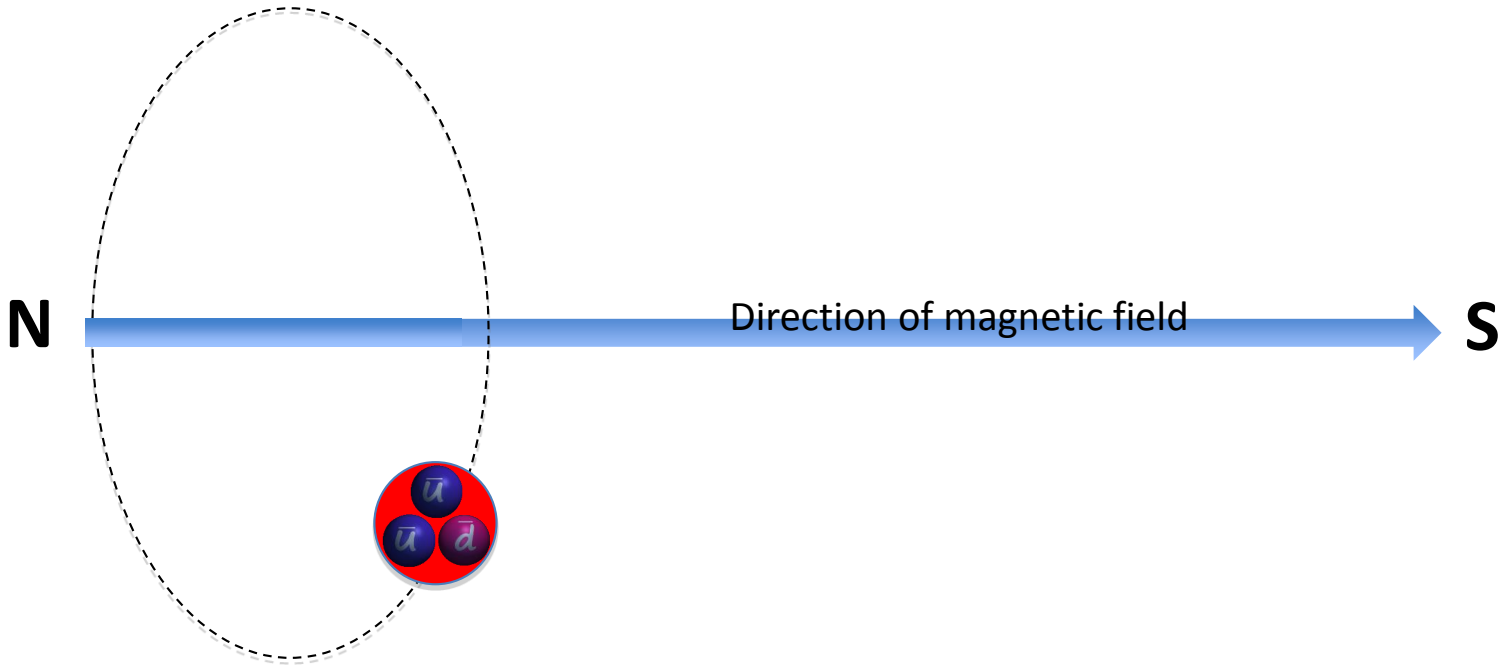
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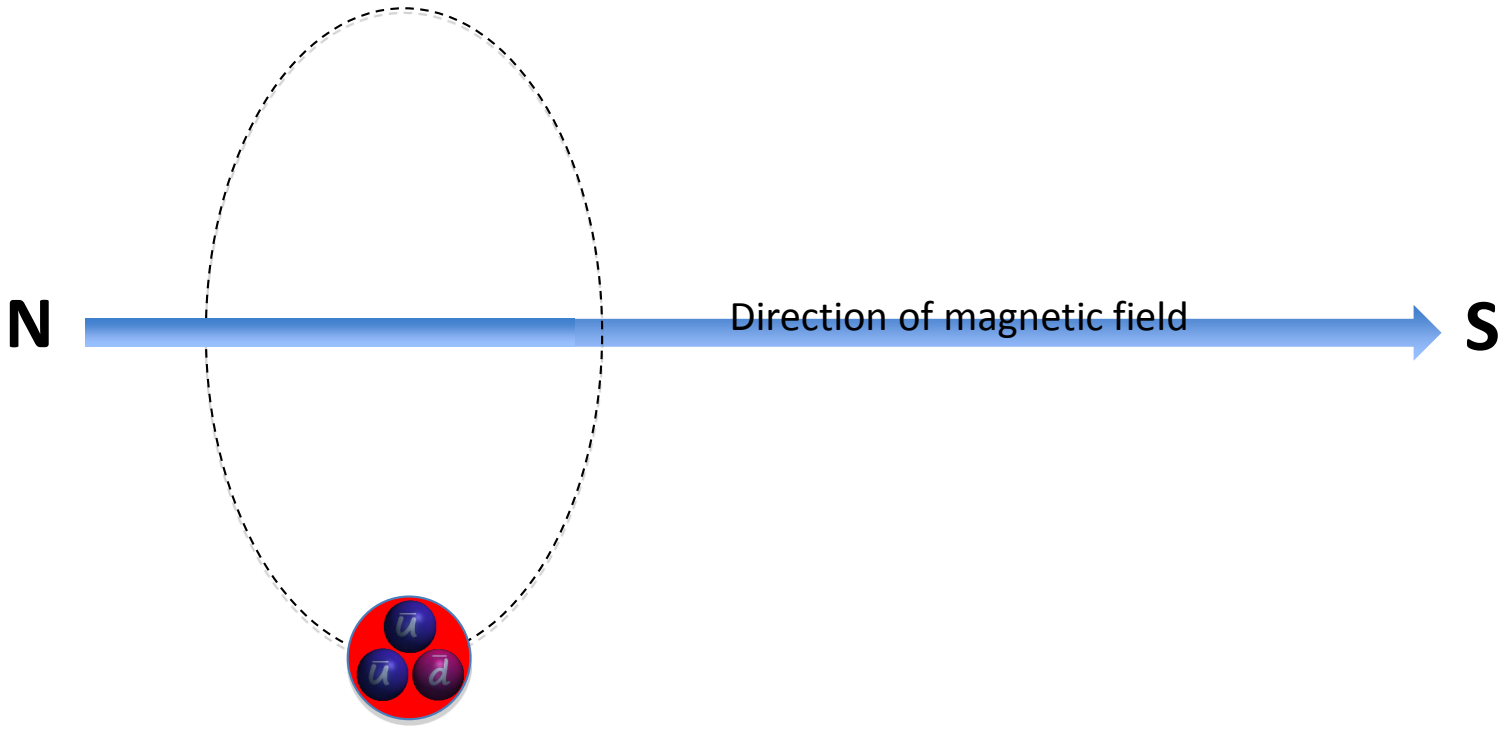
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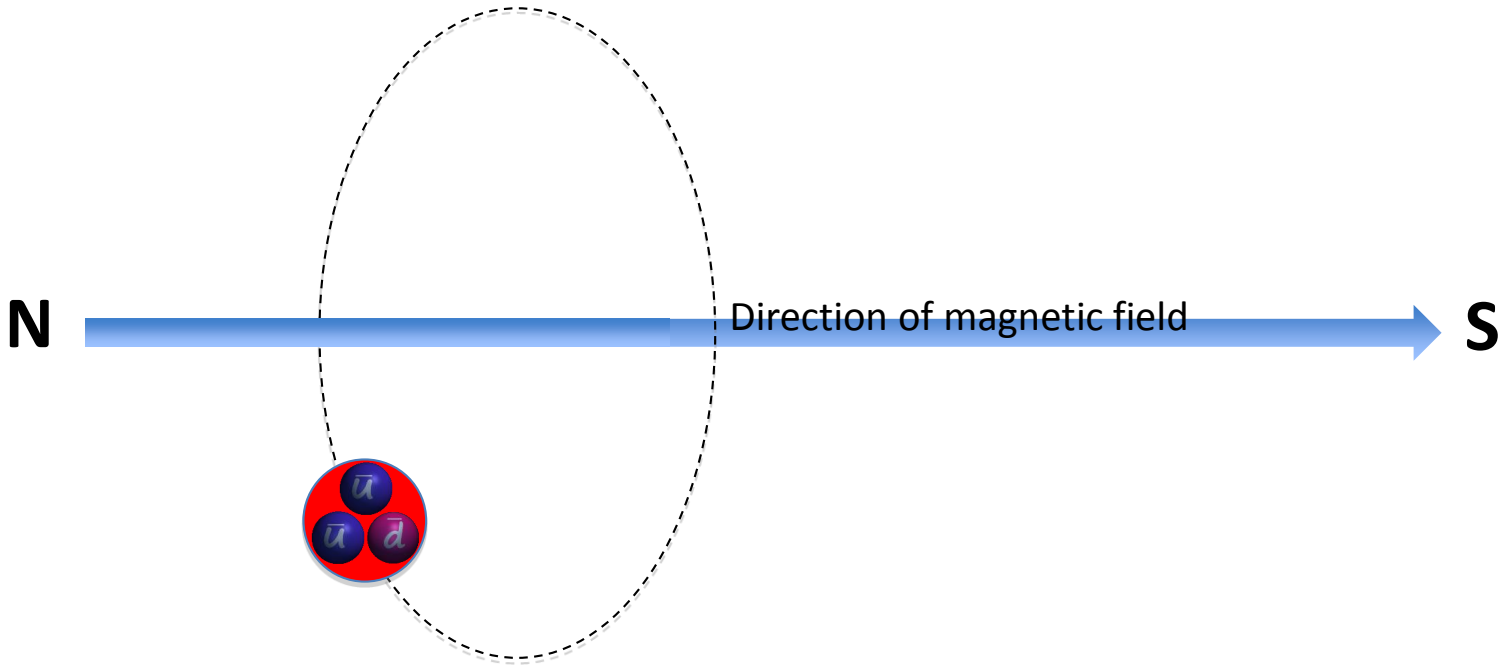
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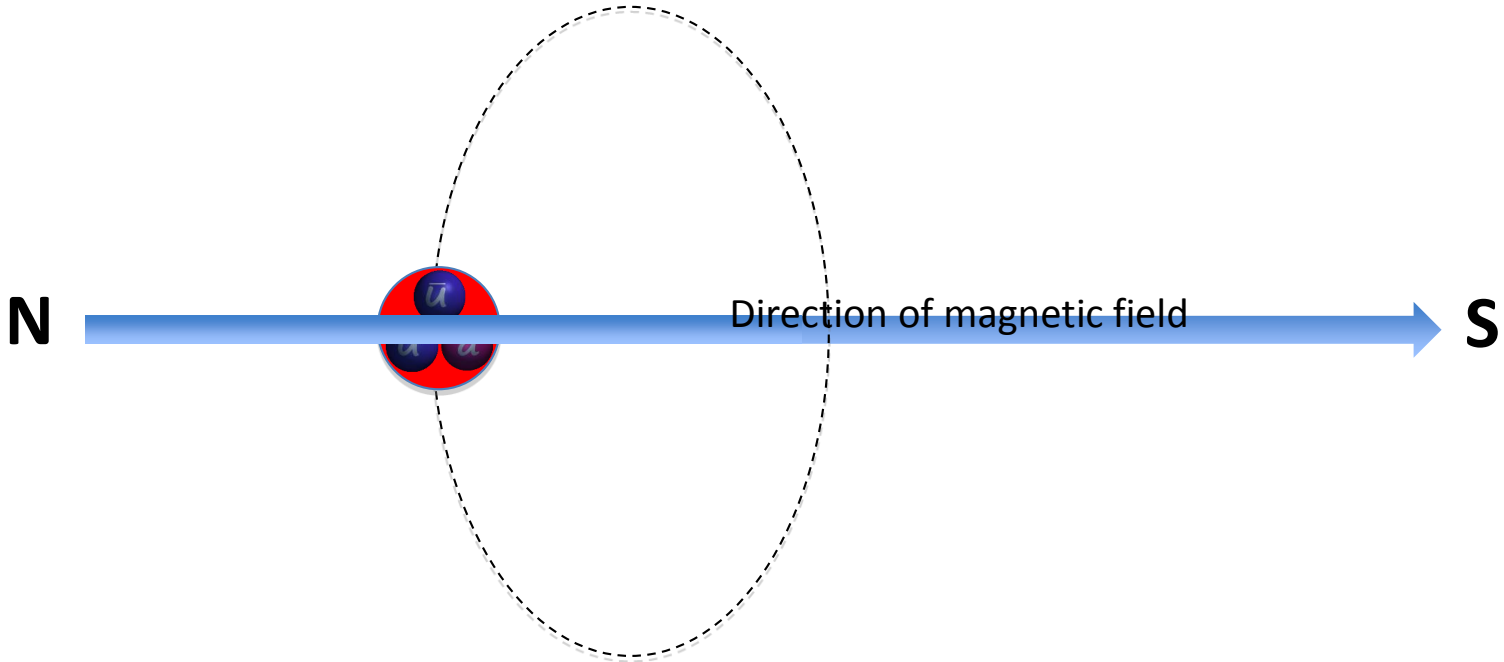
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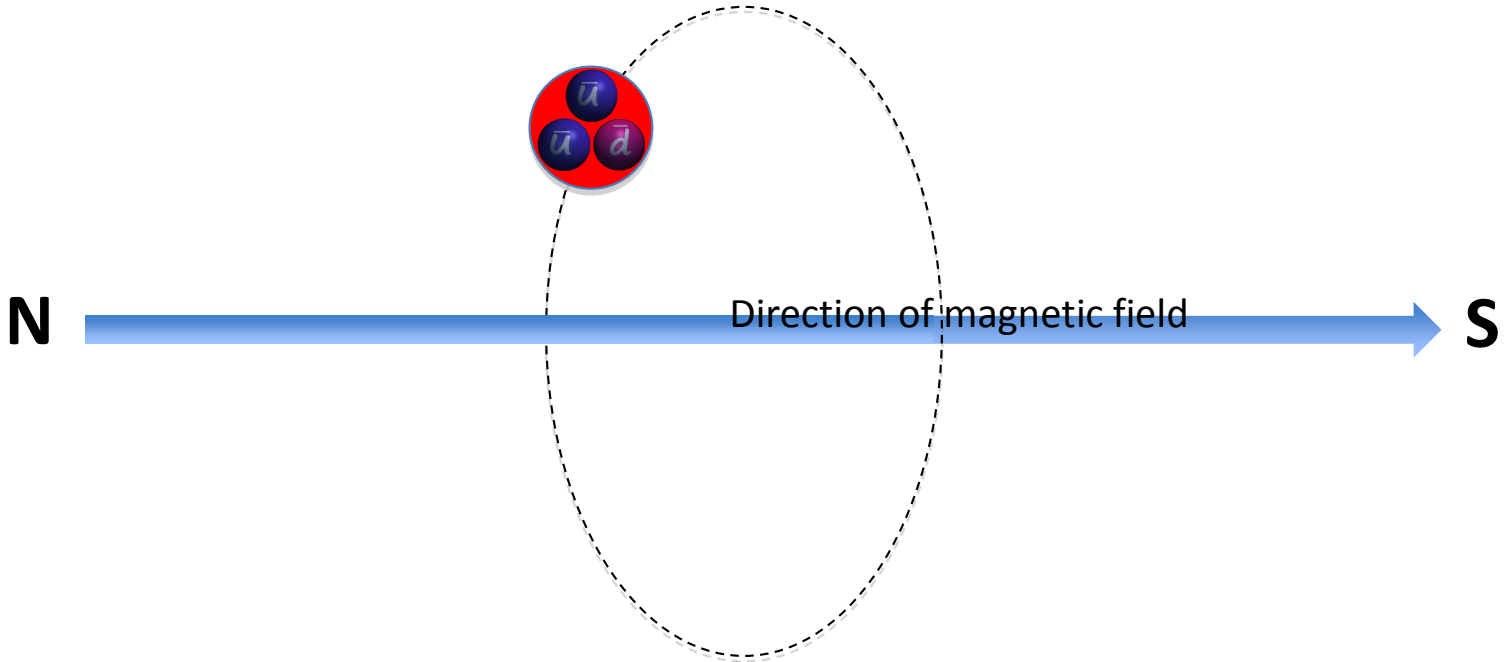
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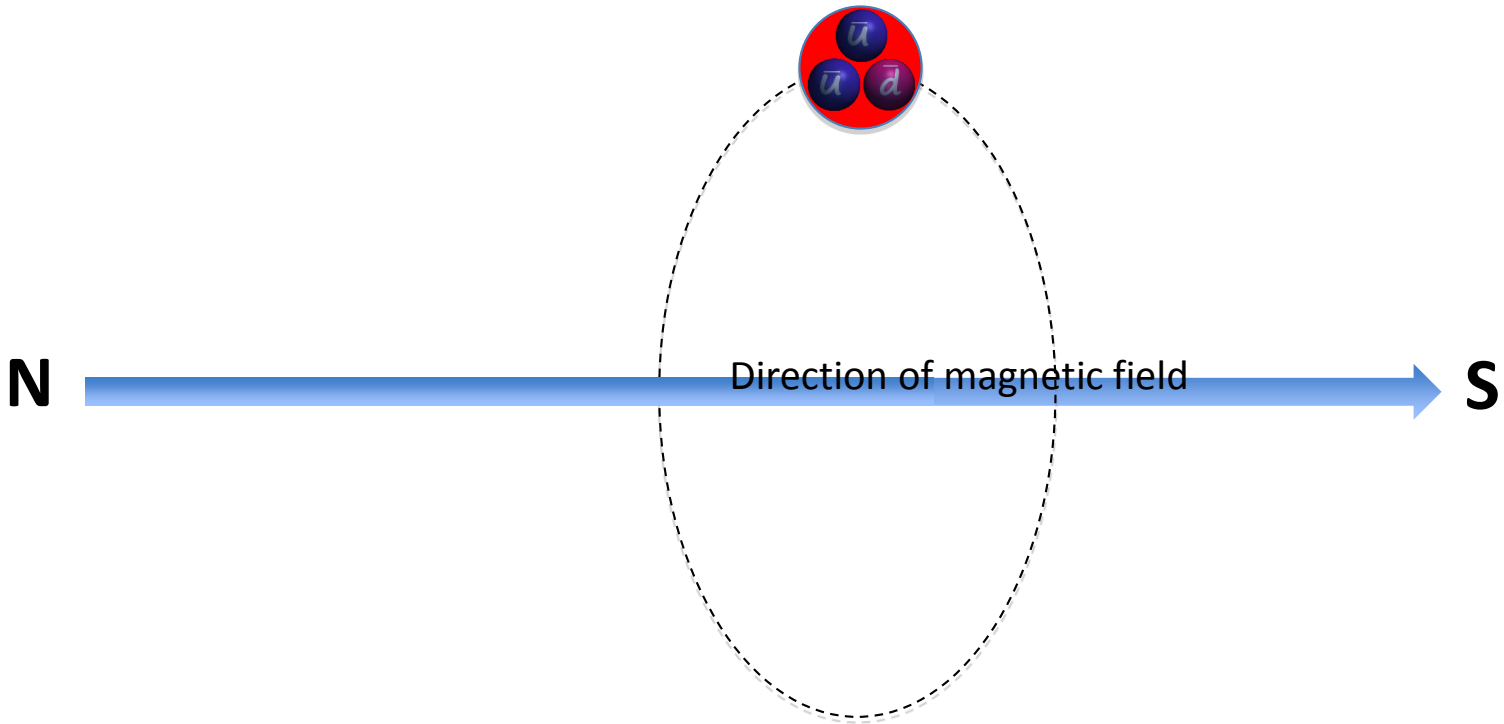
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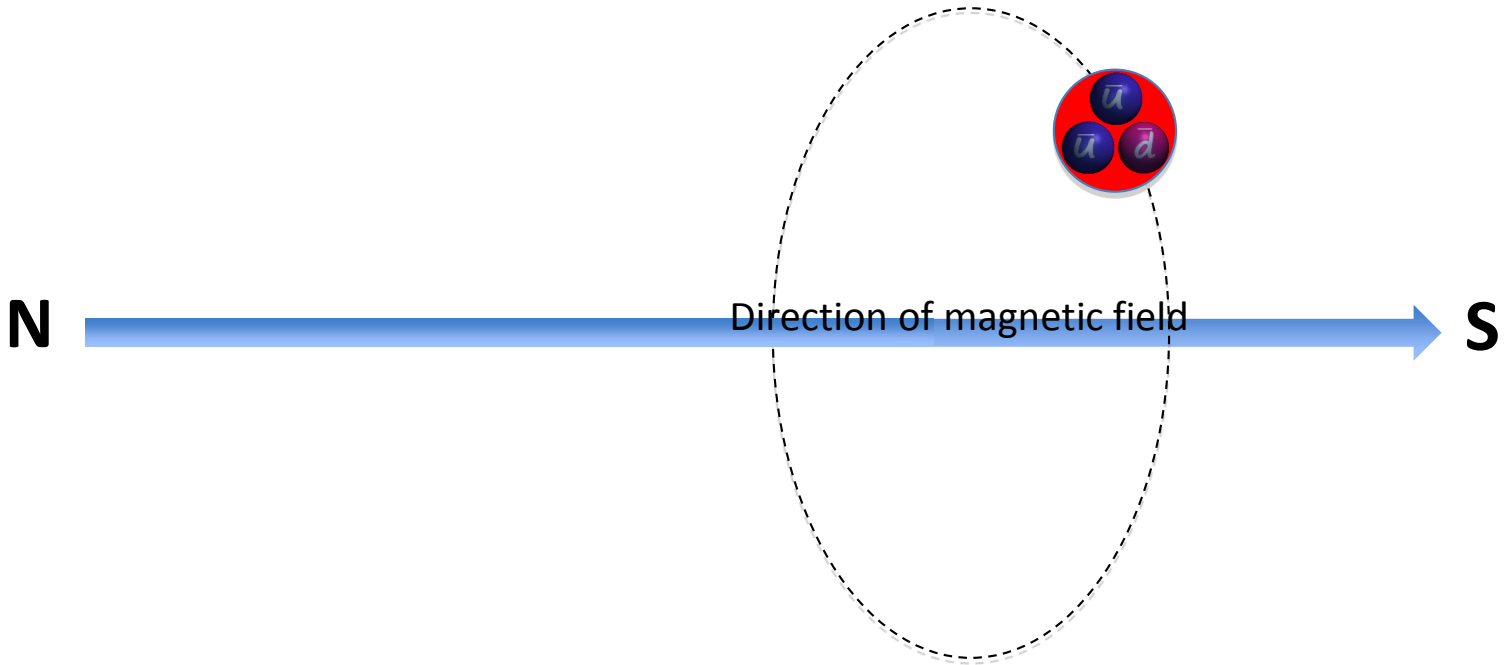
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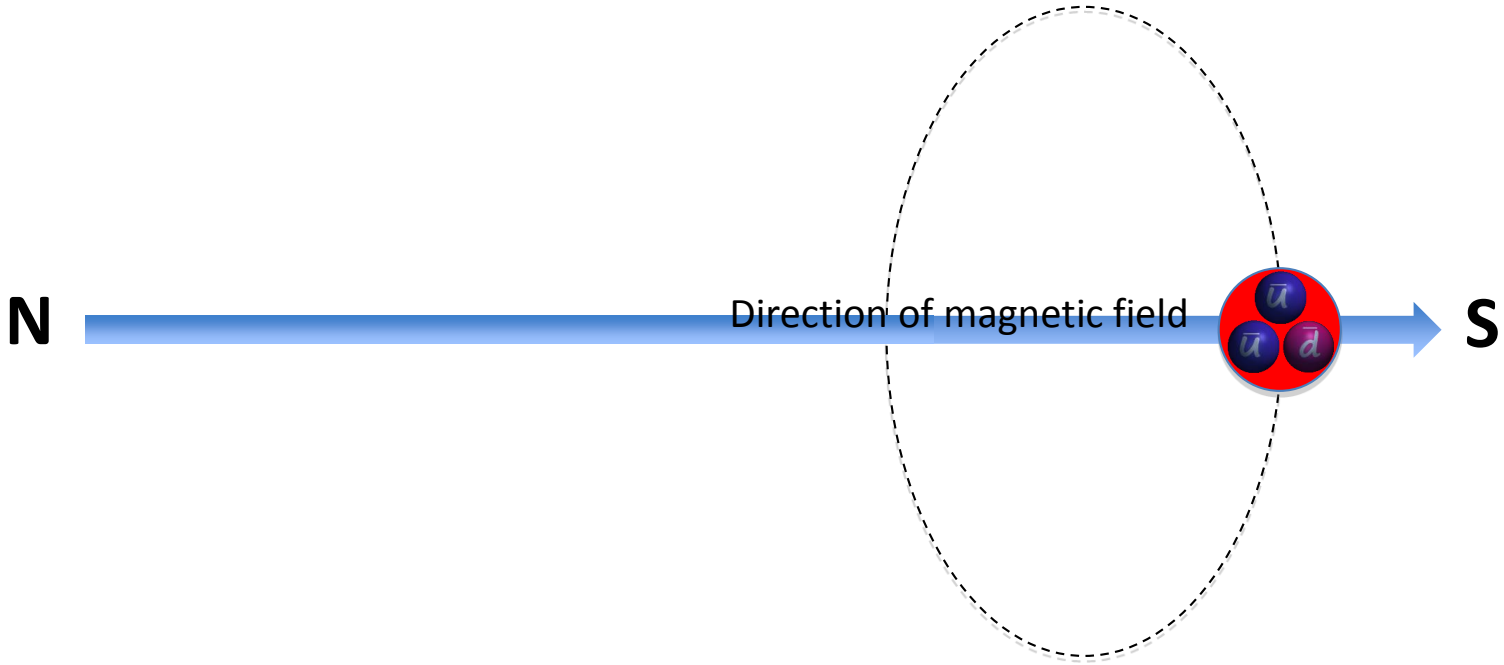
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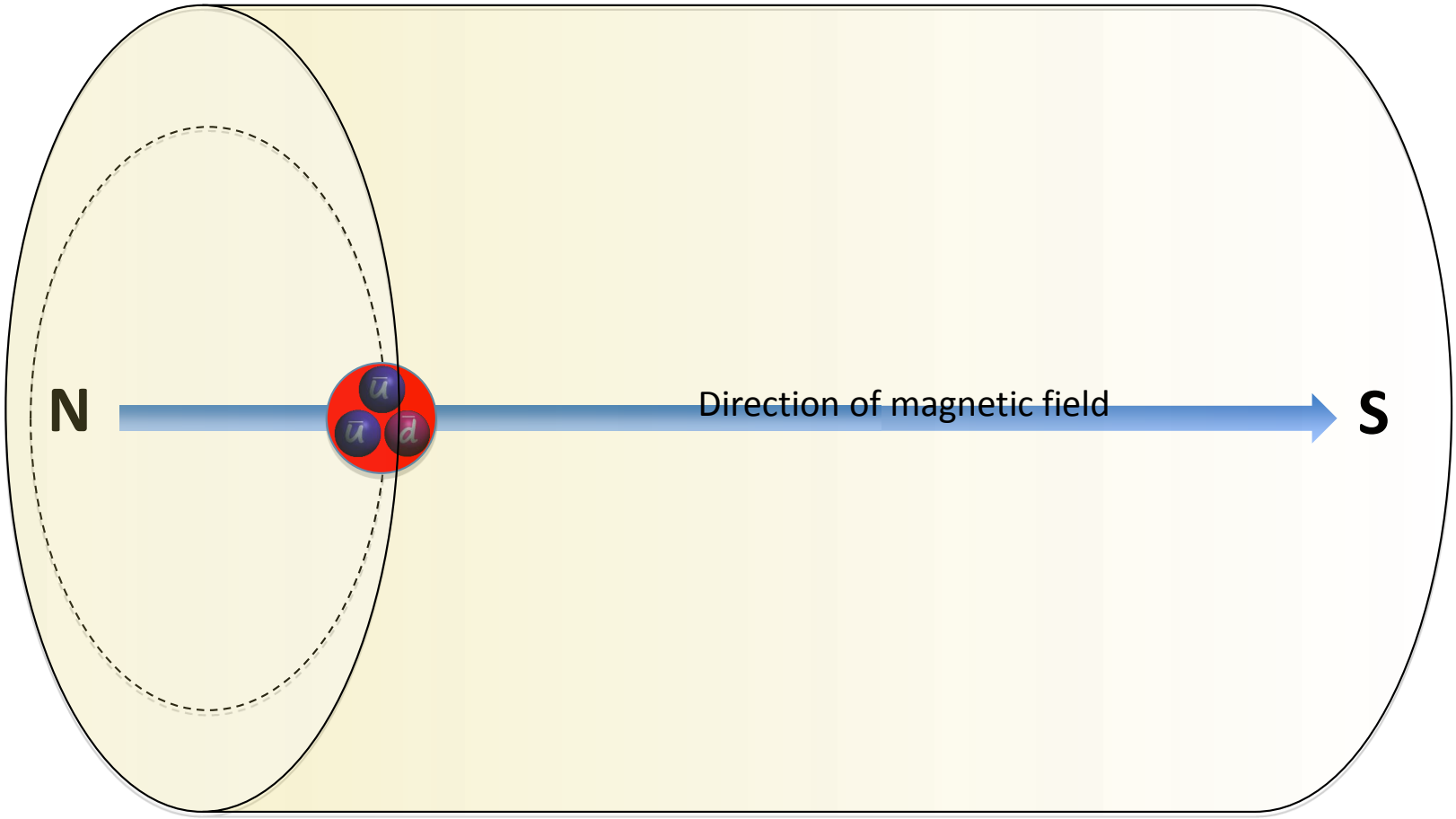
We can say that the antiproton is spiraling (moving in a spiral path). This prevents the antiproton from coming into contact with the sides of the trap.

But the magnetic field alone is not sufficient to contain the antiproton, since if it continues in this path, it will annihilate as soon as it reaches the opposite end of the trap!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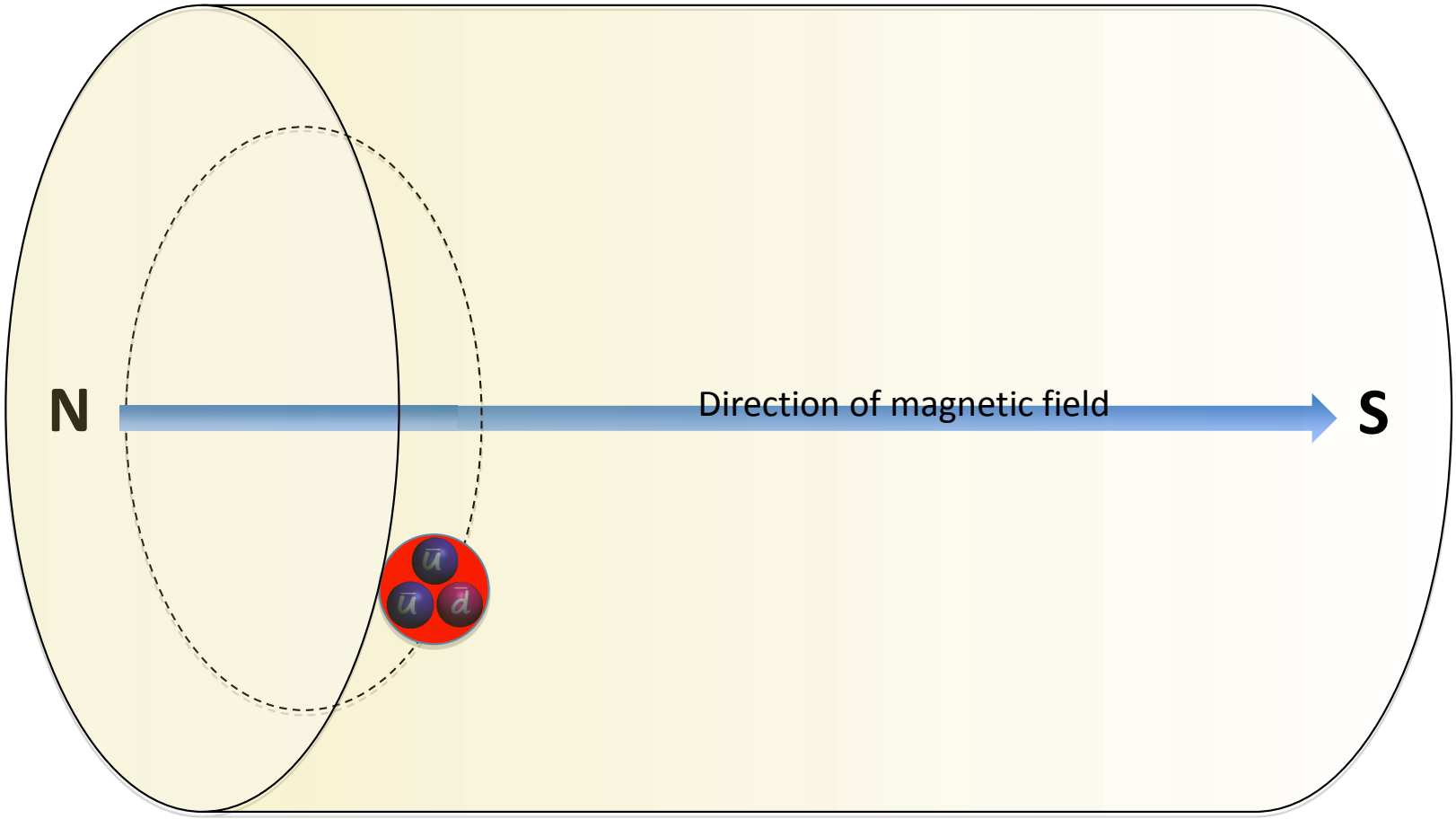
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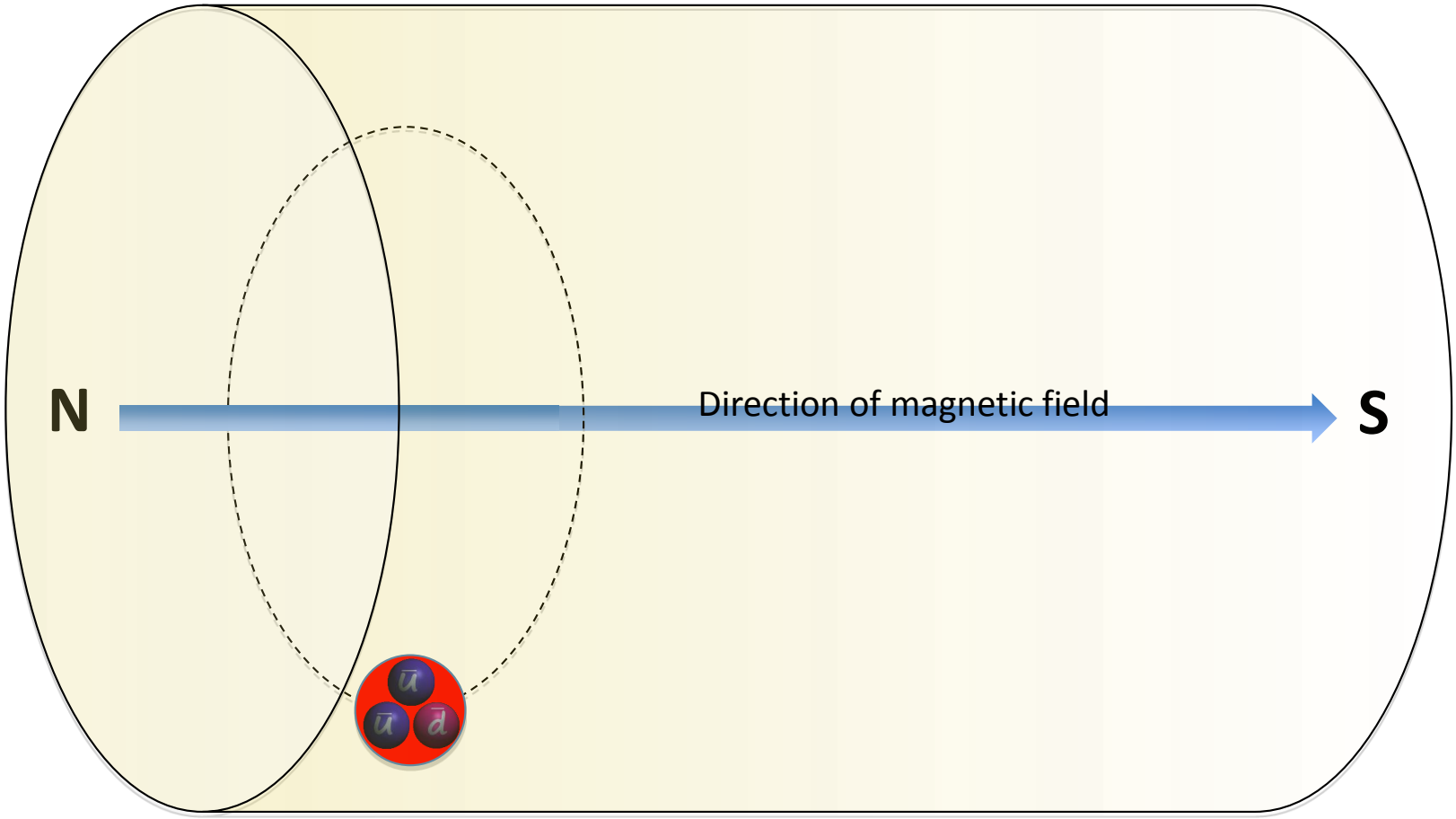
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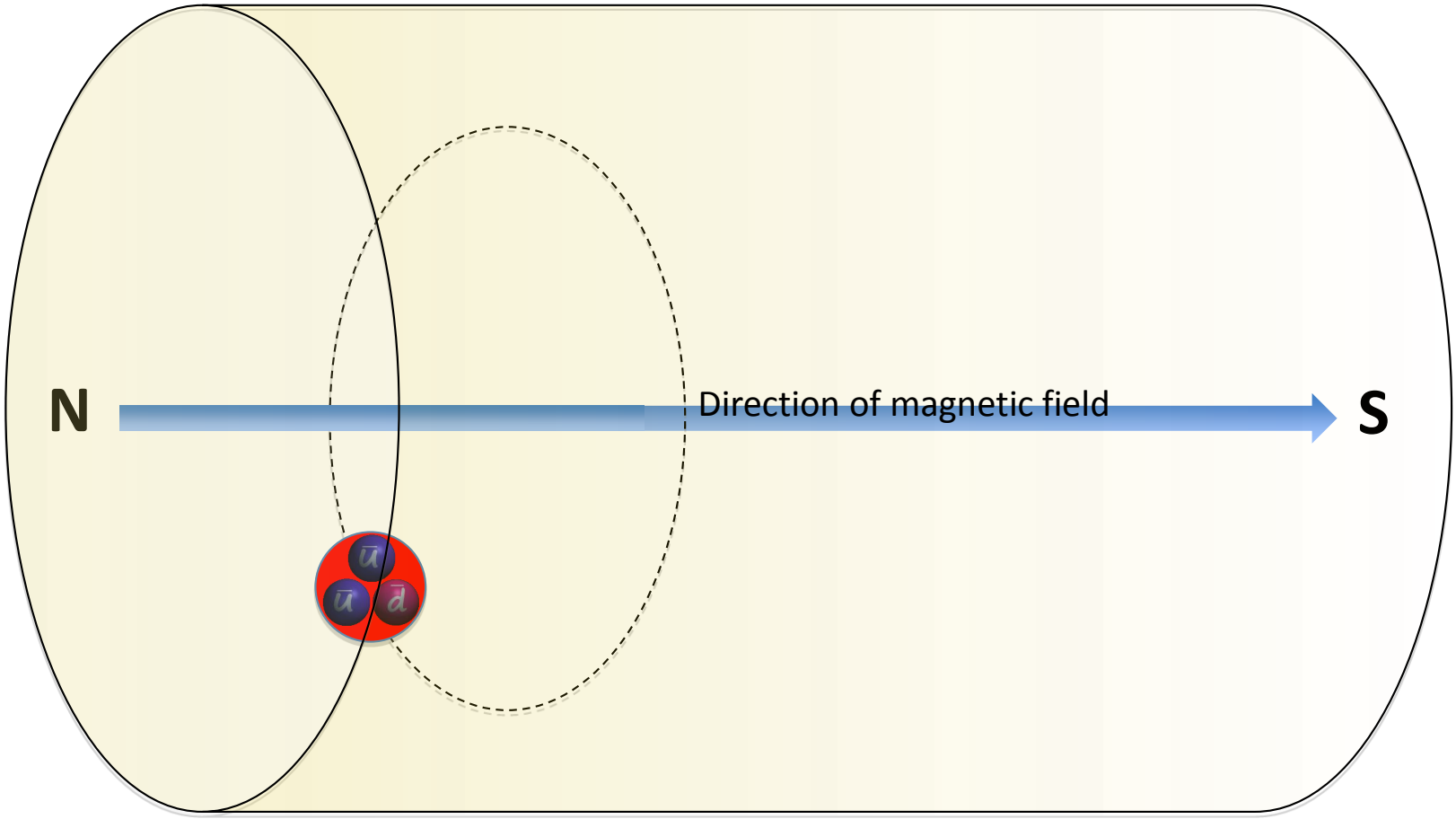
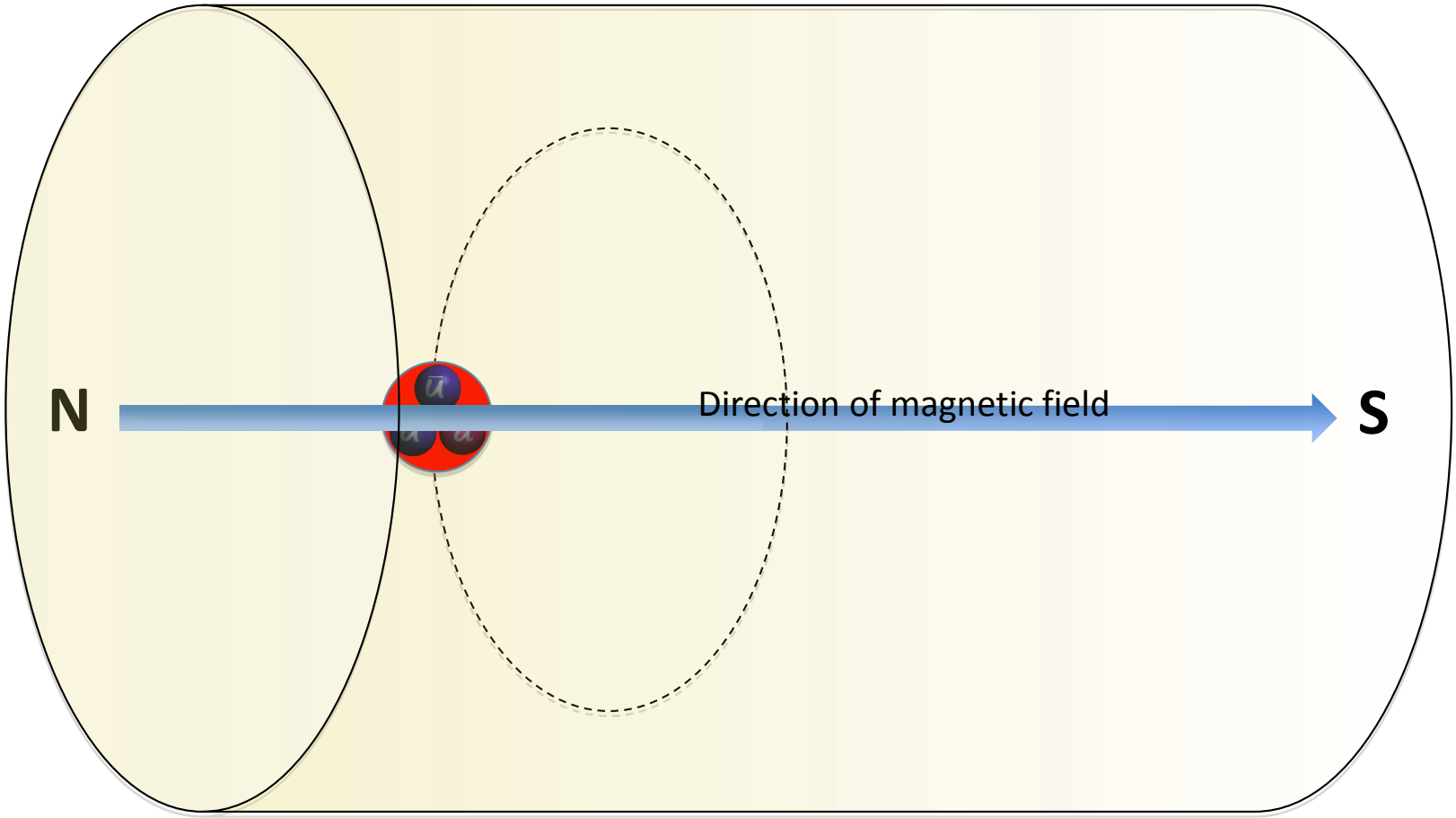
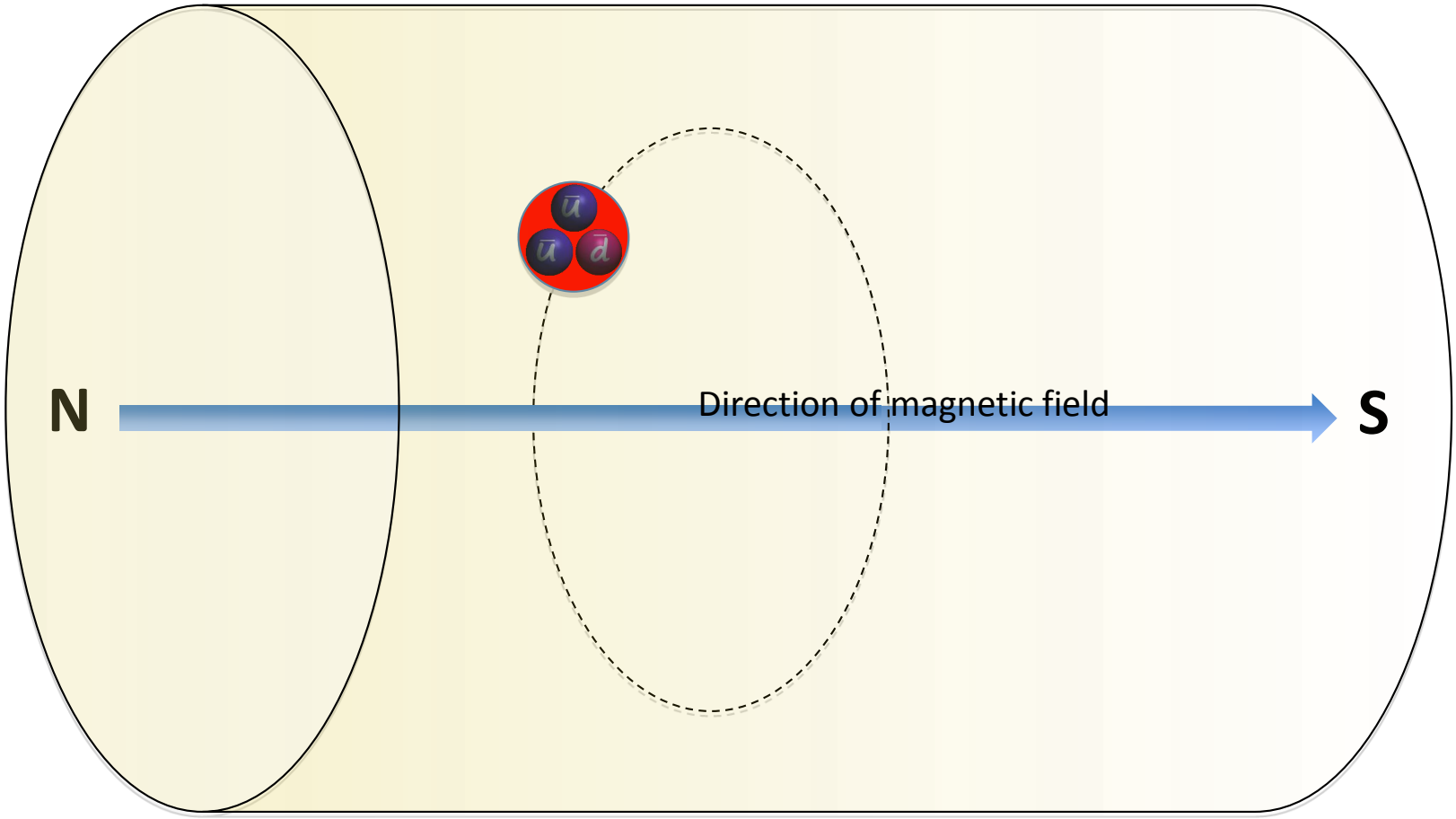
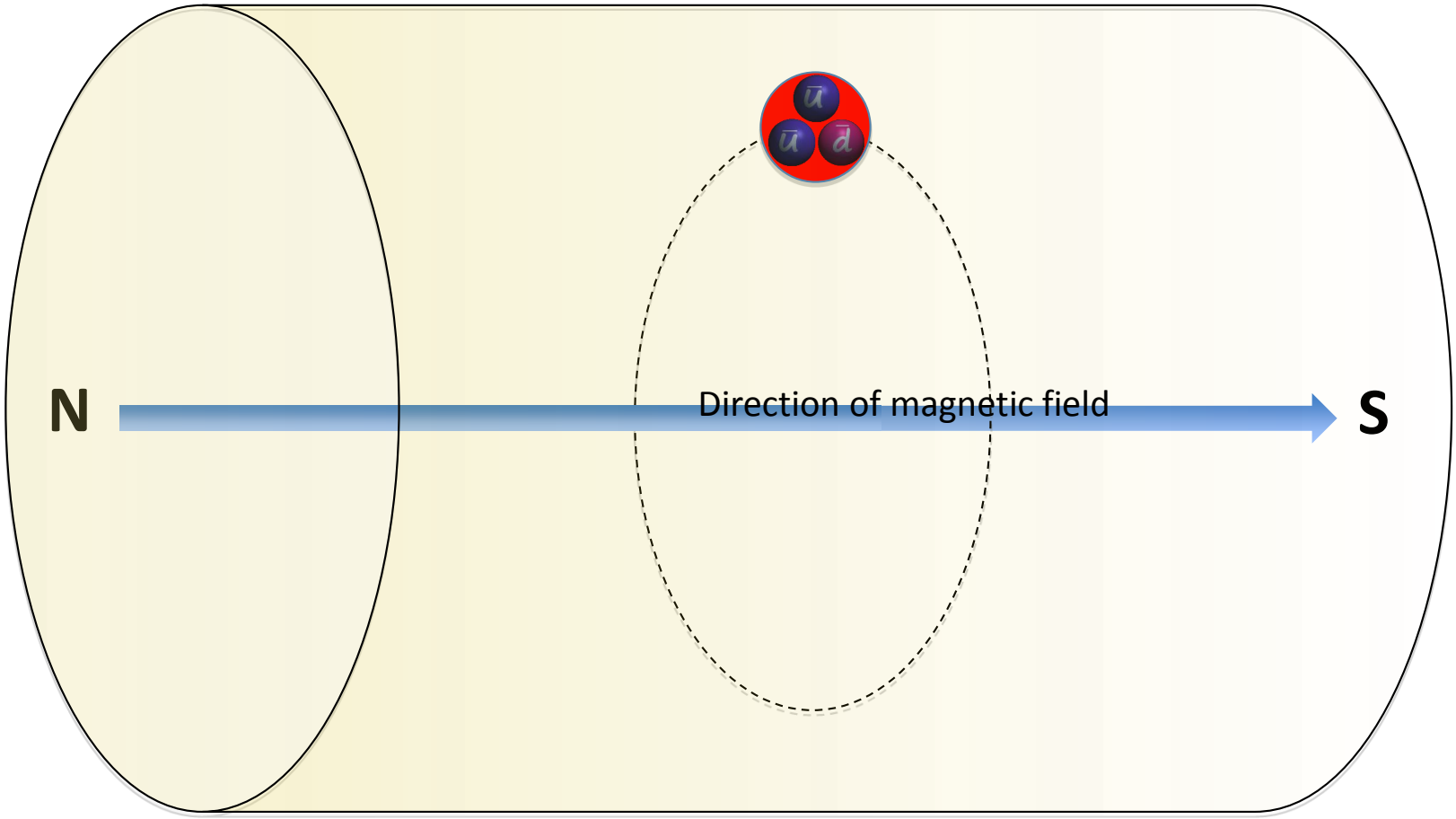
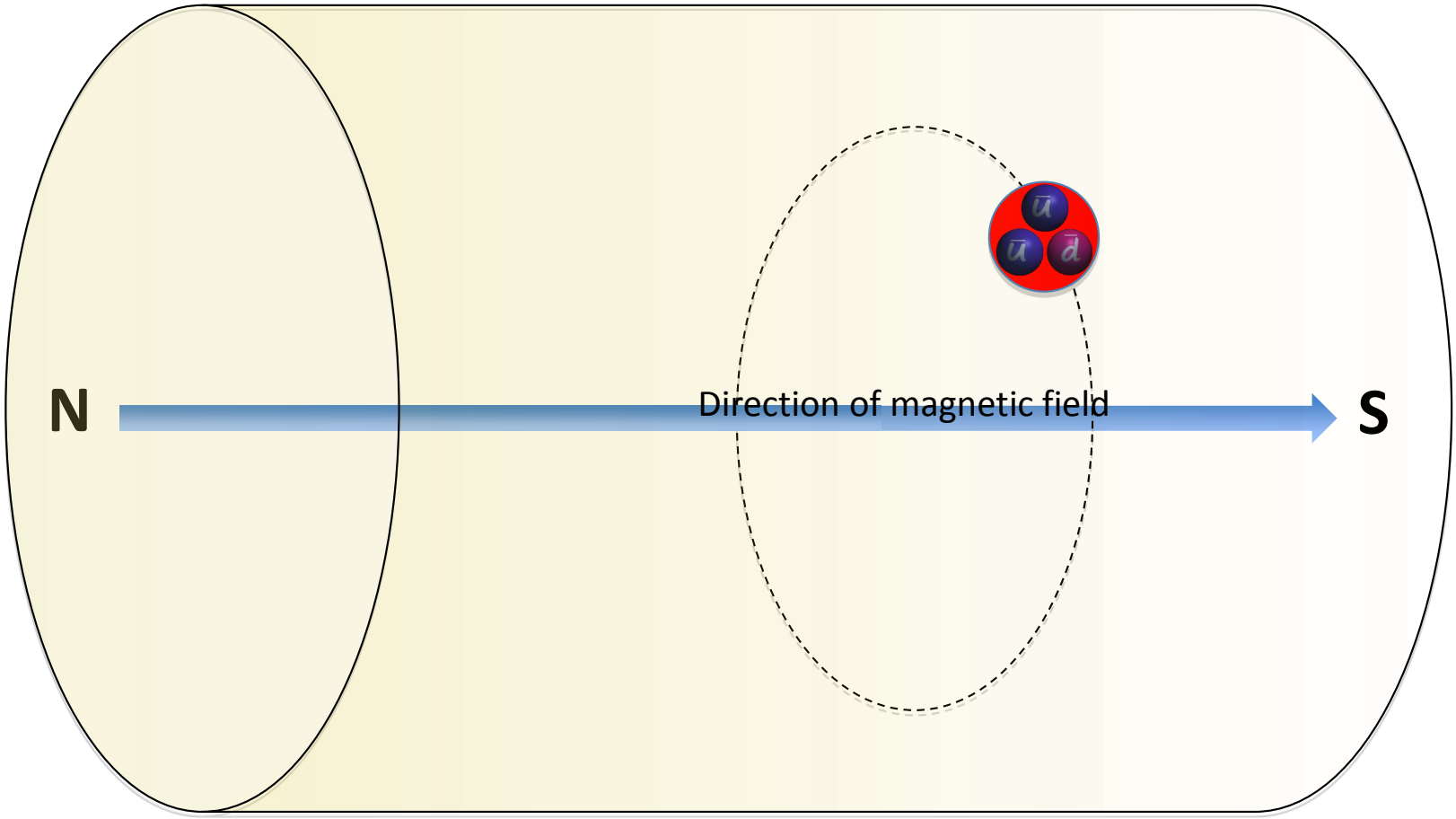
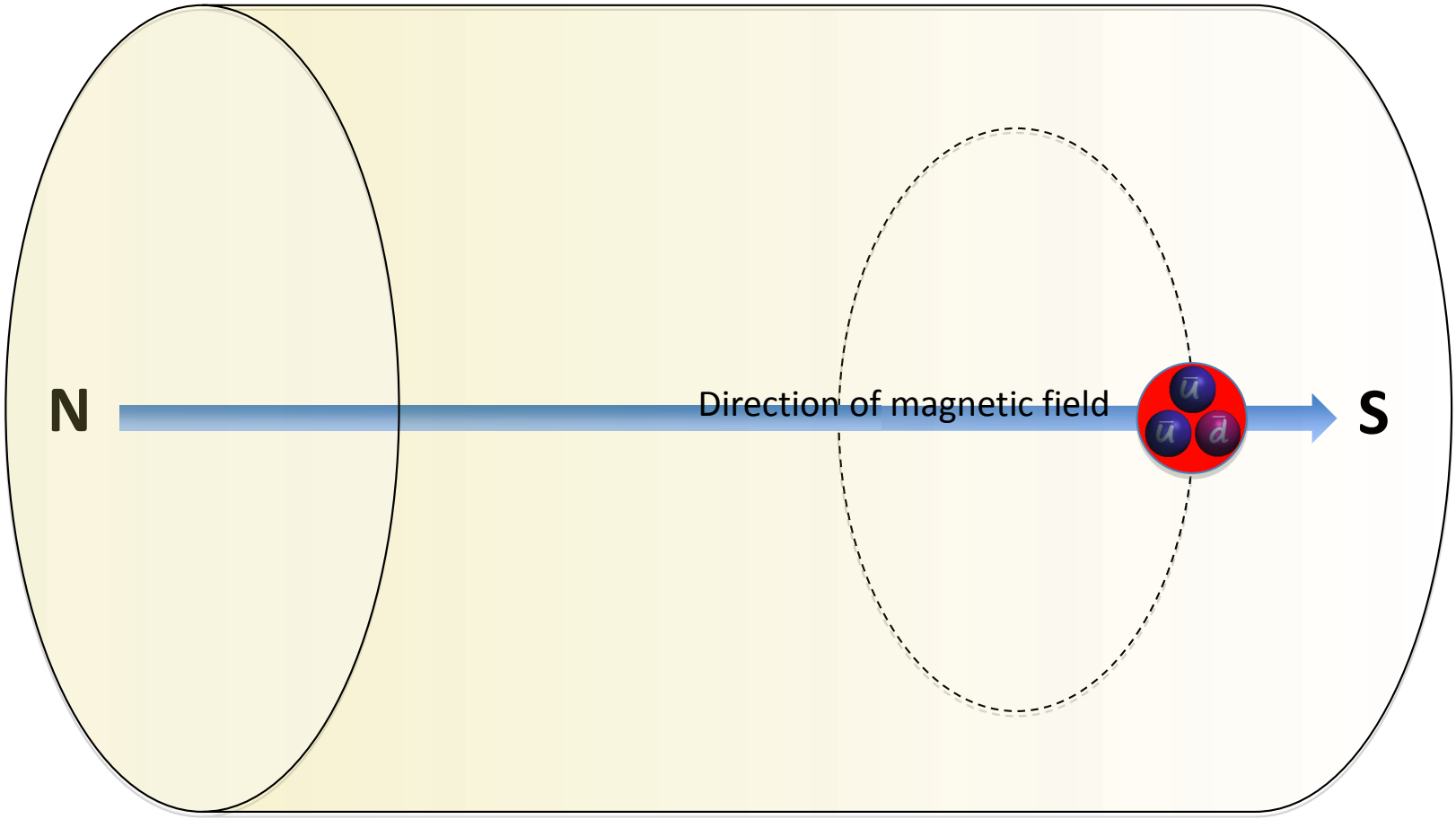

N
Direction of magnetic field
S
$\bar{u}$
$\bar{u}$
$\bar{d}$

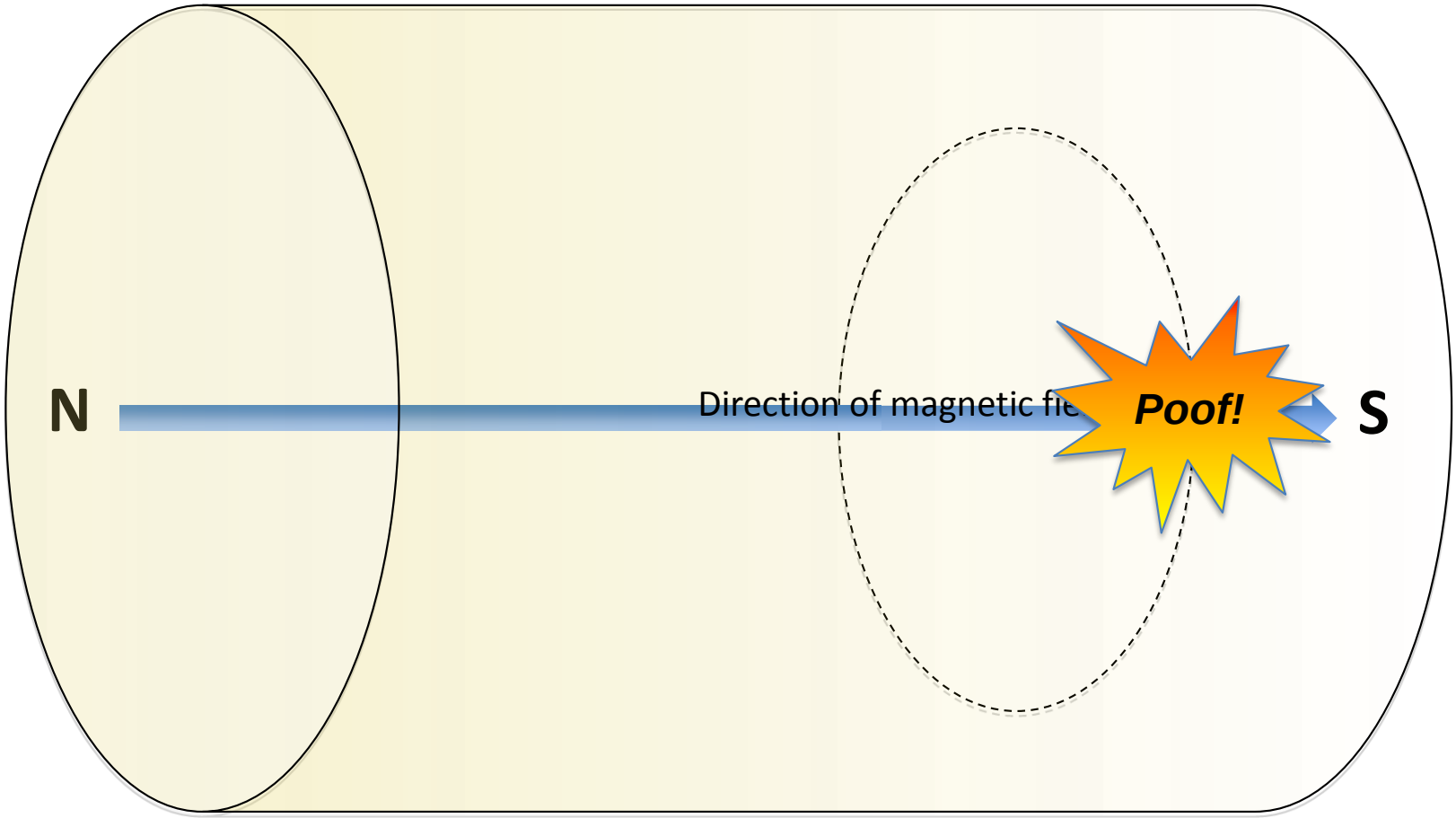

N
Direction of magnetic field
S

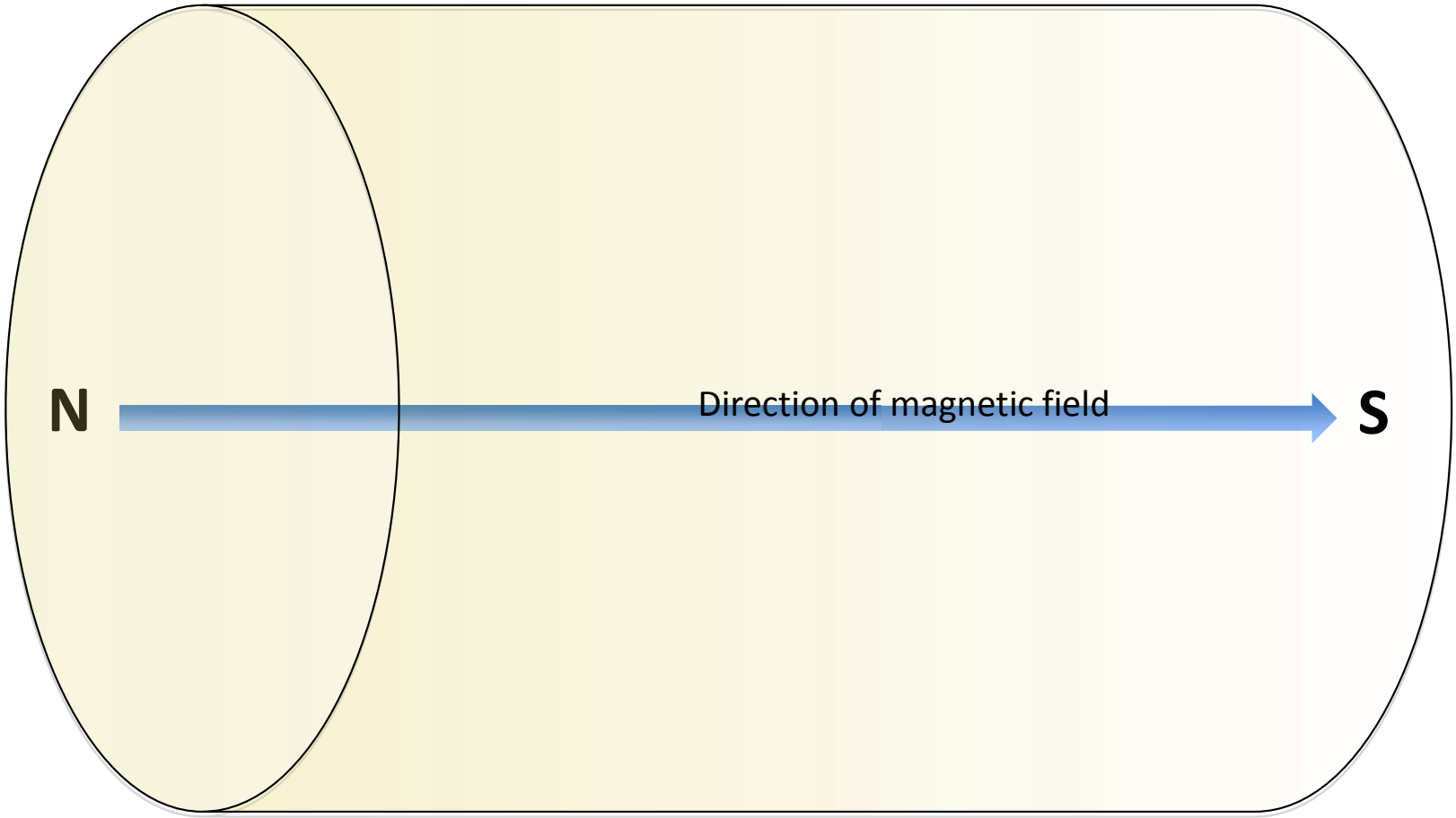

N
Direction of magnetic field
S


N
Direction of magnetic field
S


N
Direction of magnetic field
S
$\bar{u}$
$\bar{u}$
$\bar{d}$


N
Direction of magnetic field
S
$\bar{u}$
$\bar{u}$
$\bar{d}$

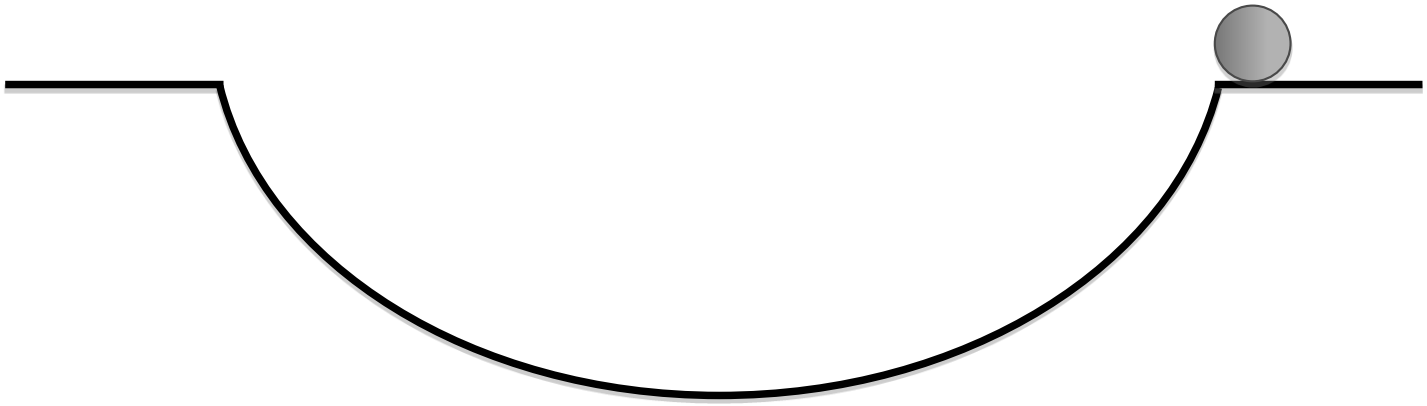

N
Direction of magnetic fie
Poof!
S


N
Direction of magnetic field
S

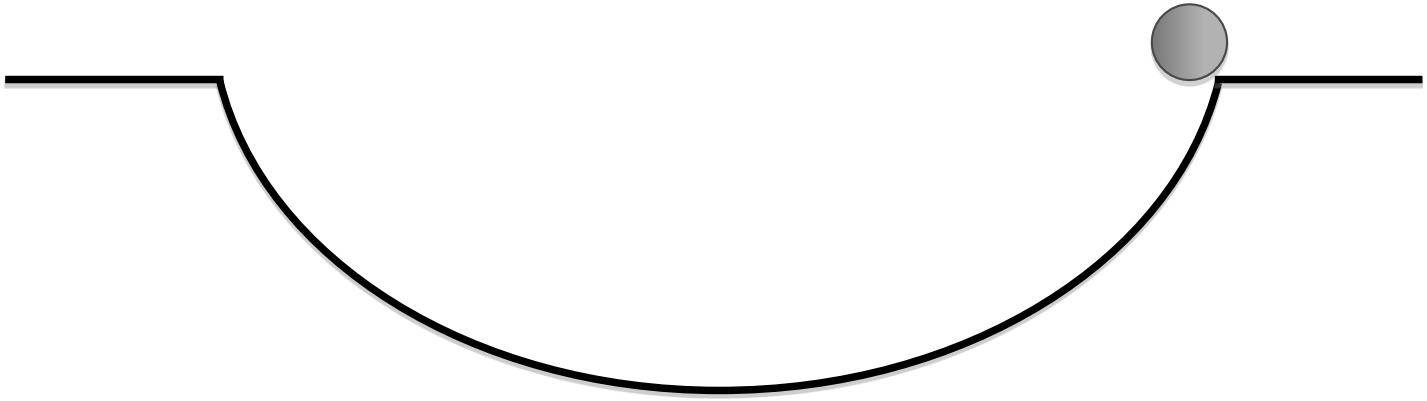
Therefore, we need a way to confine the particle along the length of the trap as well.
To achieve this, we use another property of a charged particle…its repulsion by a like charge.

In order to explain how this works, we can use a simple analogy with gravity…

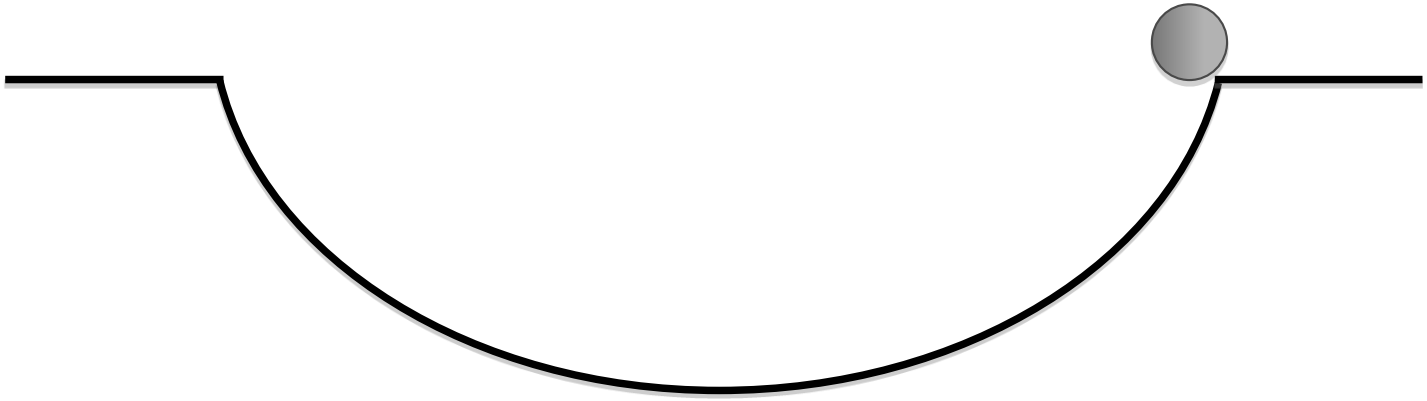
If we were to take a small metal sphere…



…and send it rolling into a smooth dip…



…we might expect its motion to look something like this…



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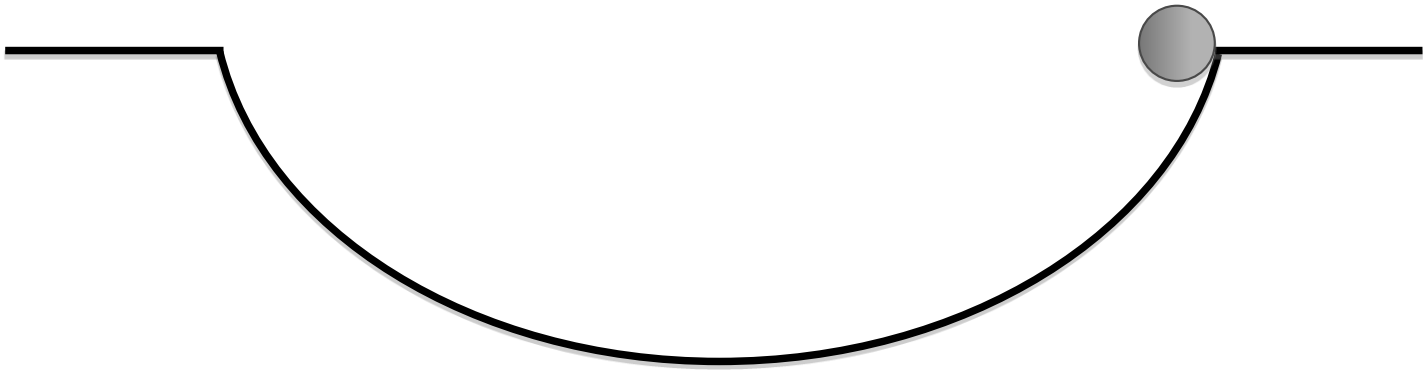

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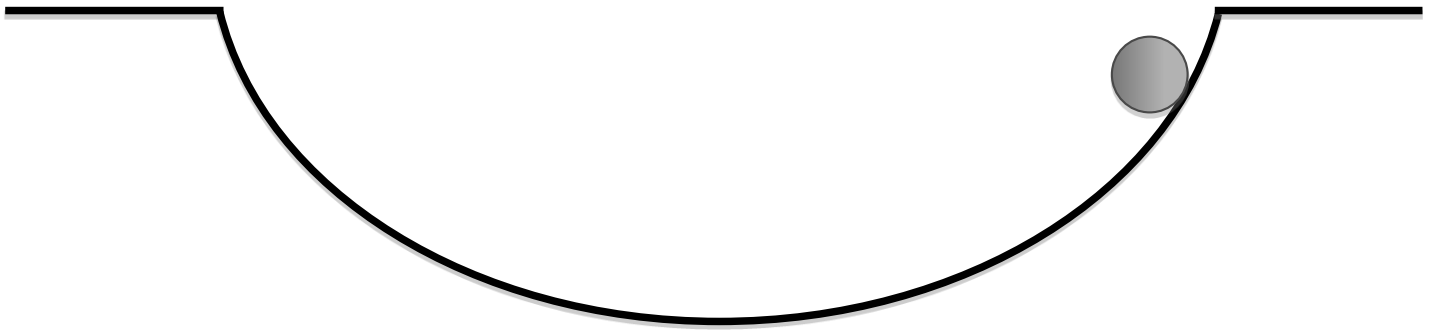

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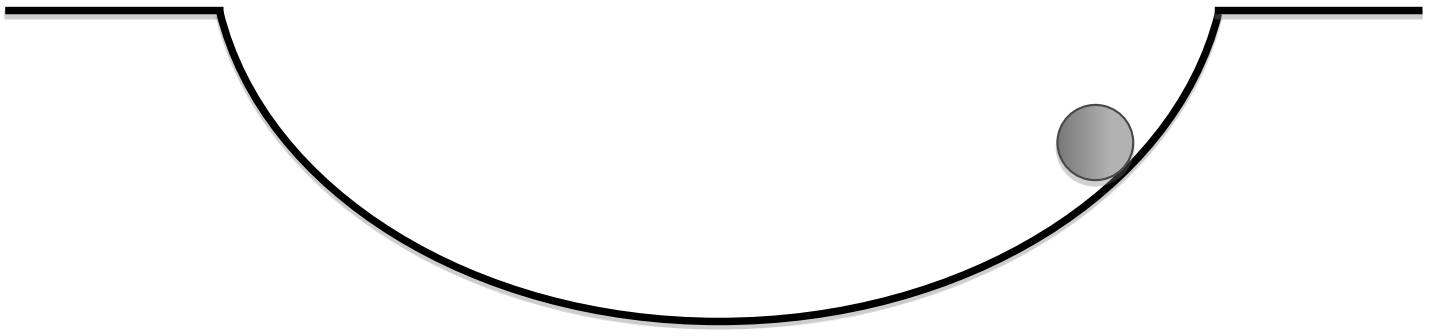

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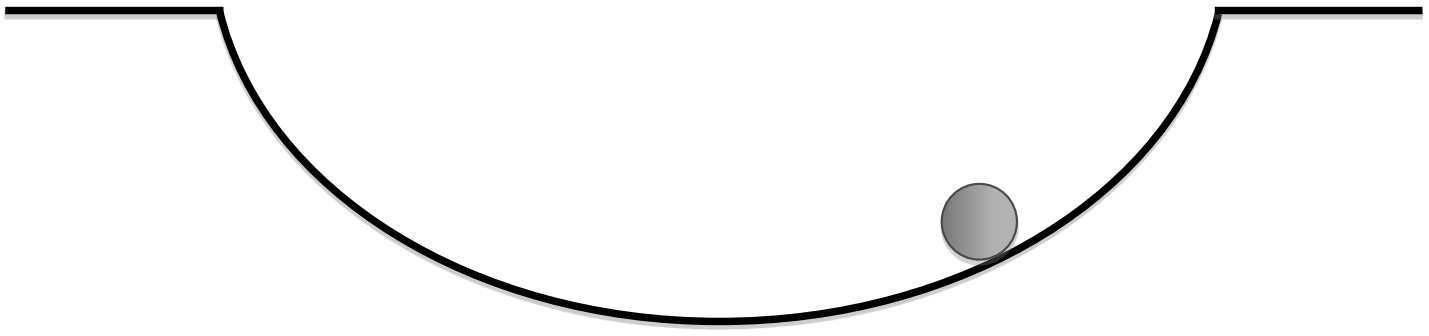

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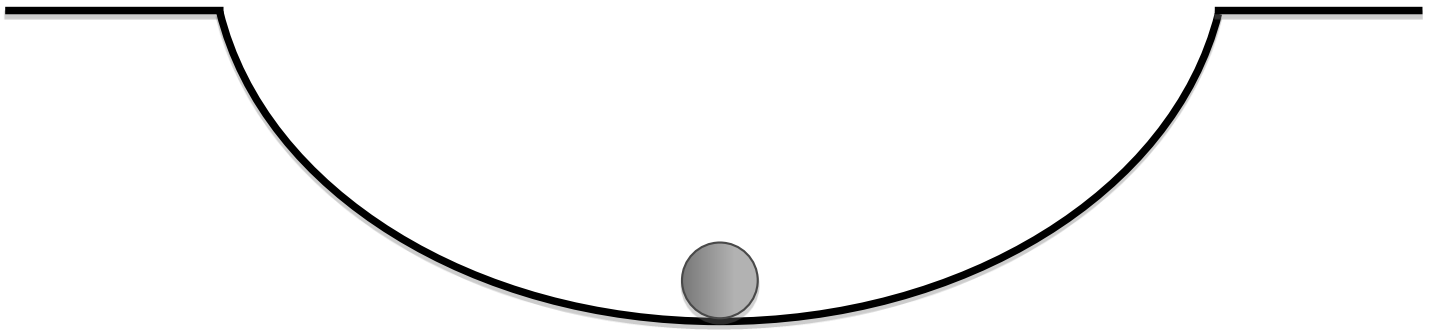

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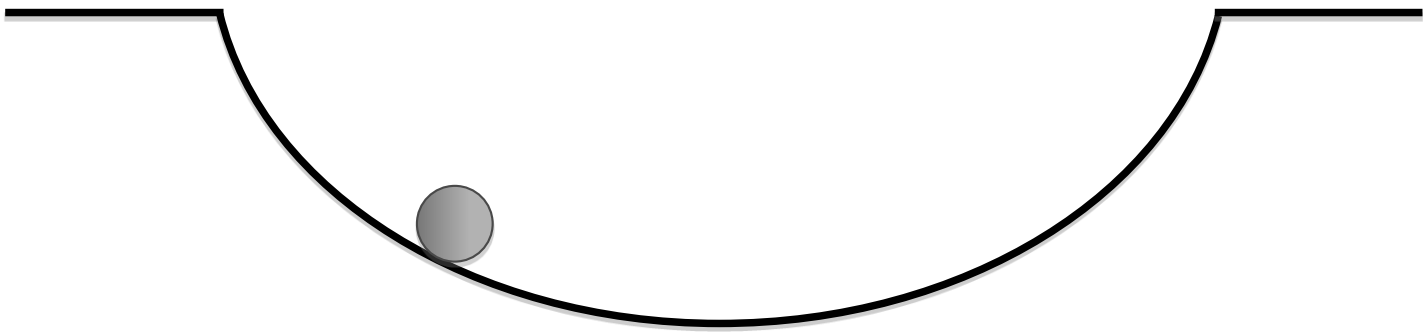

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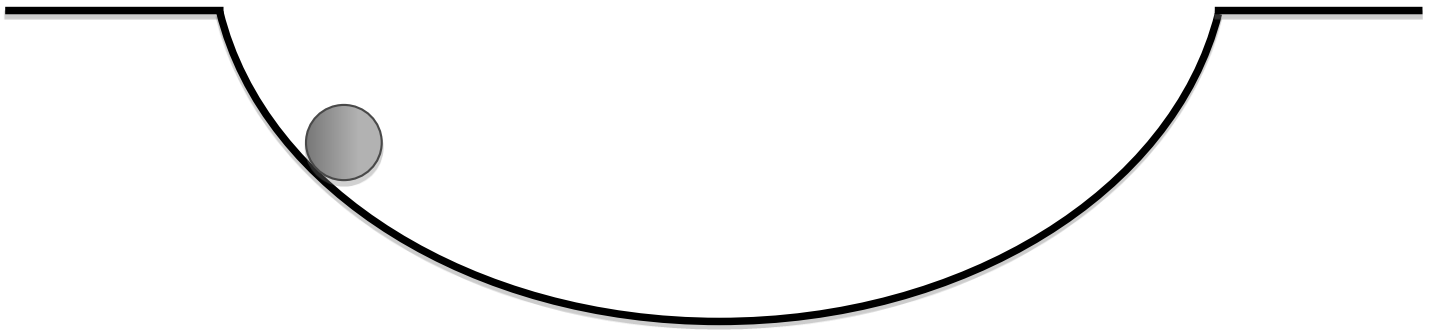

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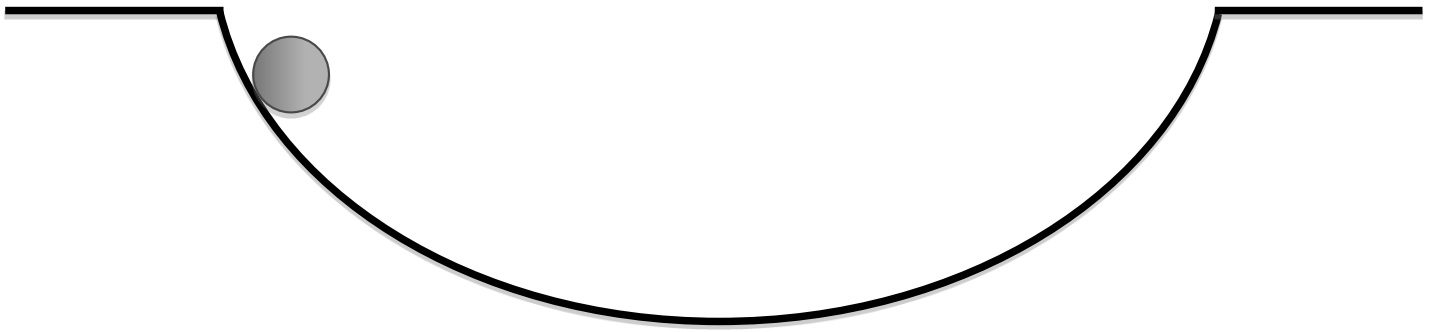

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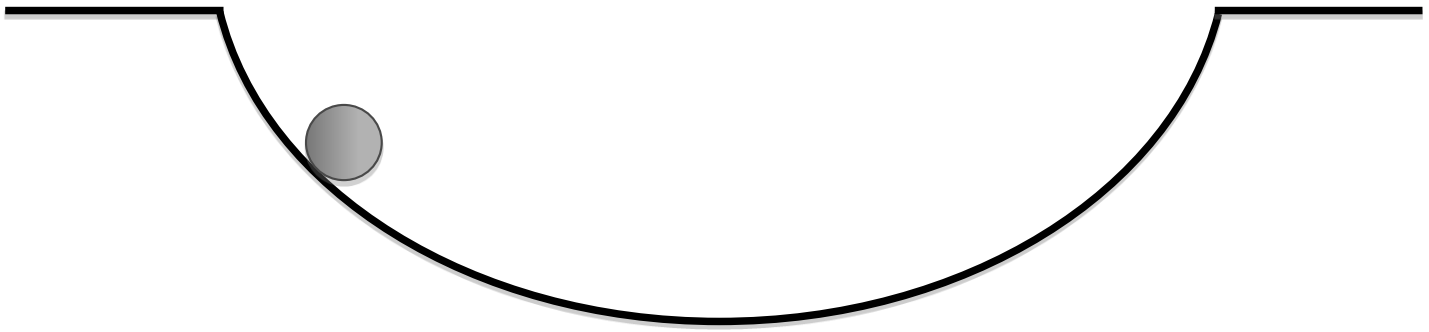

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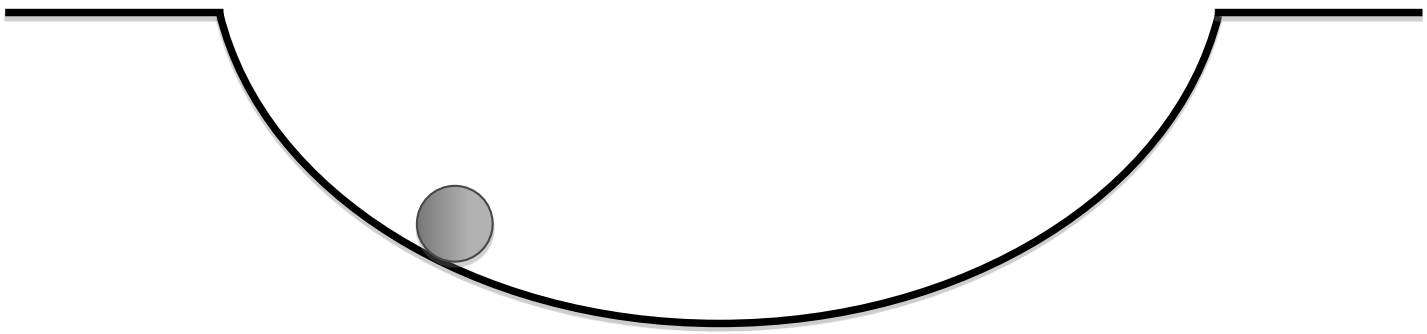

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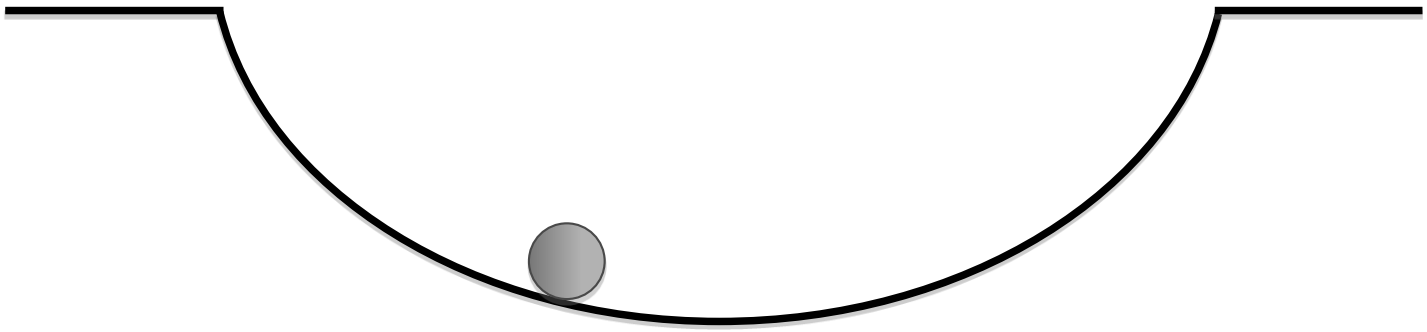

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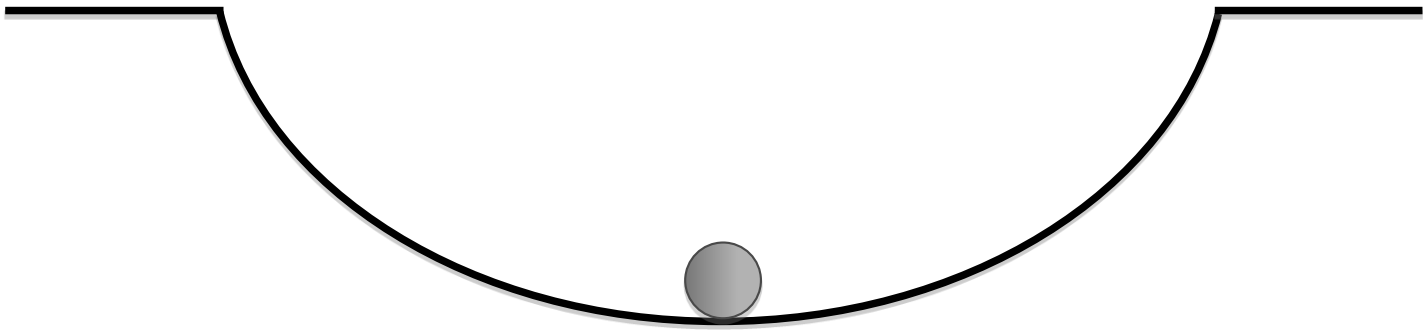

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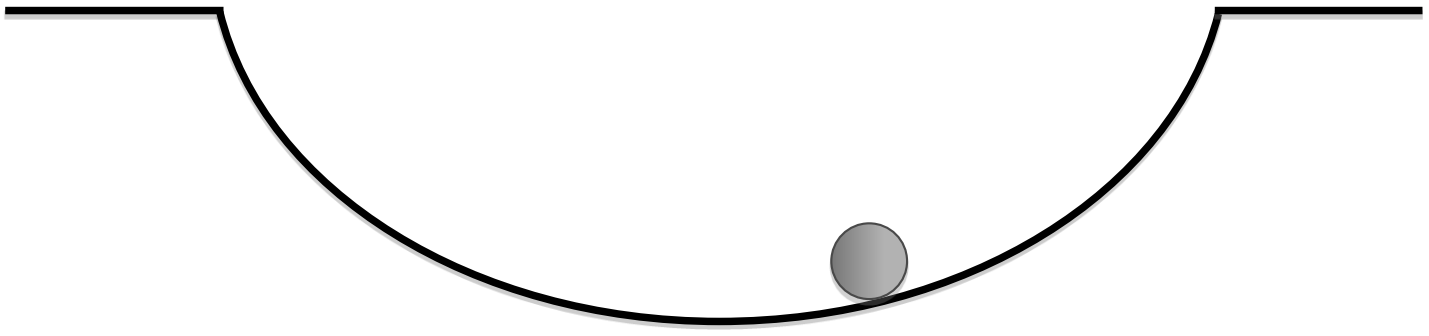

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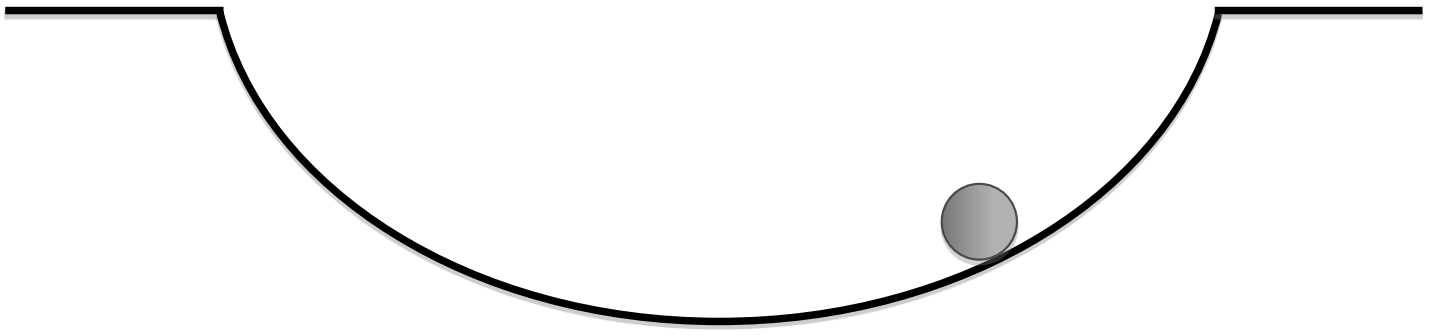

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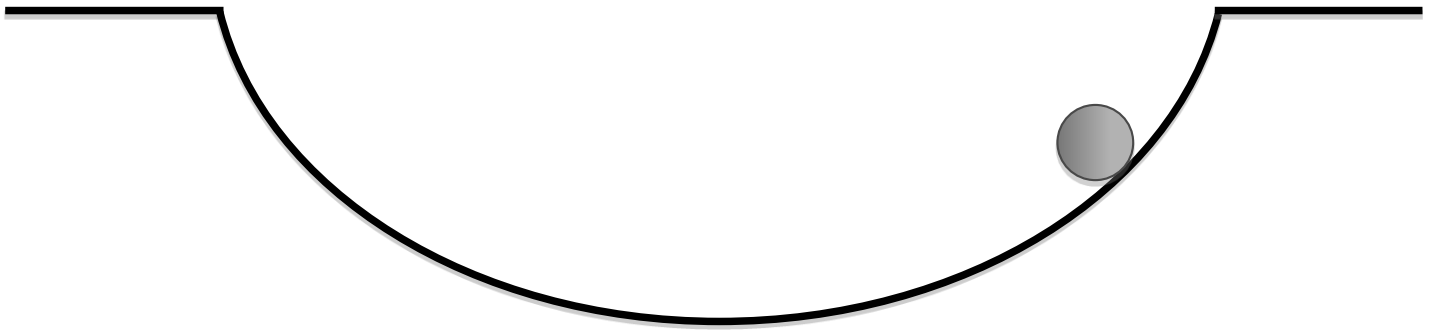

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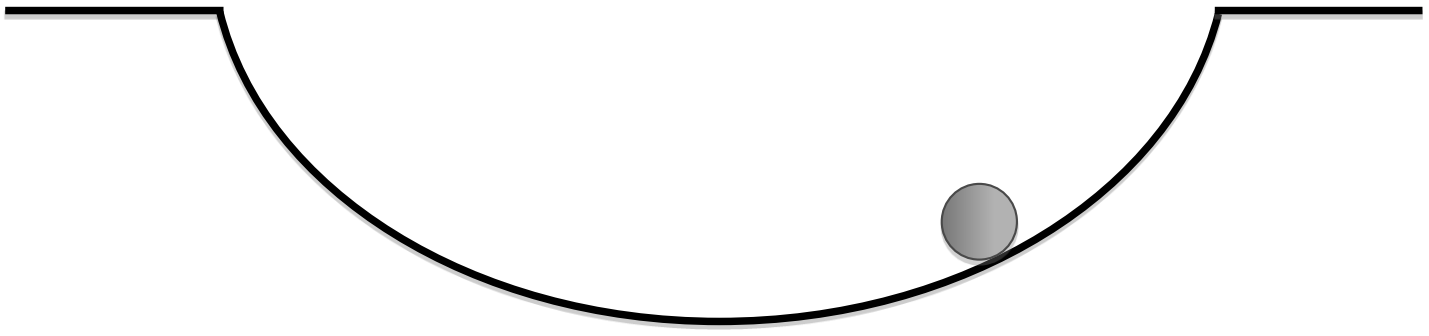

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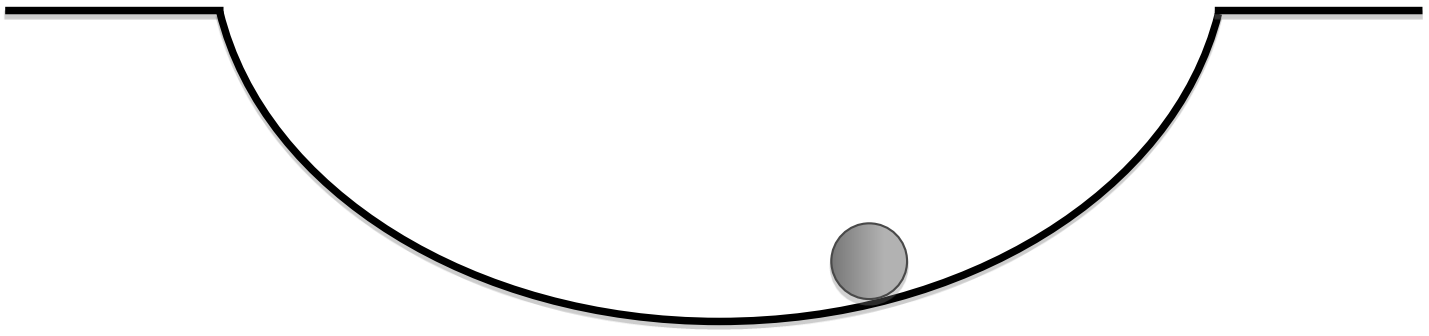

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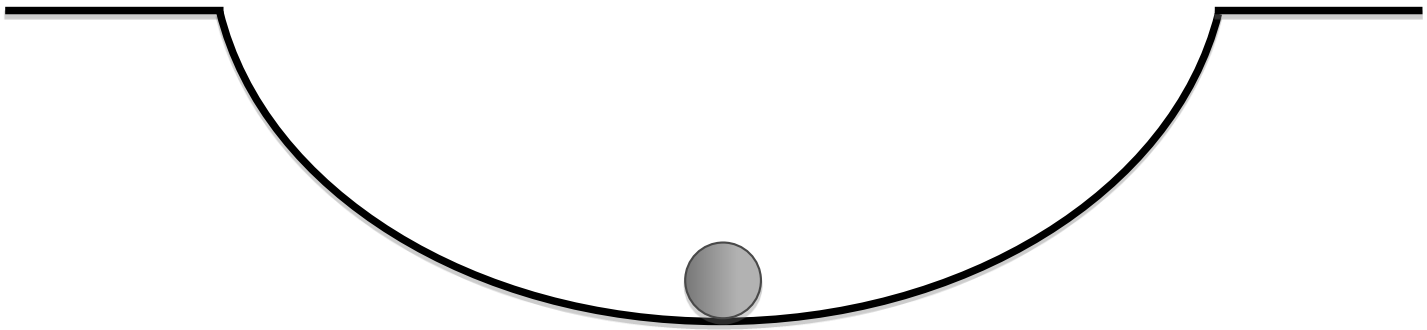

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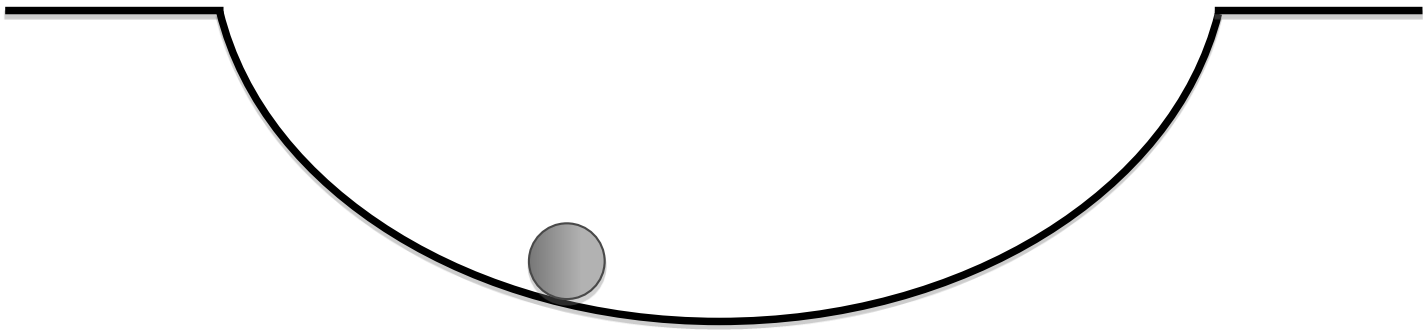

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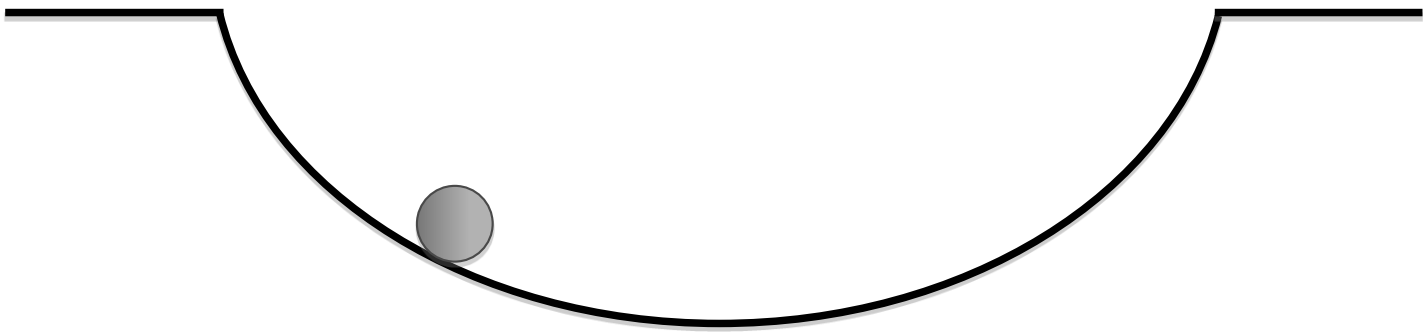

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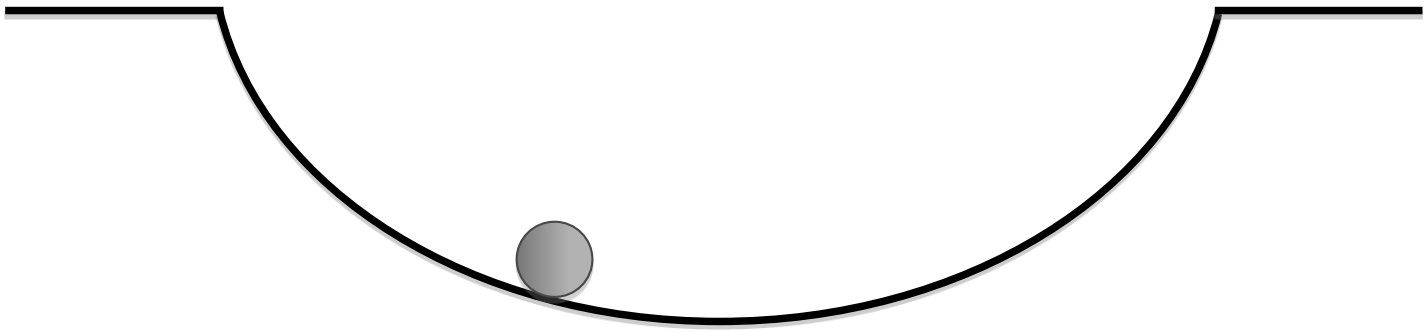

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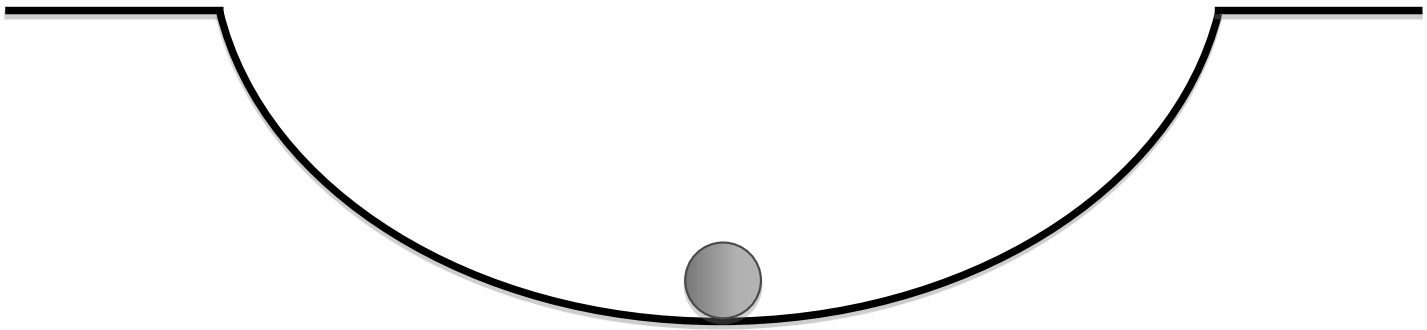

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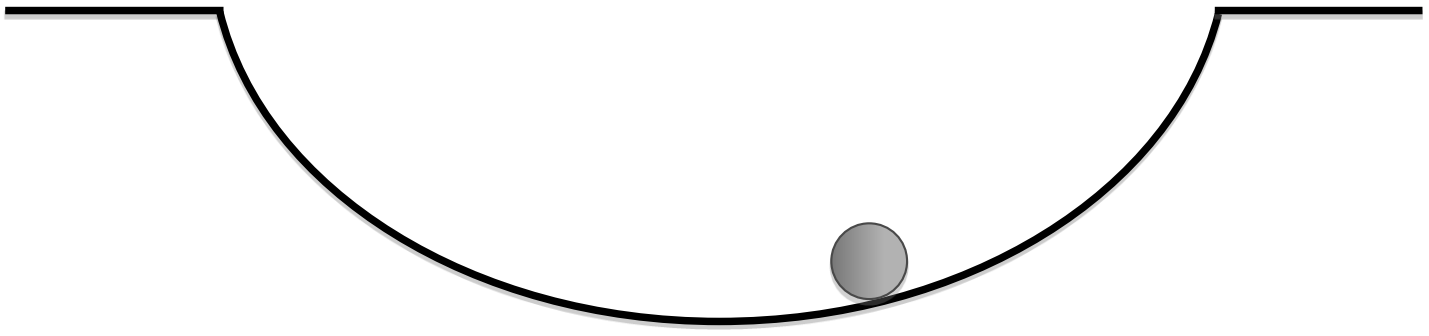

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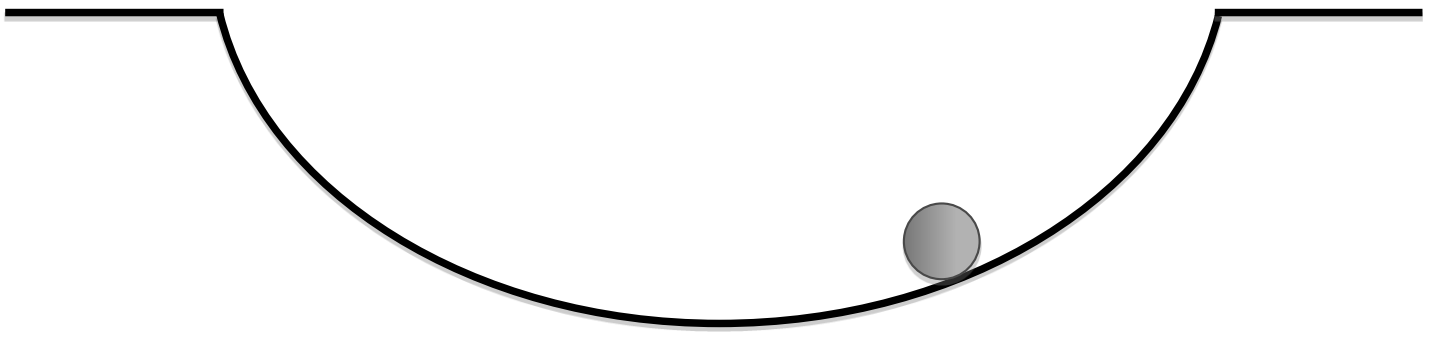

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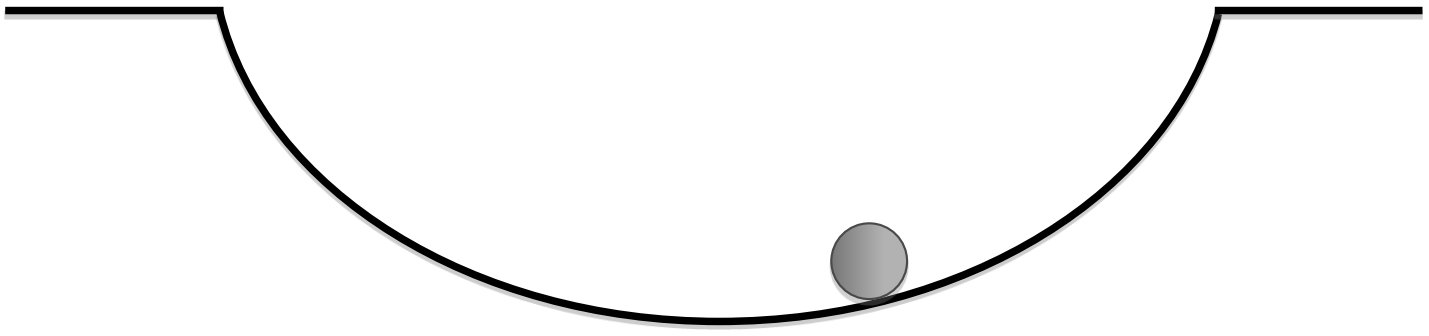

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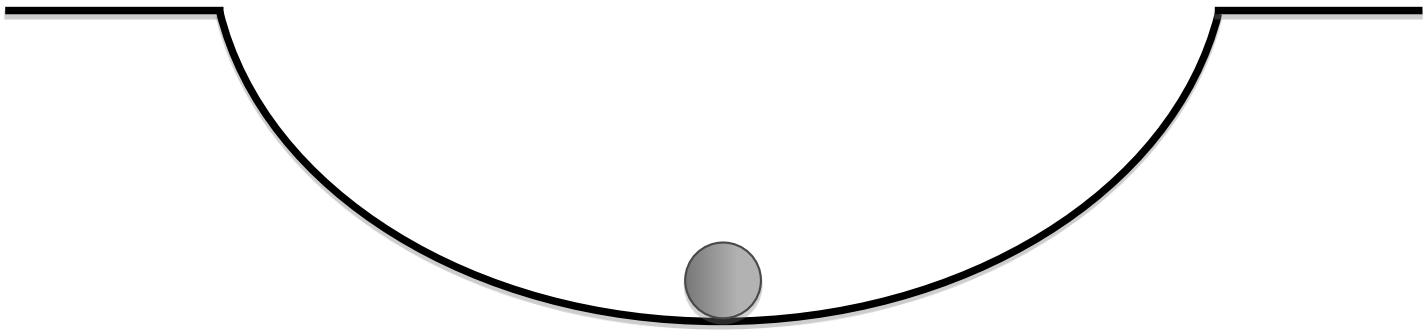

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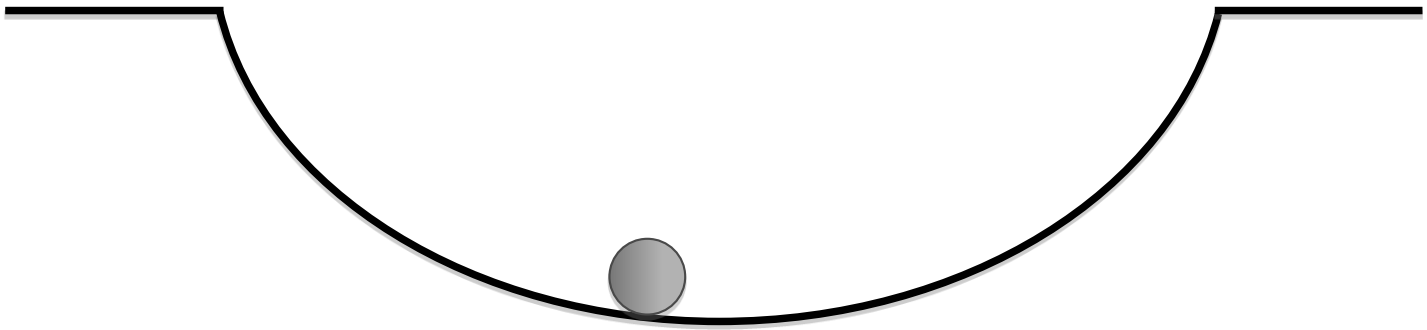

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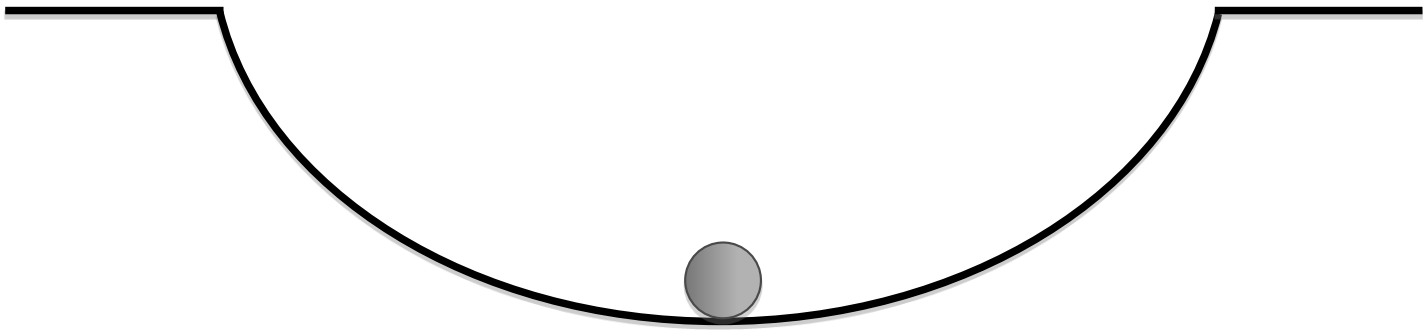

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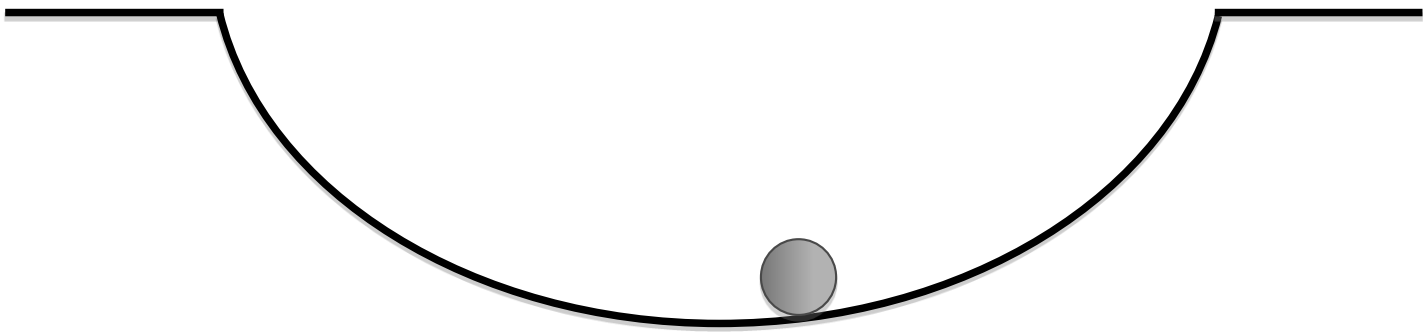

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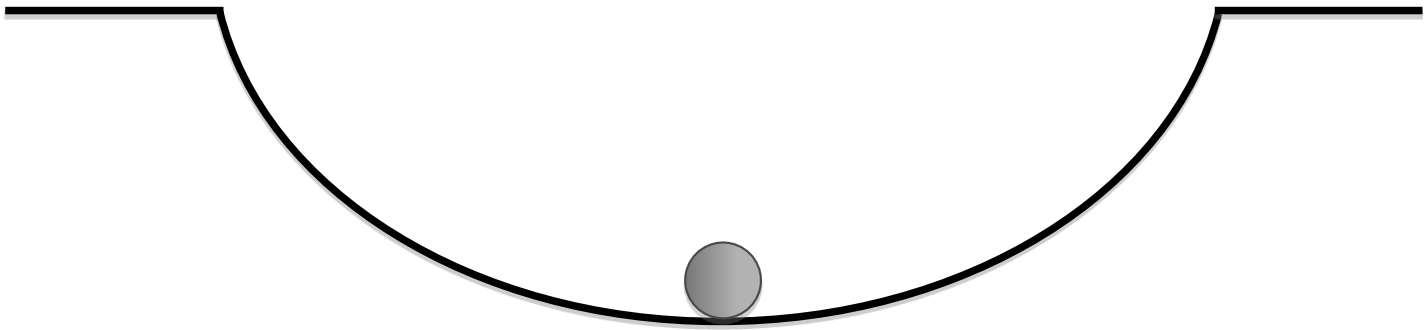
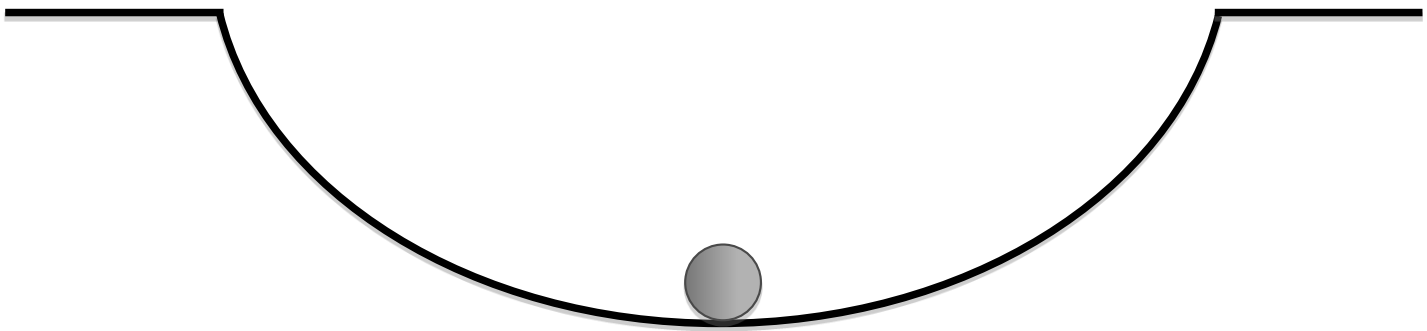
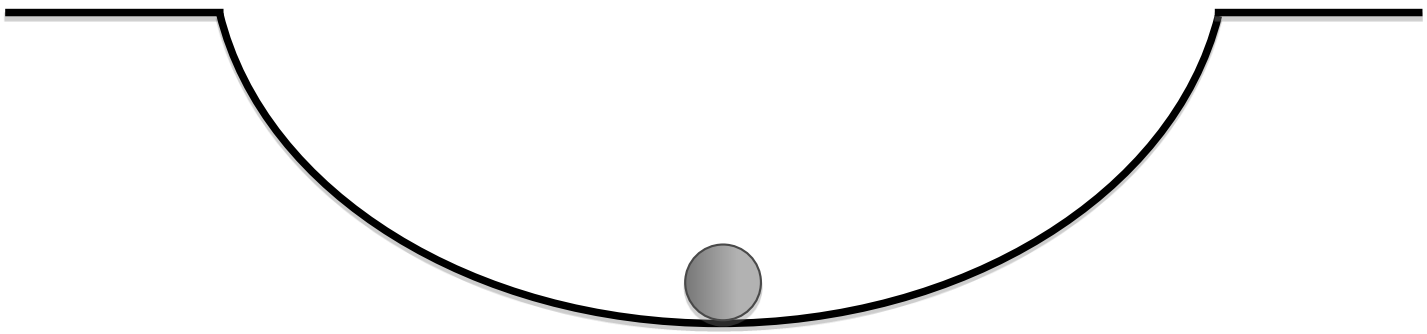


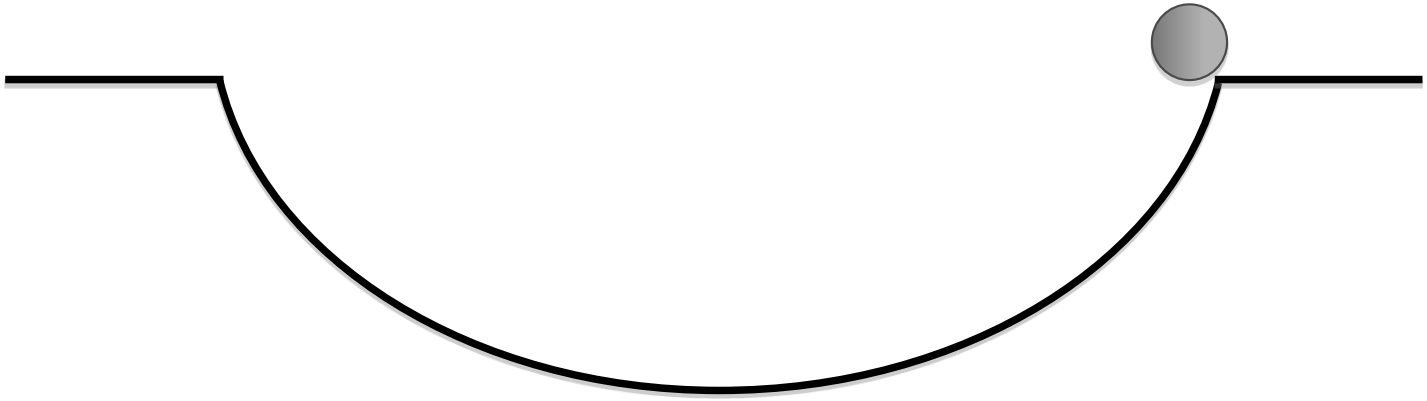
..until it stopped at the bottom.



This happens because the ball continuously loses energy as it moves in the dip.



However, if we gave it an extra little push (i.e., give it more energy) every time it passed, say, the bottom of the dip, we could keep it in motion…



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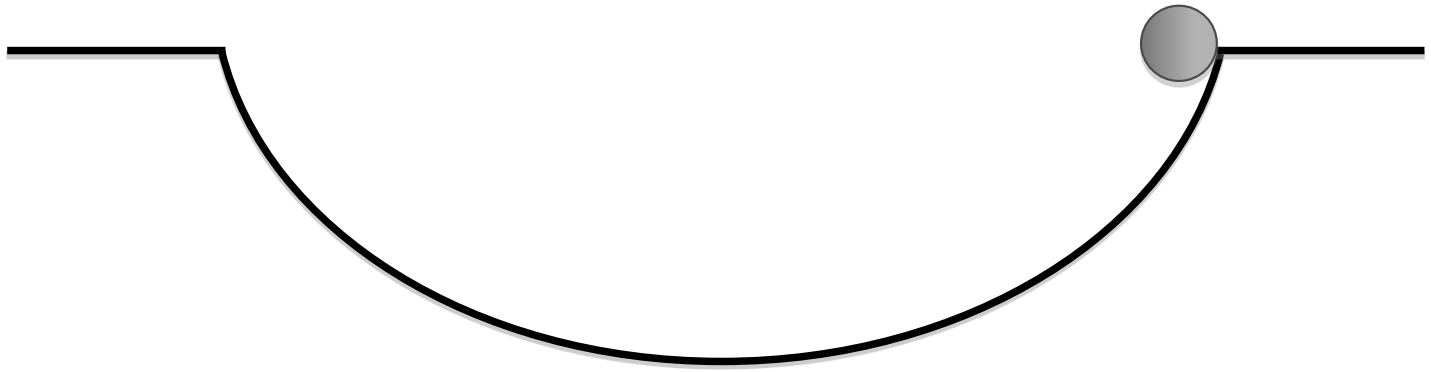

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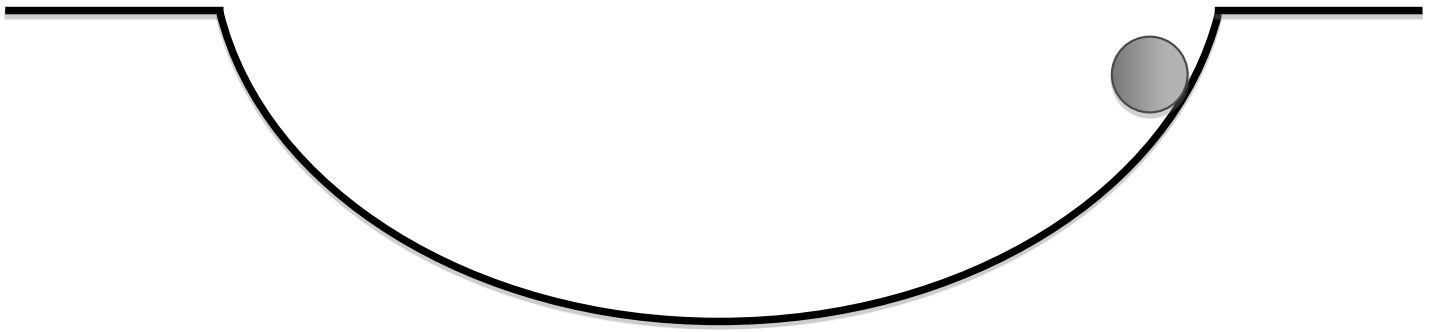

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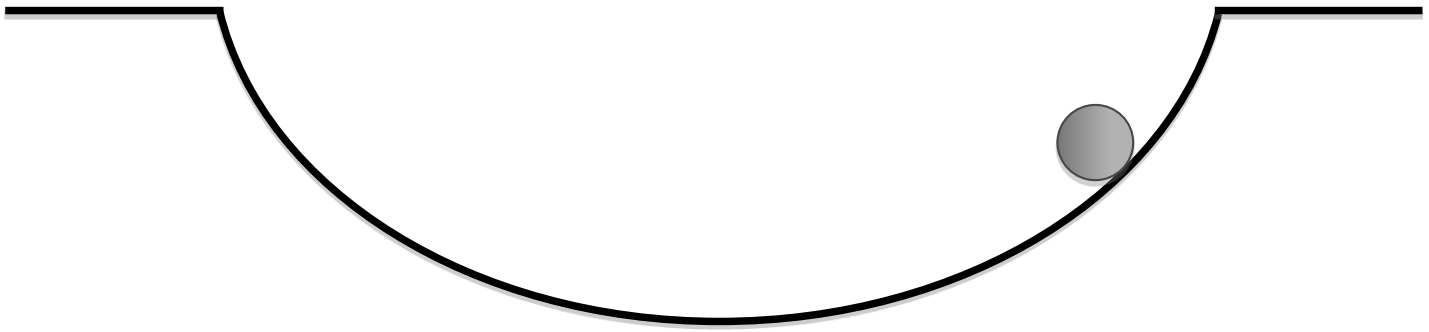

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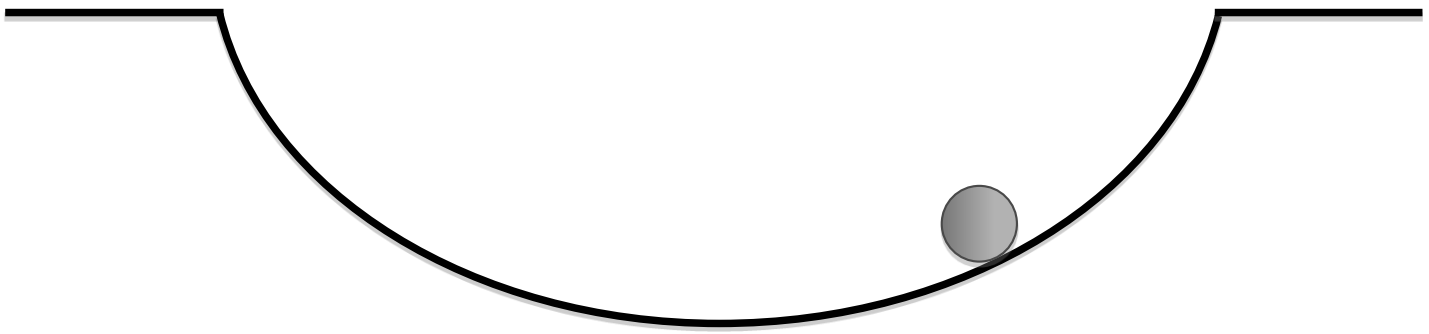

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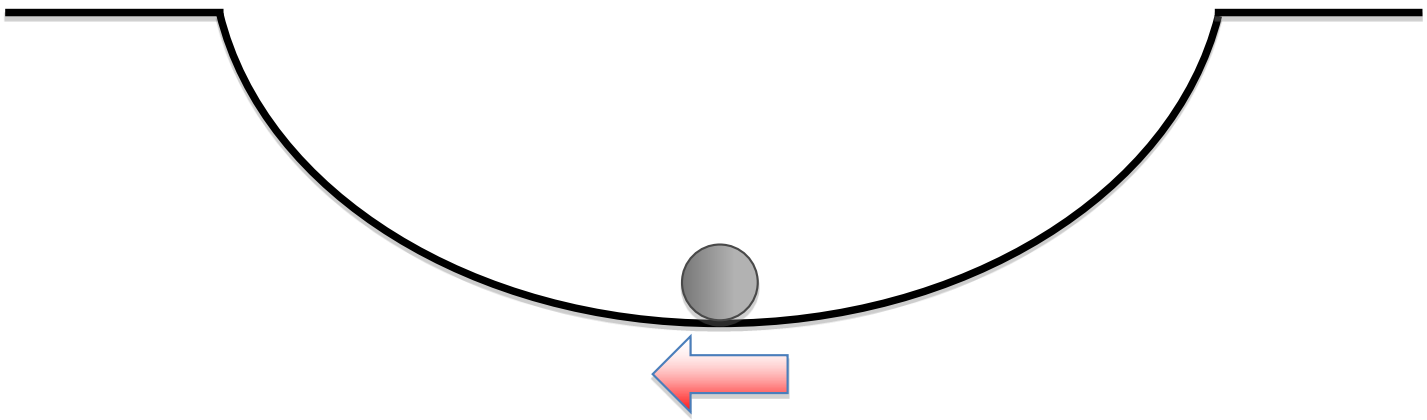

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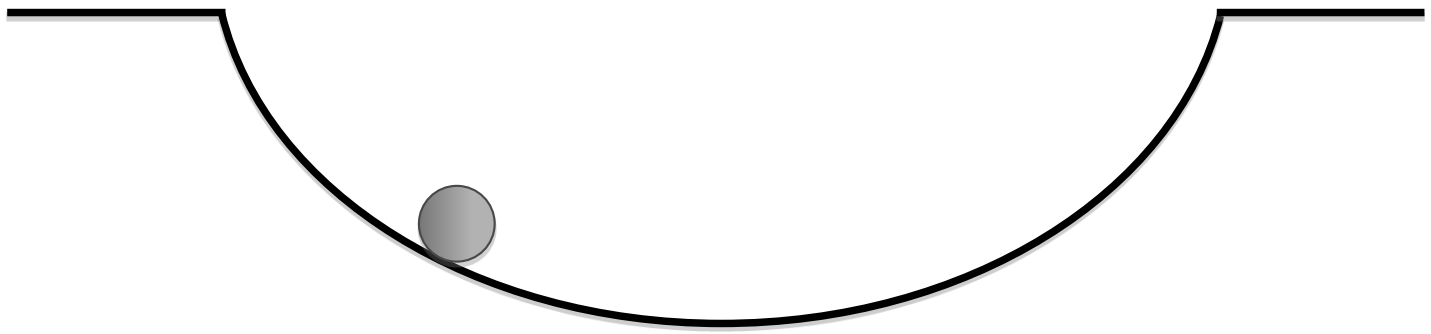

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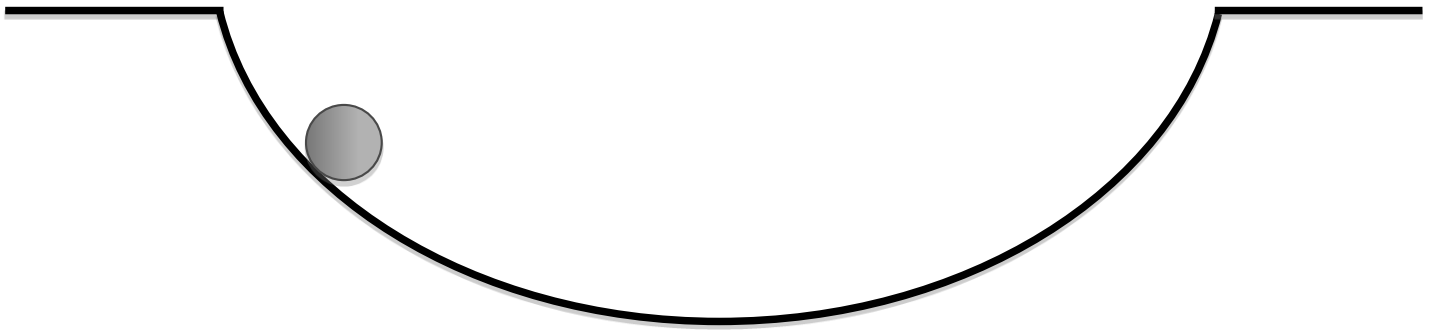

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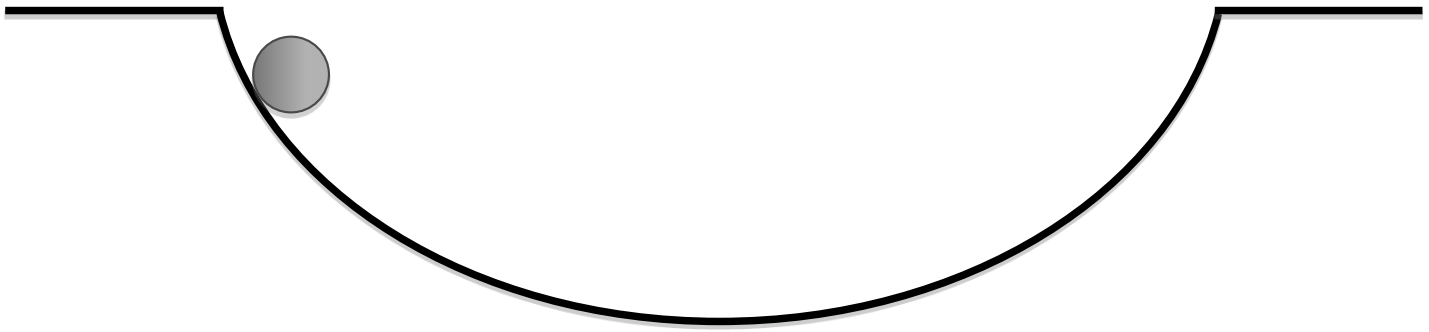

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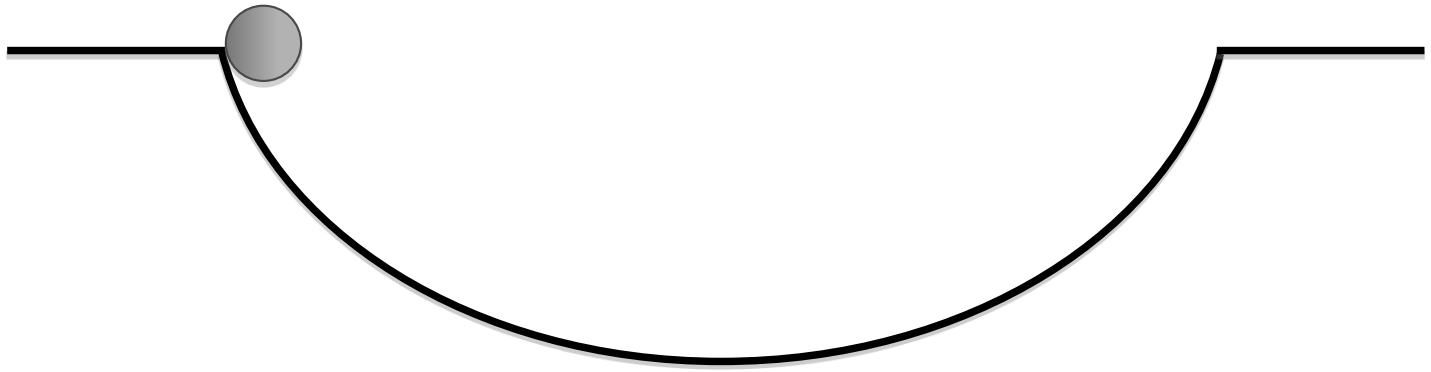

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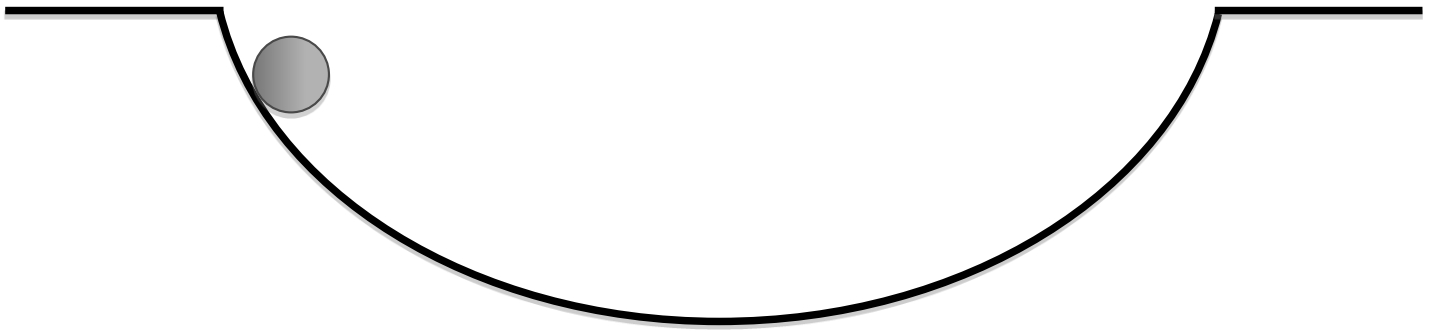

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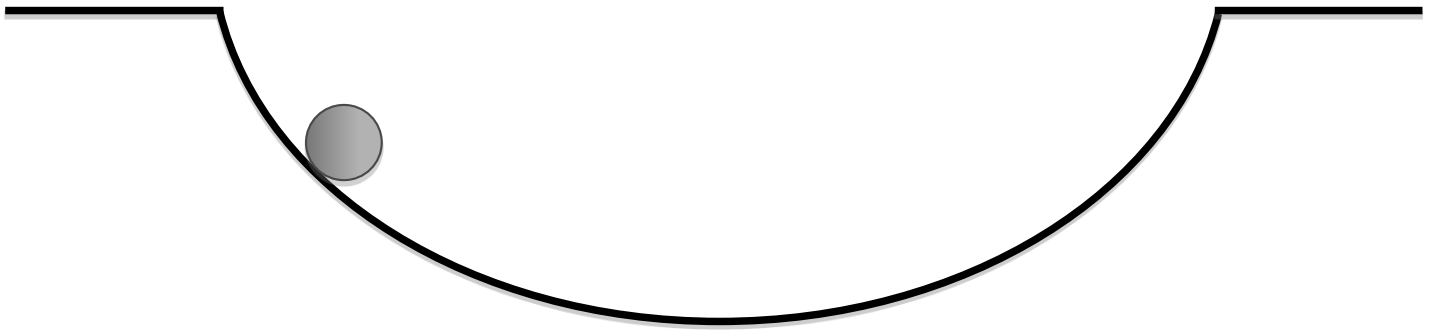

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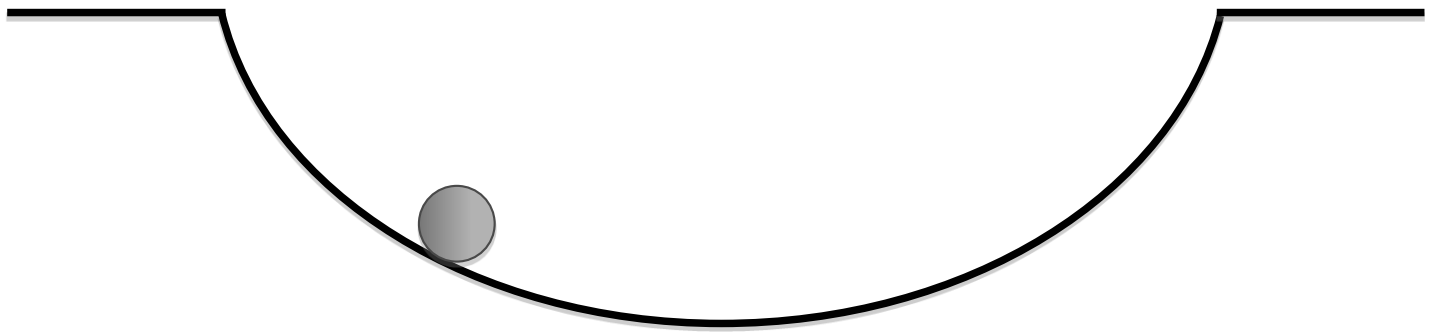

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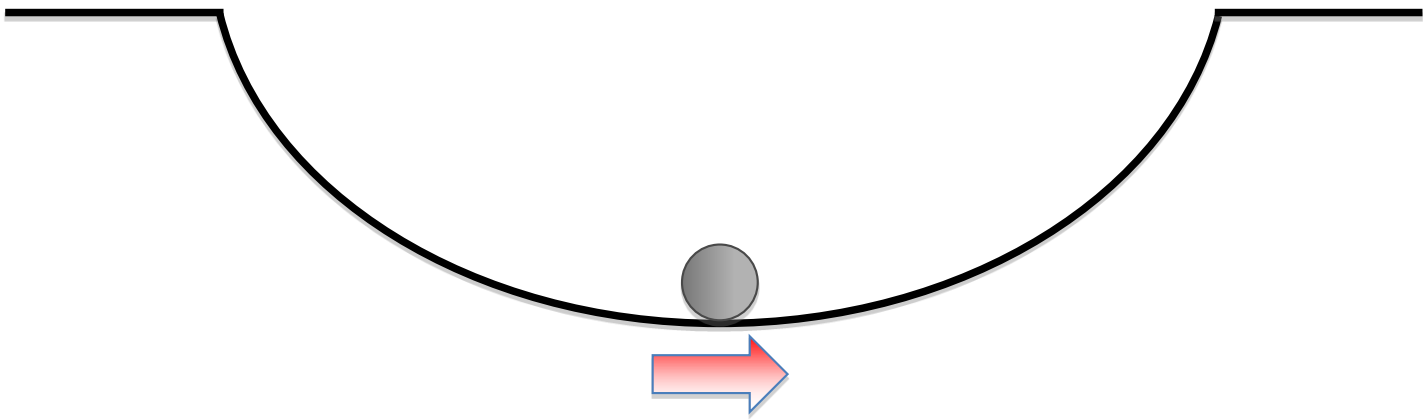

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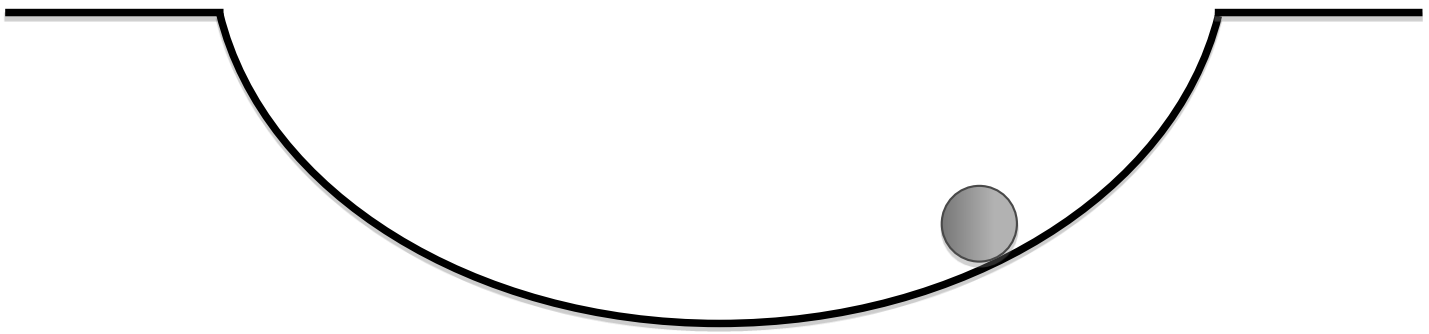

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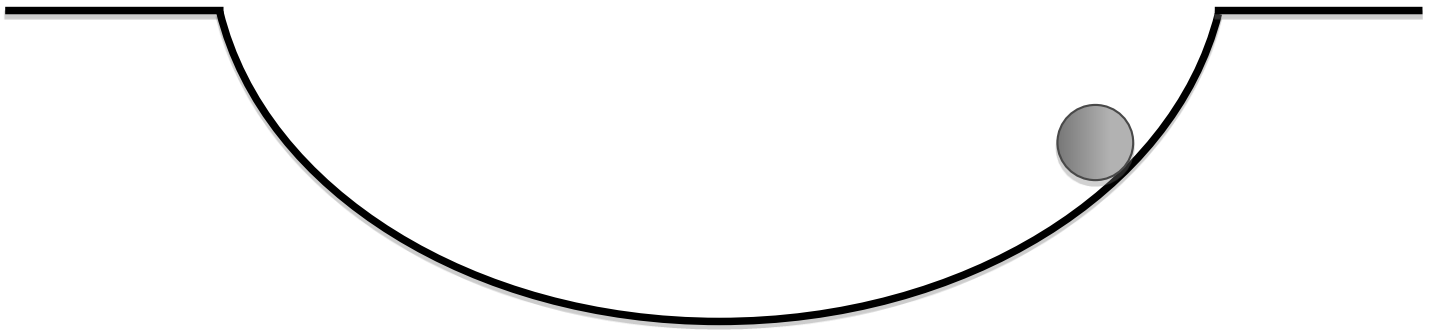

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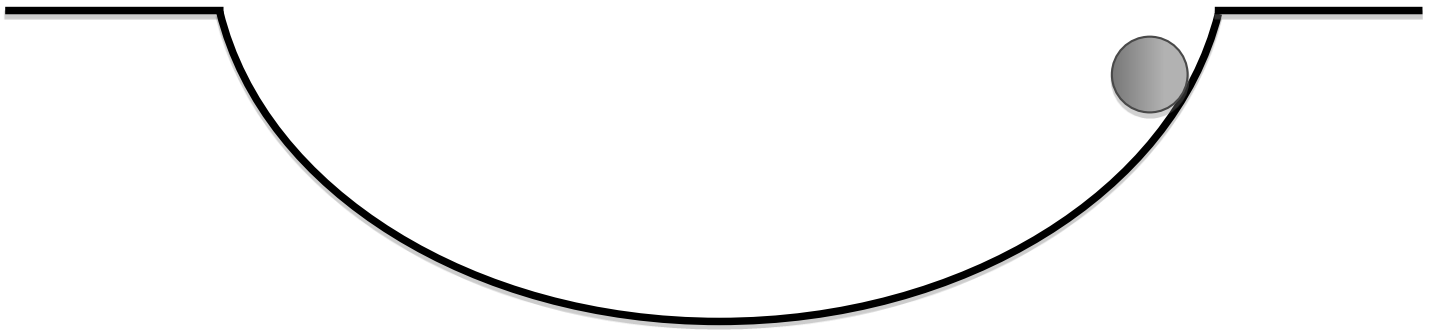

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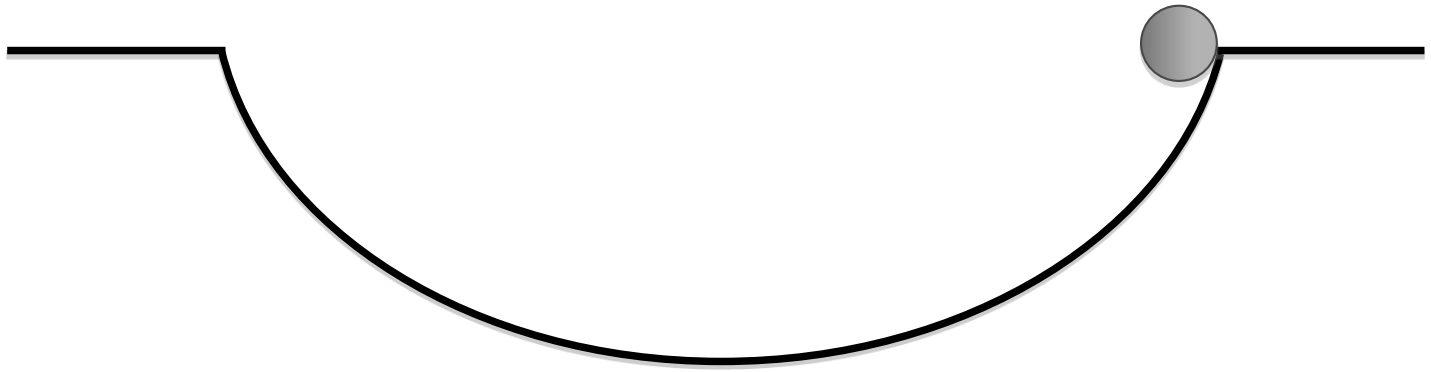

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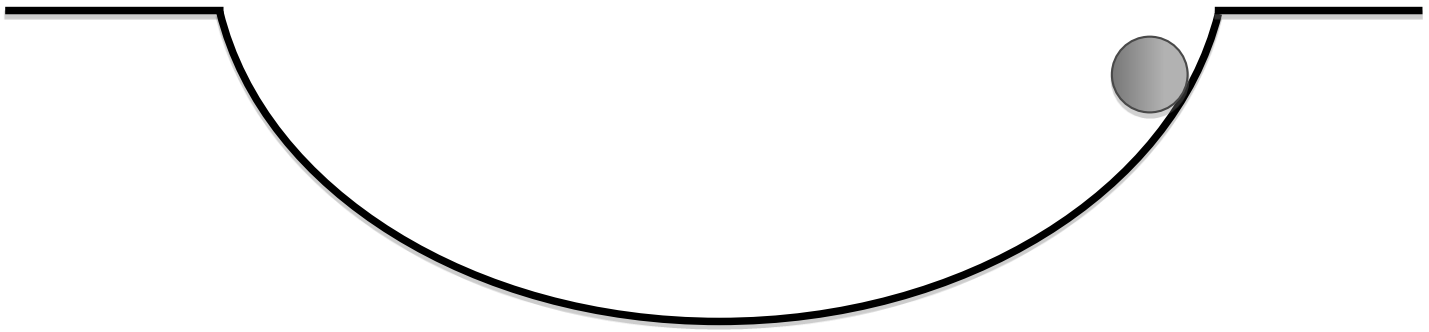

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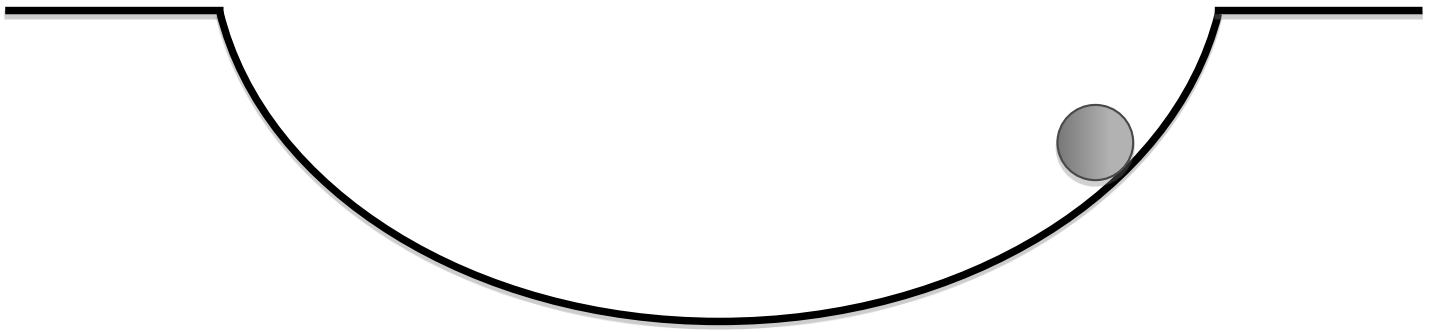

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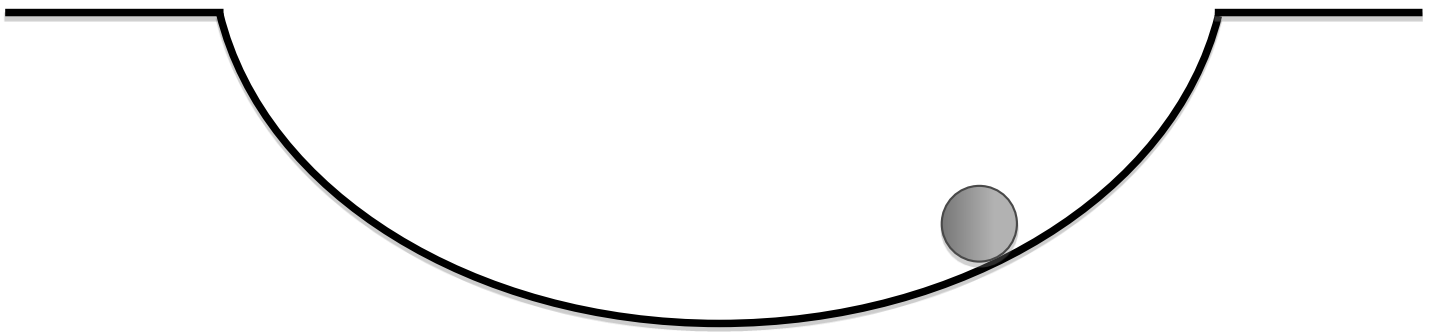

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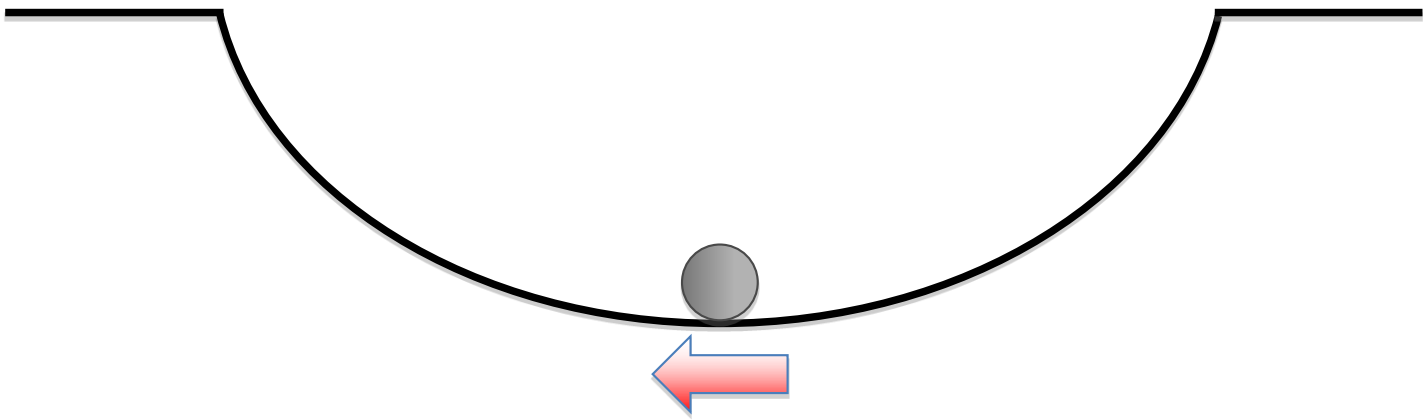

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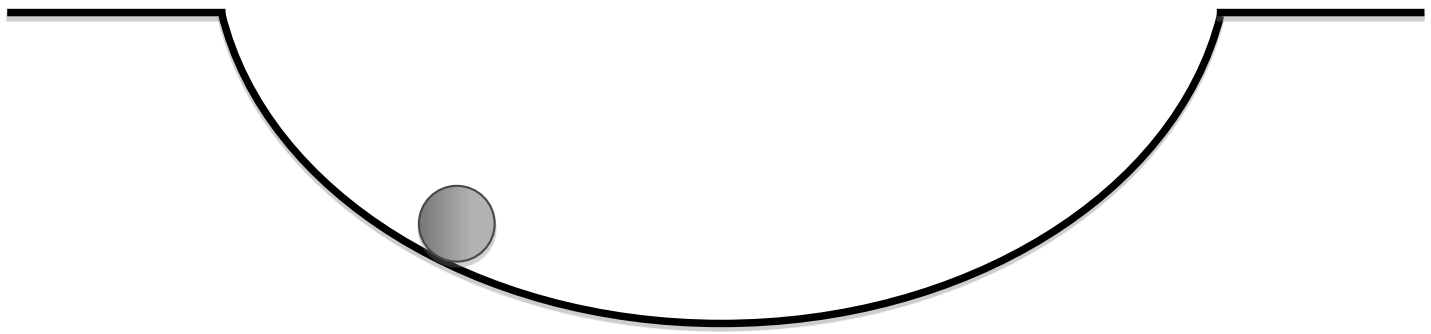

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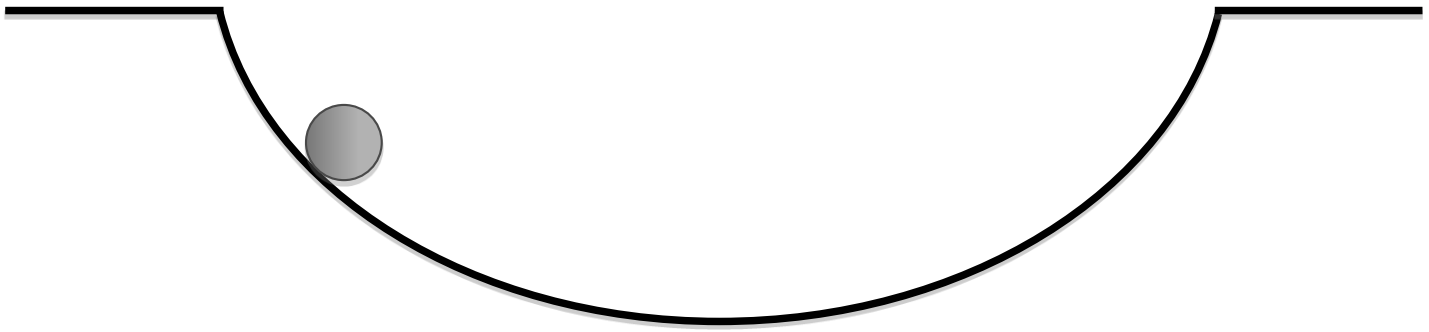

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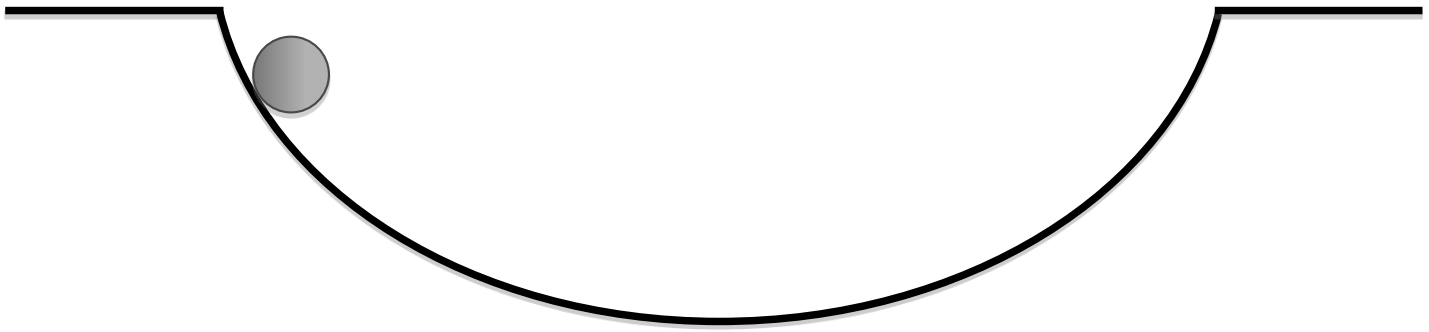

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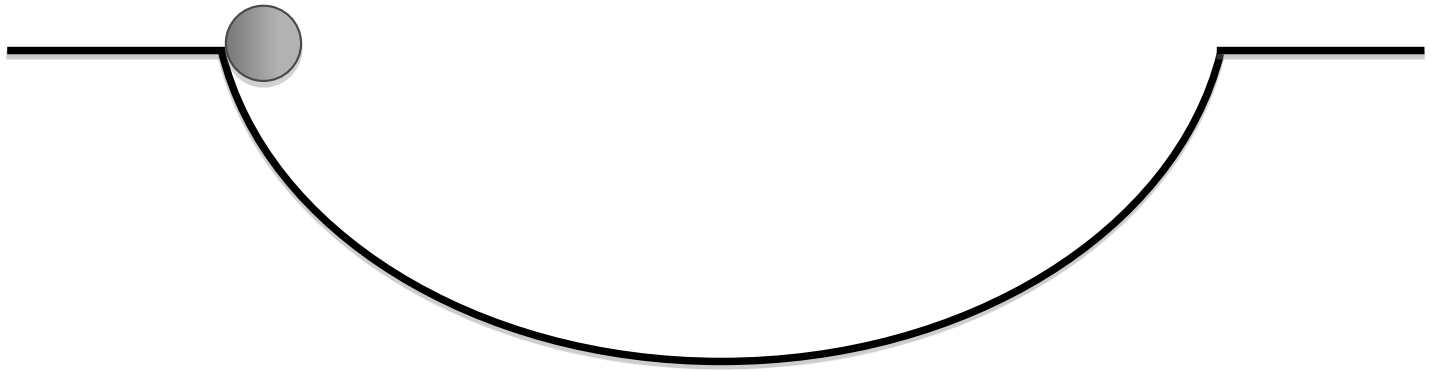

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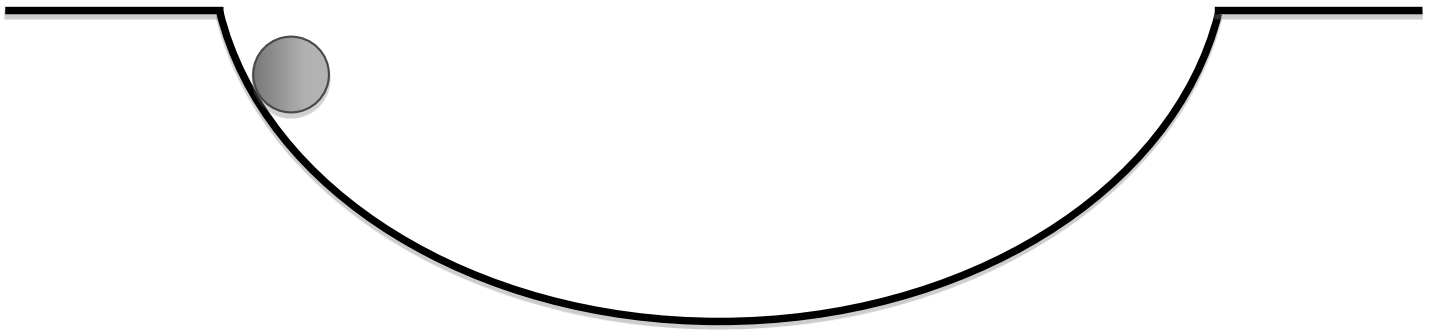

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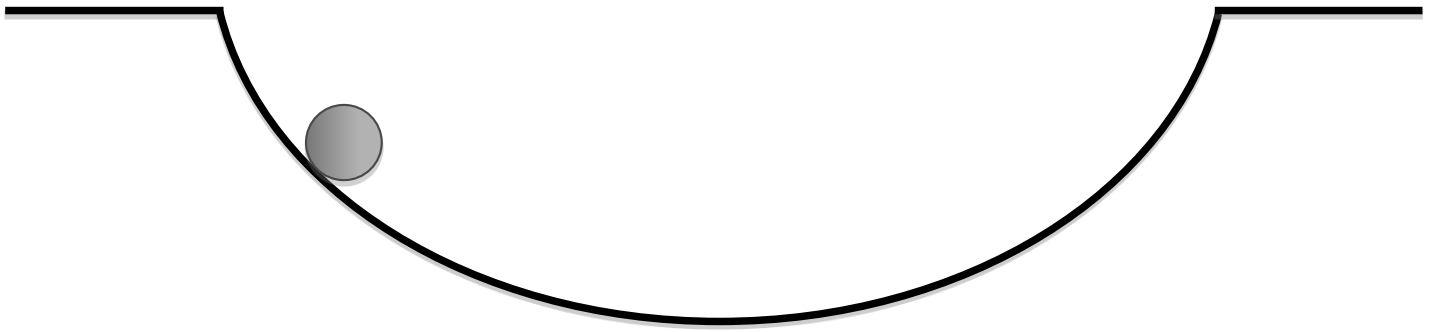

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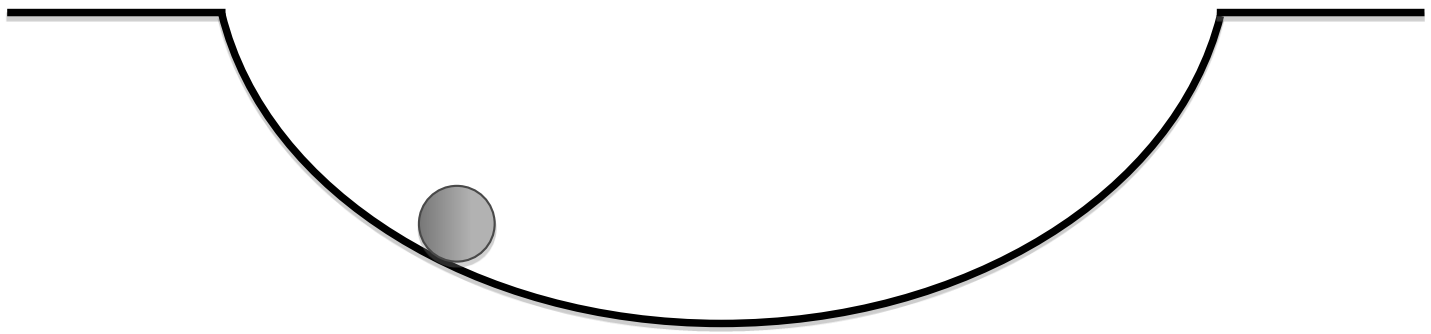

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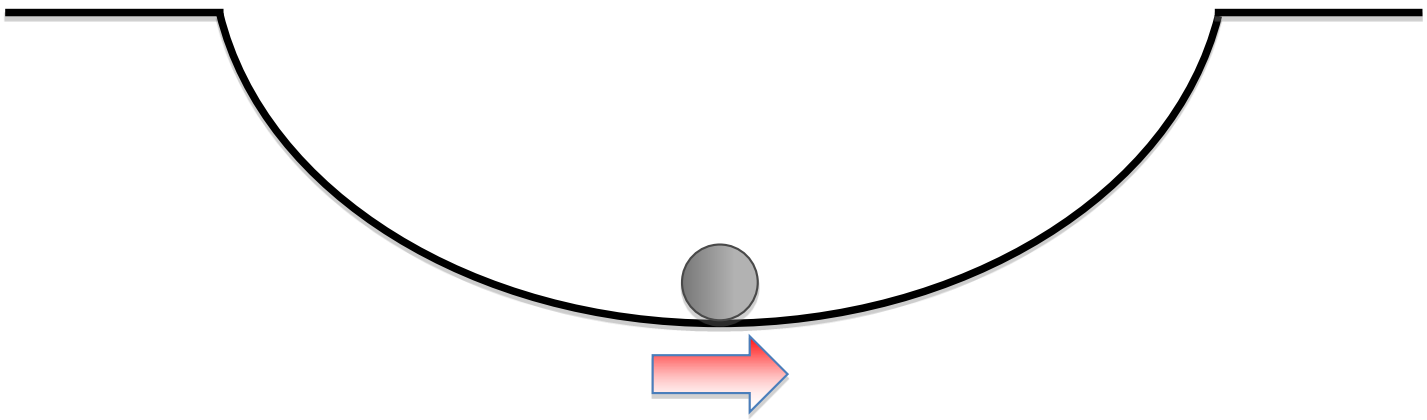

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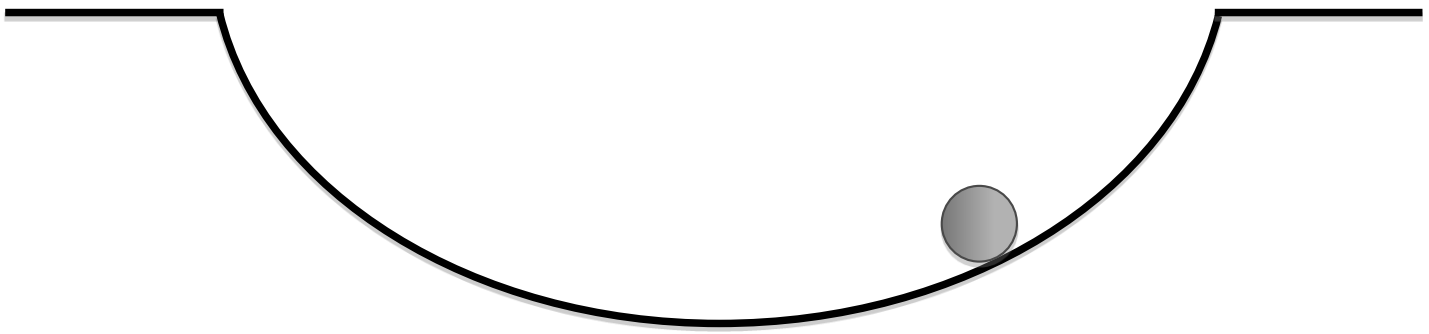

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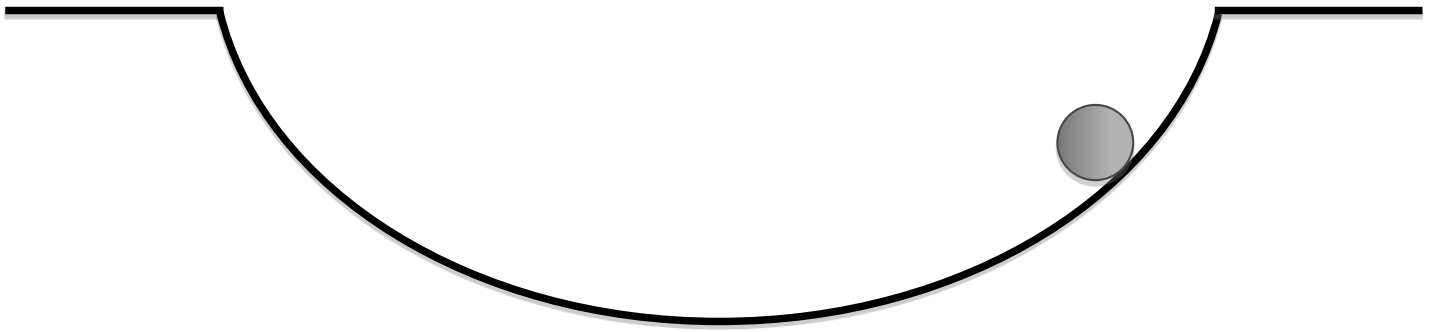

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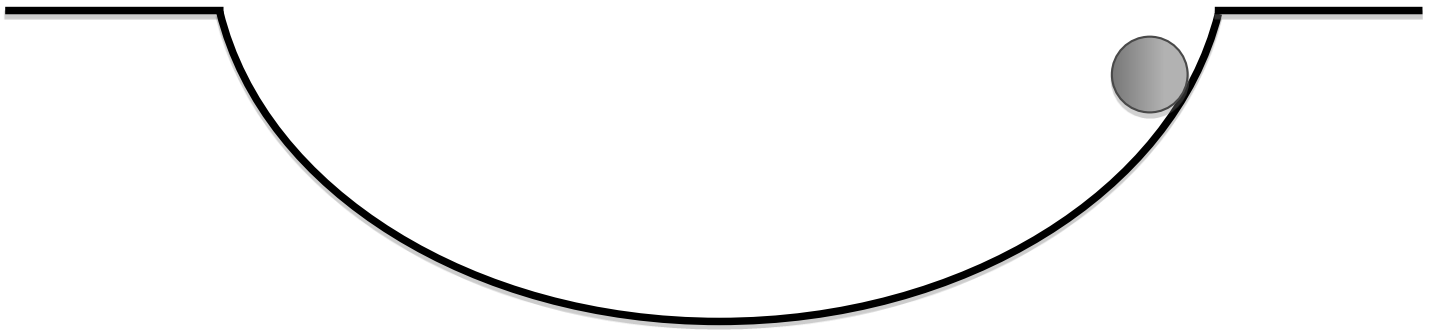

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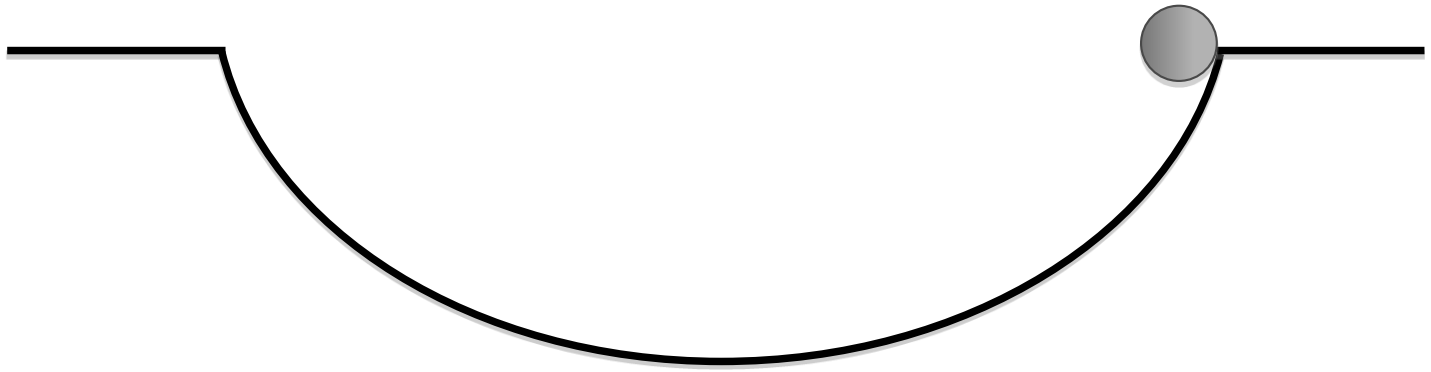
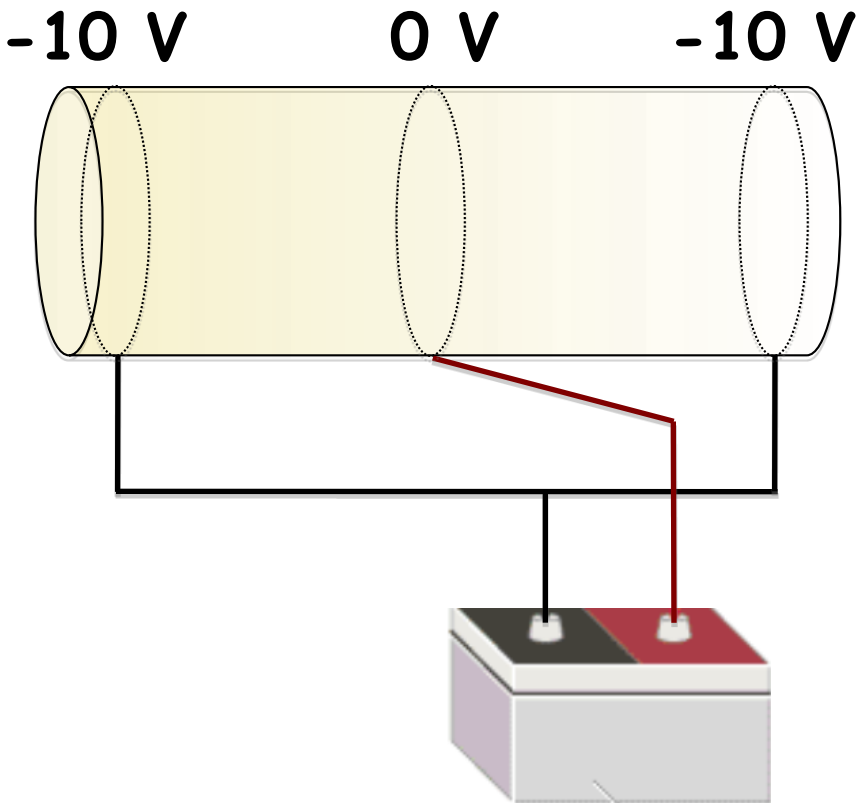


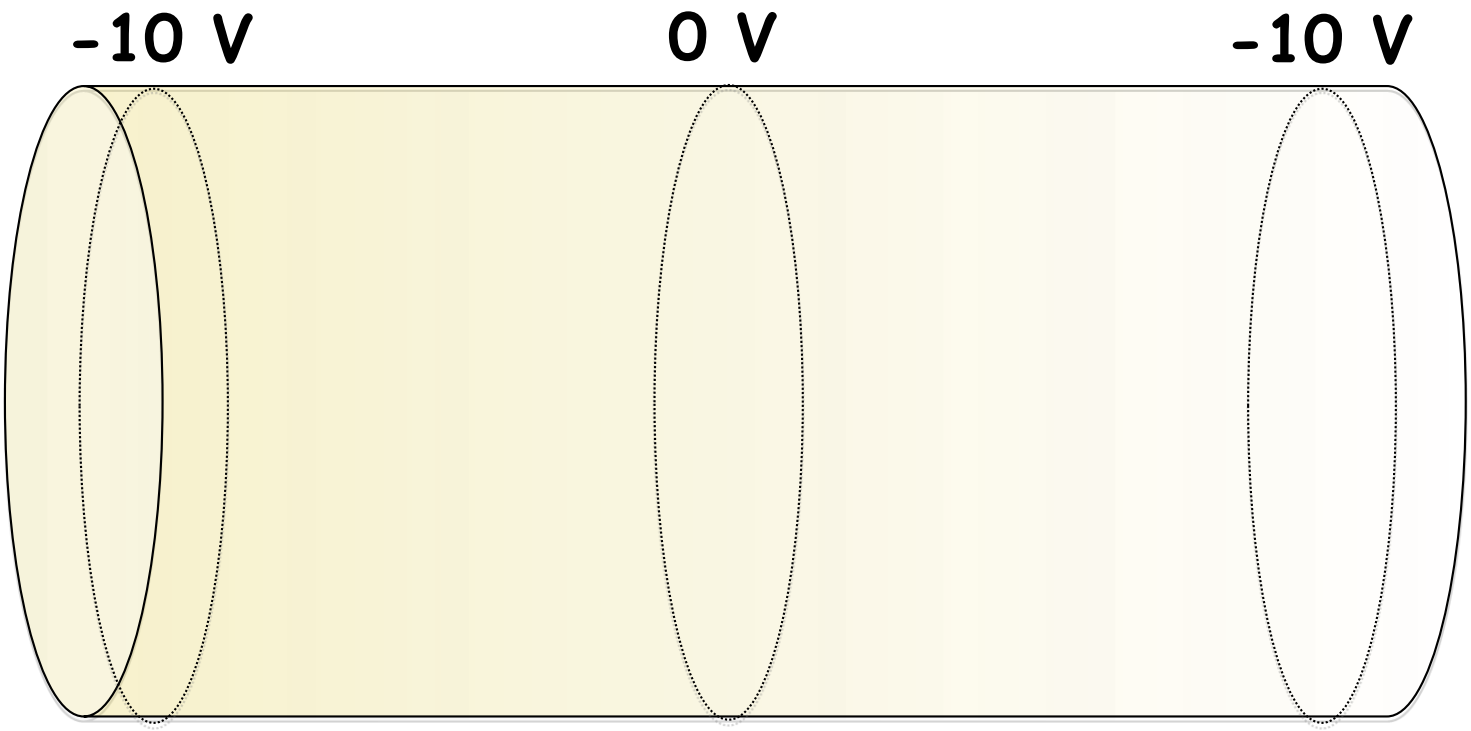
*Well, that was just an analogy. We, of course, are not dealing with a small sphere moving under the under the influence of gravity (or a **gravitational** field), but with a charged particle that we wish to control using an **electric** field.*



For a negatively-charged particle like the antiproton, we can achieve something similar to the gravitational analogy using a power supply connected in such a way as to give a negative voltage at either end of the trap relative to the ground (0 volts) *at the centre.*

The power supply serves to maintain this negative voltage relative to the ground.

In this way the antiproton will be contained along the length of the trap, confined to “roll back and forth” in a voltage “dip”.



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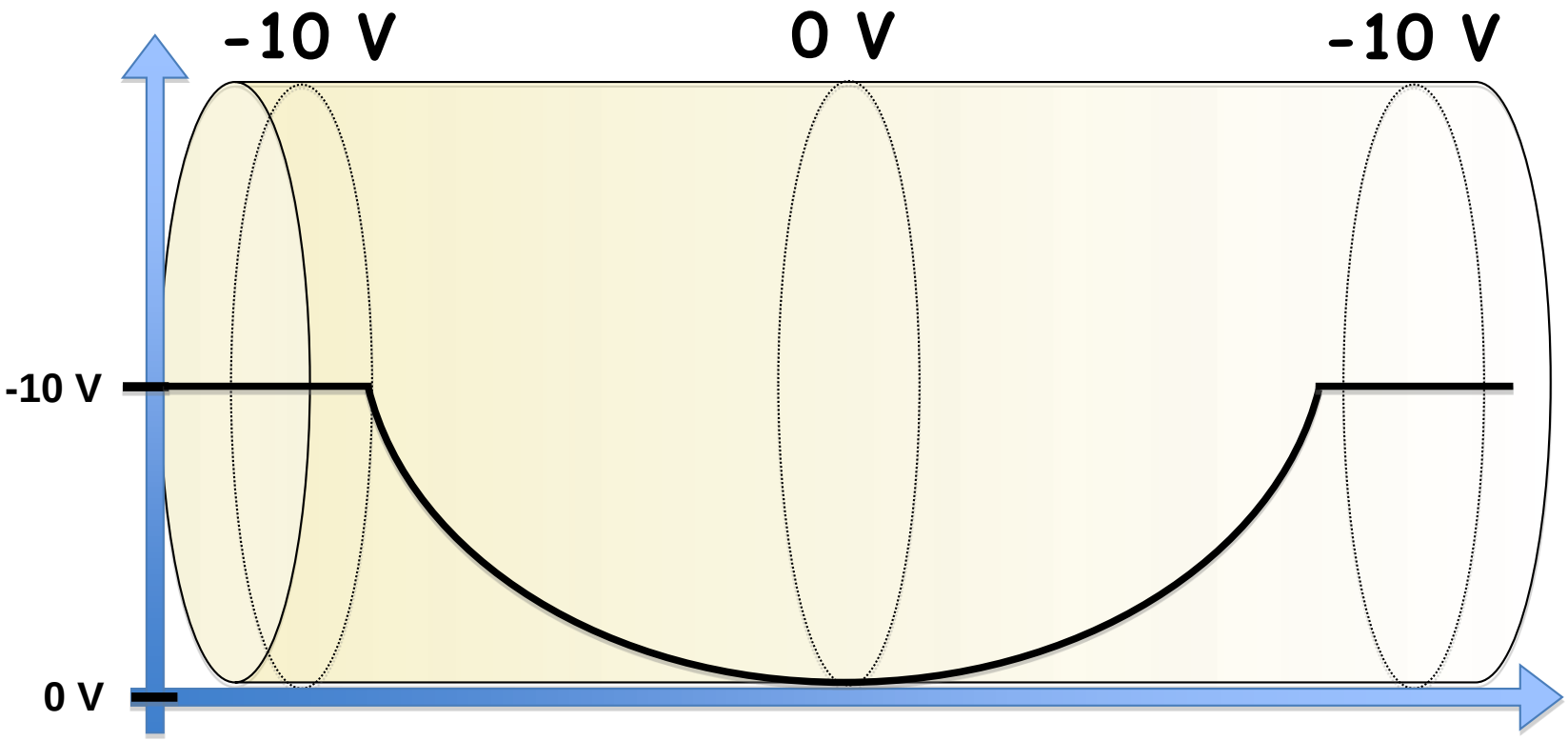
(more commonly known as an electric potential "well")



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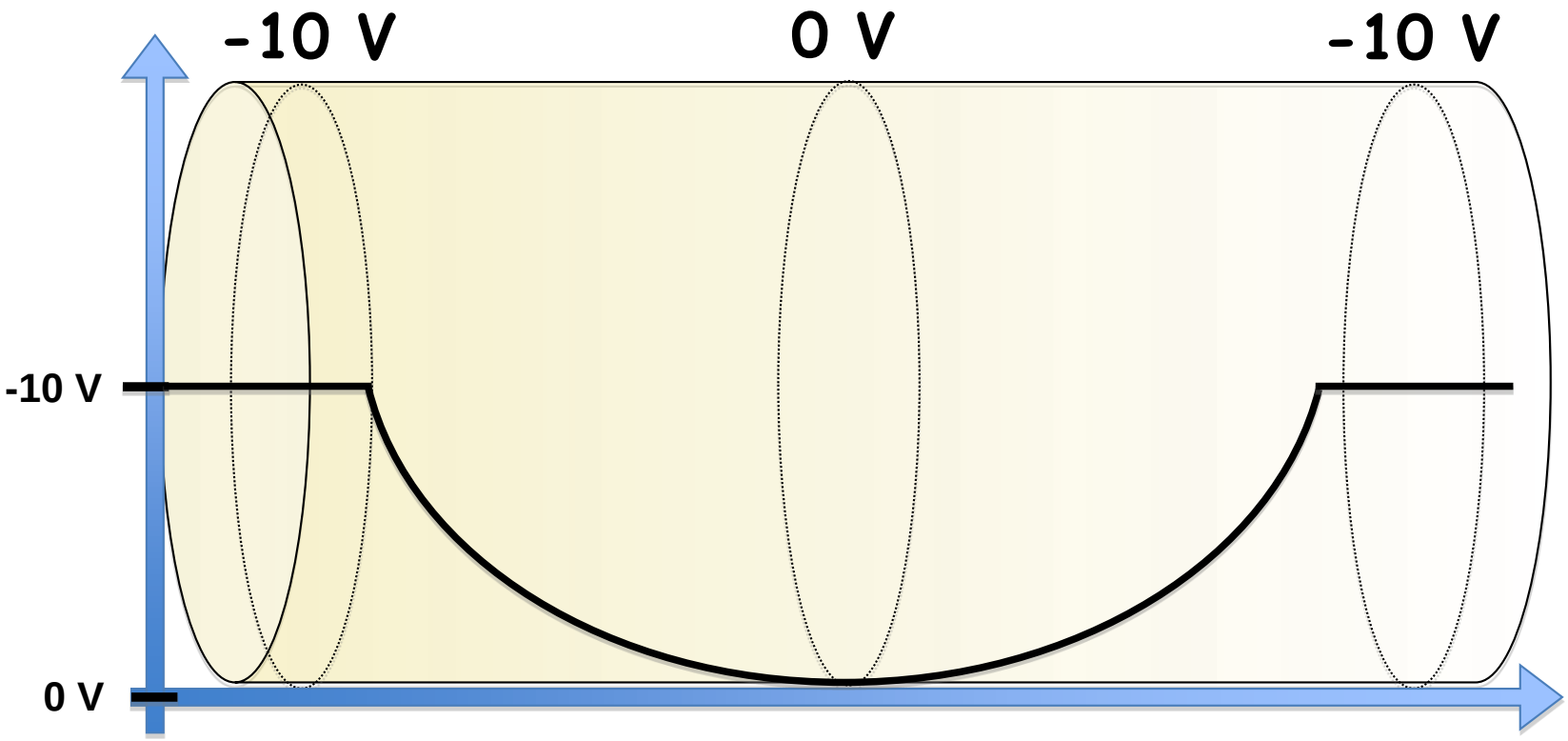

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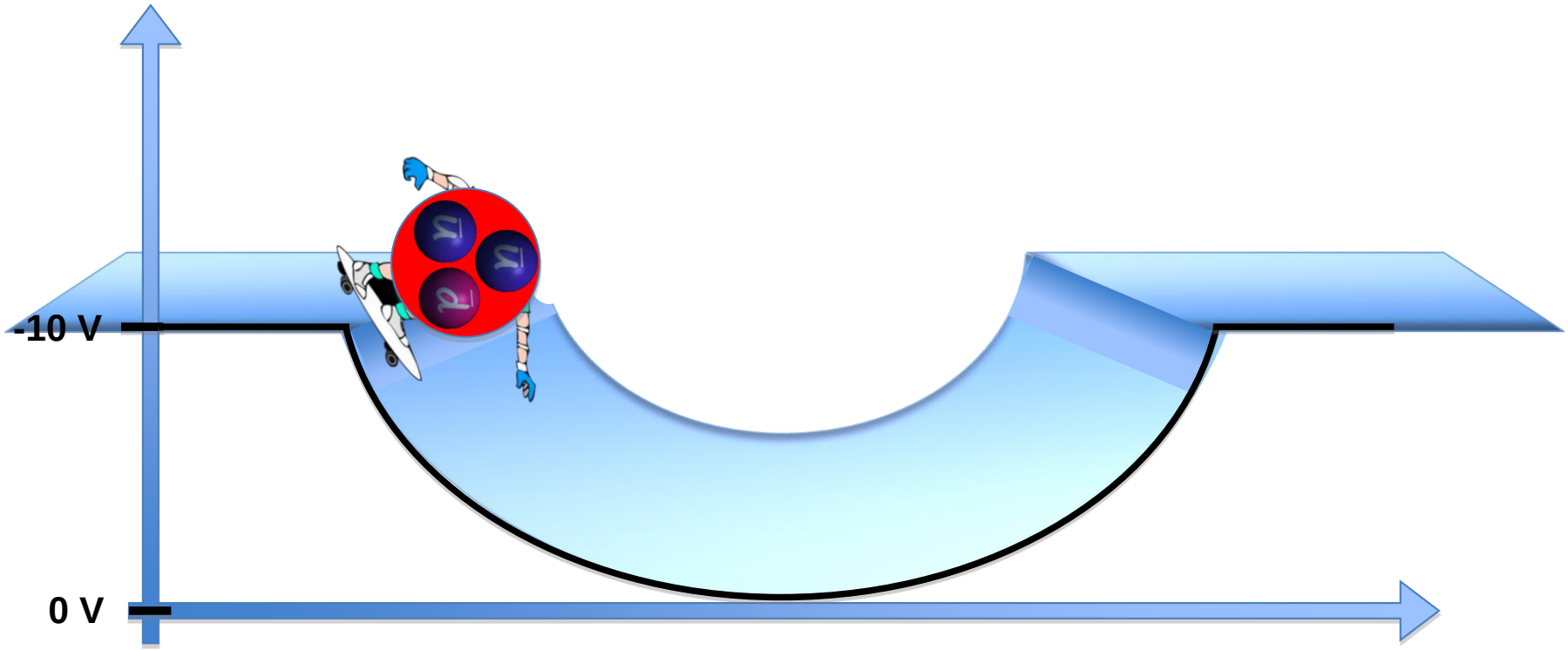

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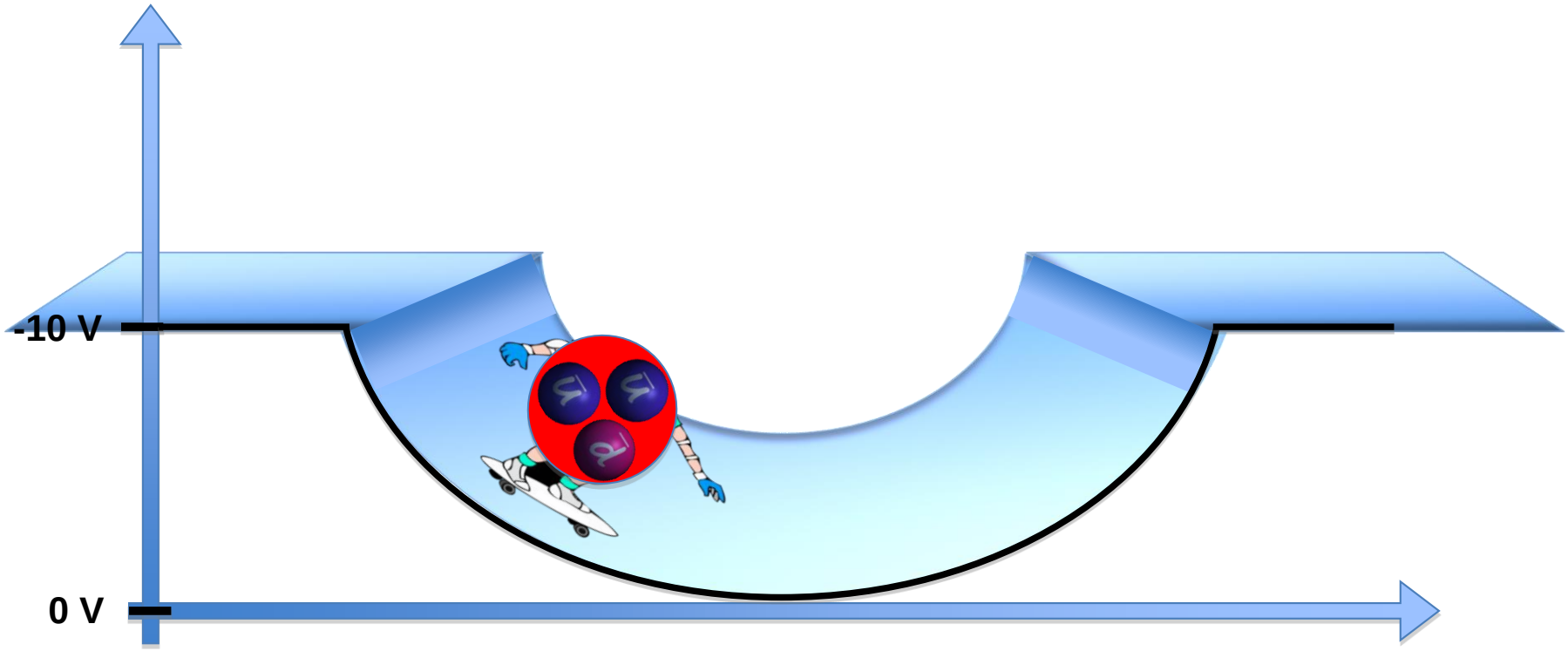

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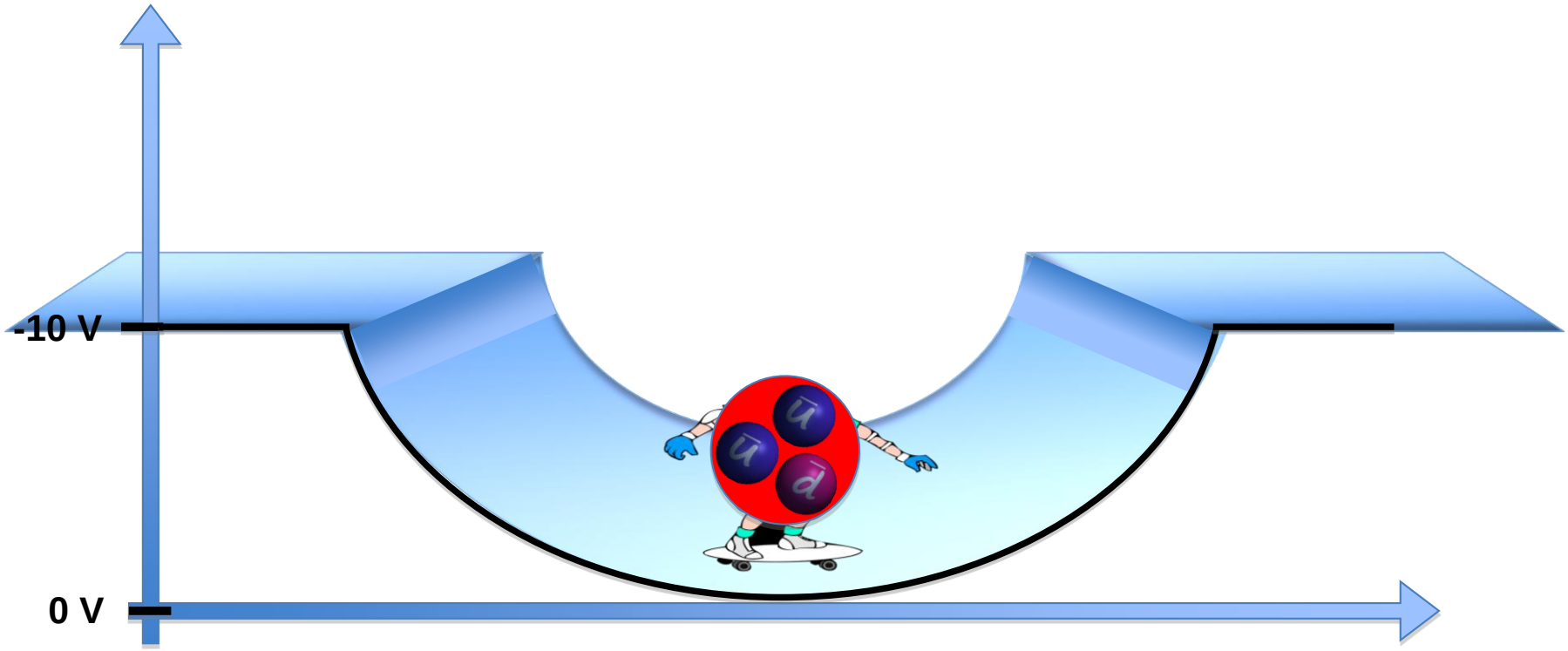

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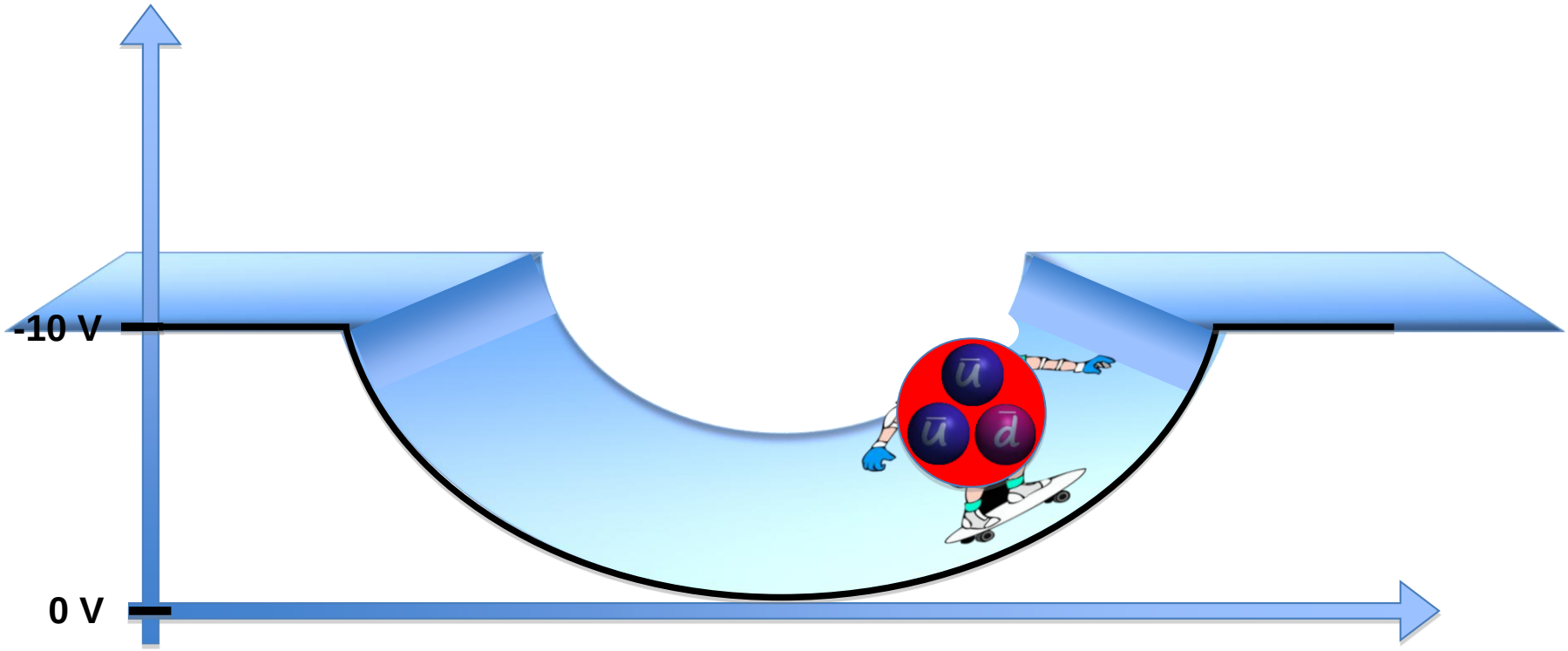

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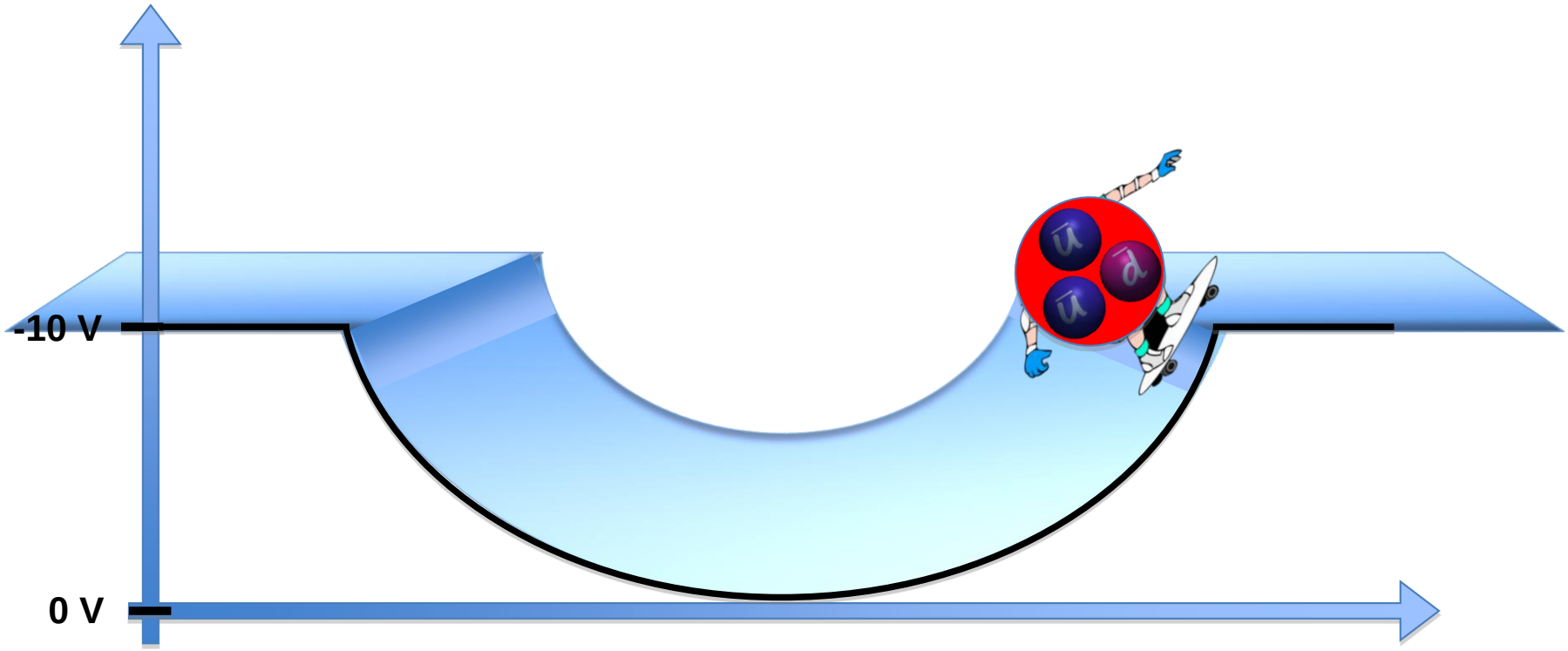

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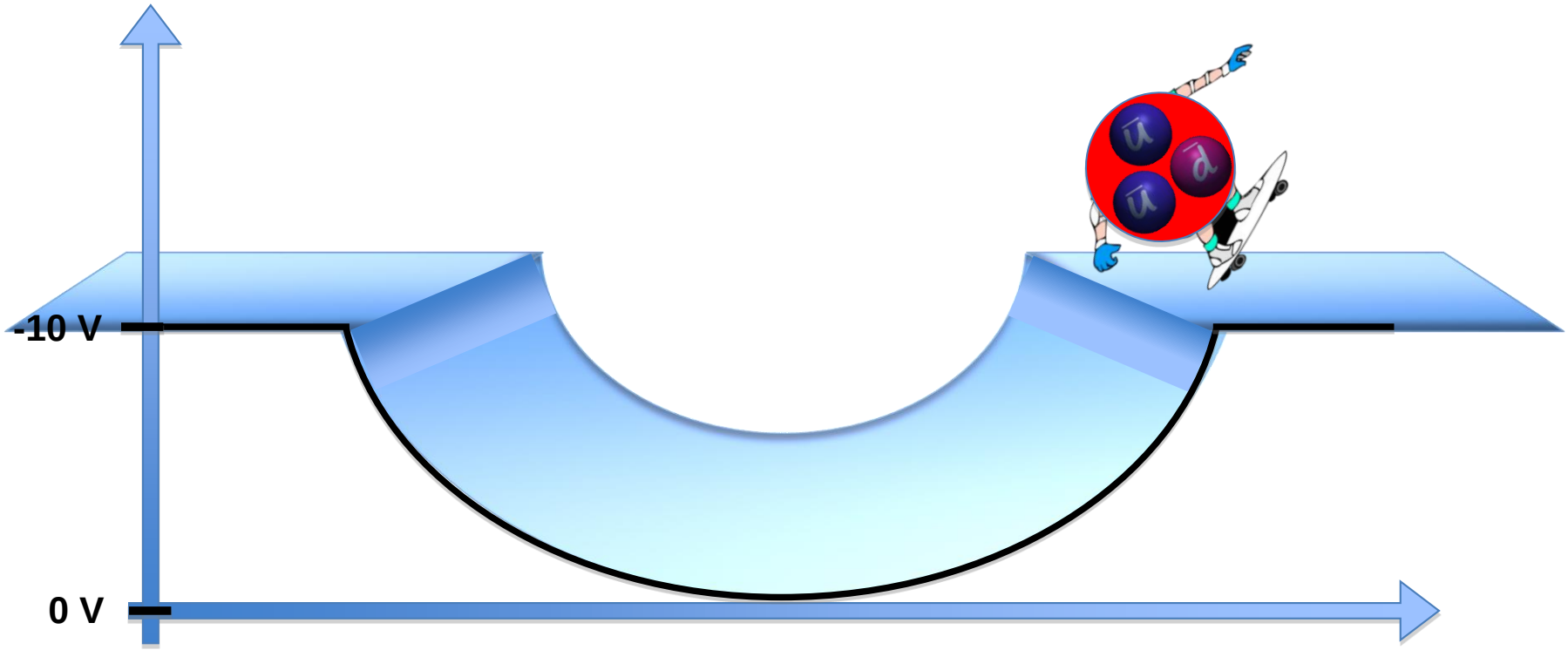

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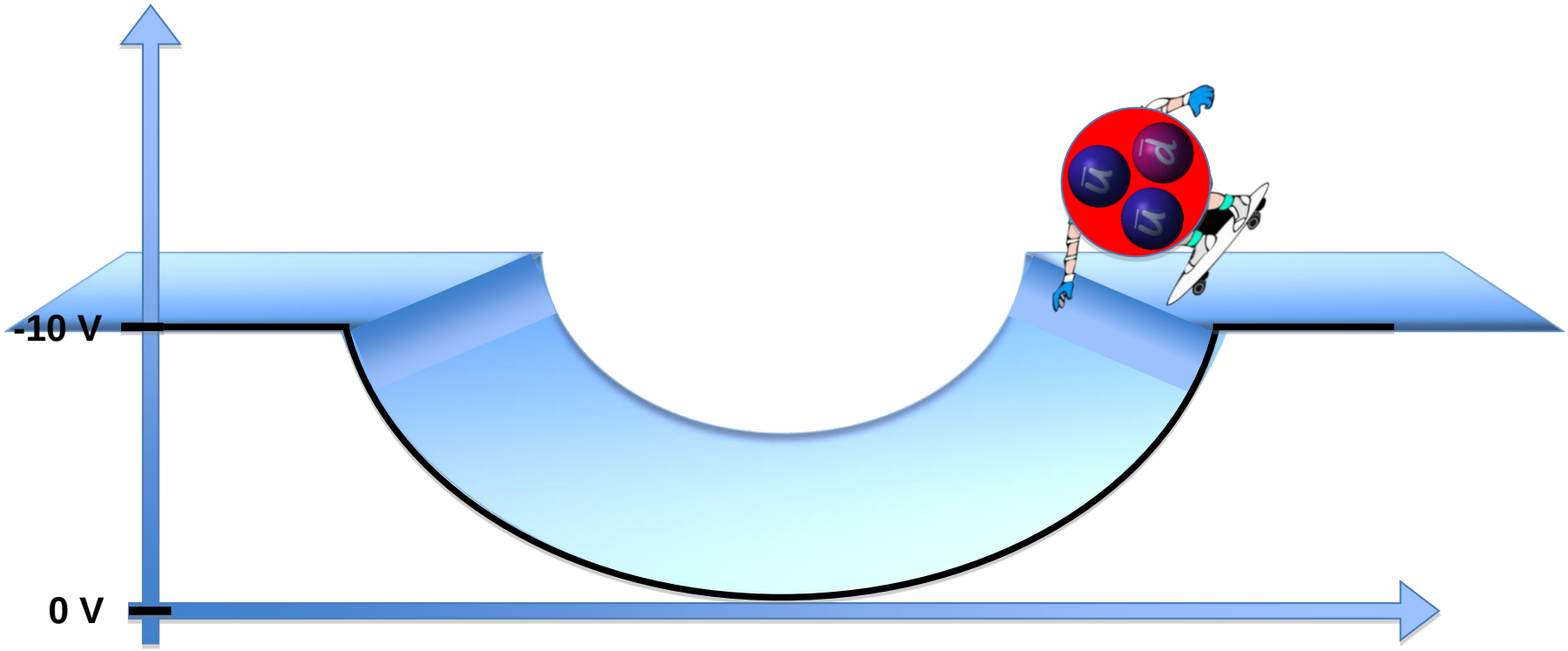

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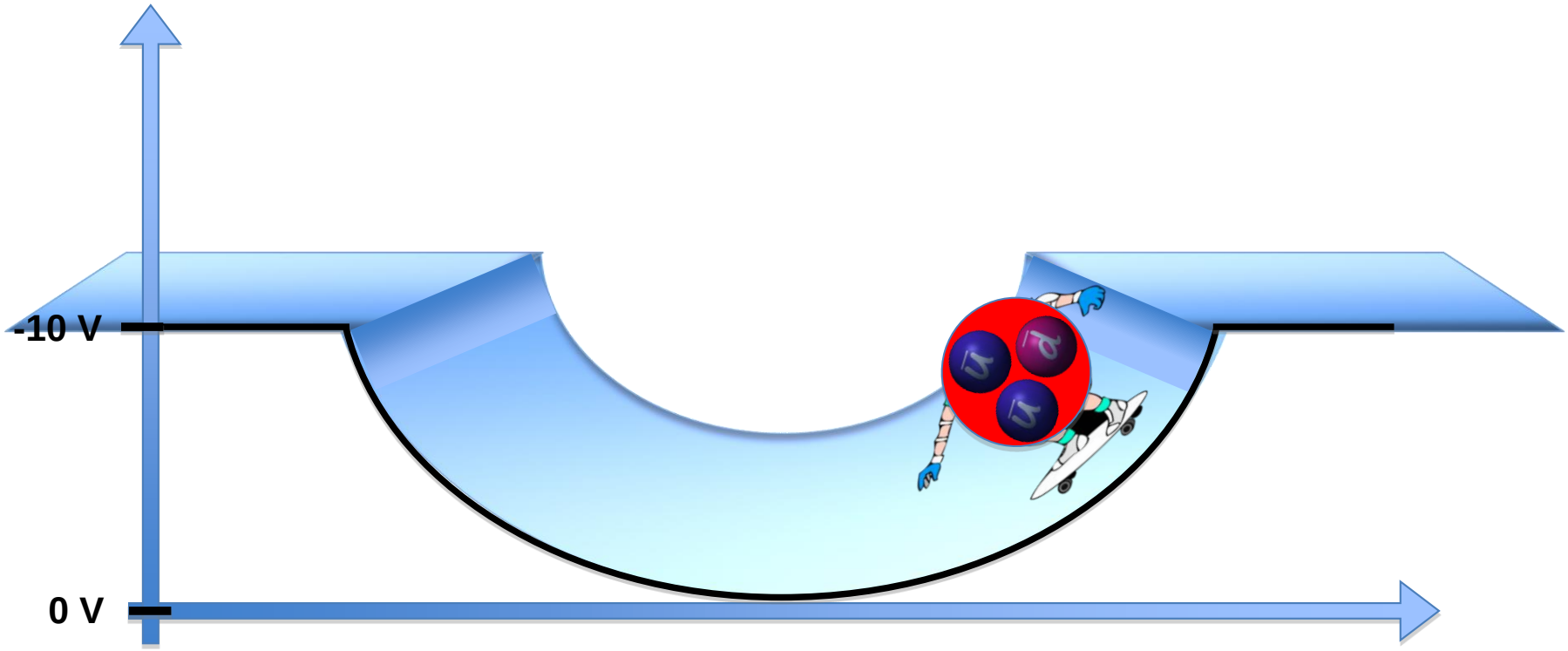

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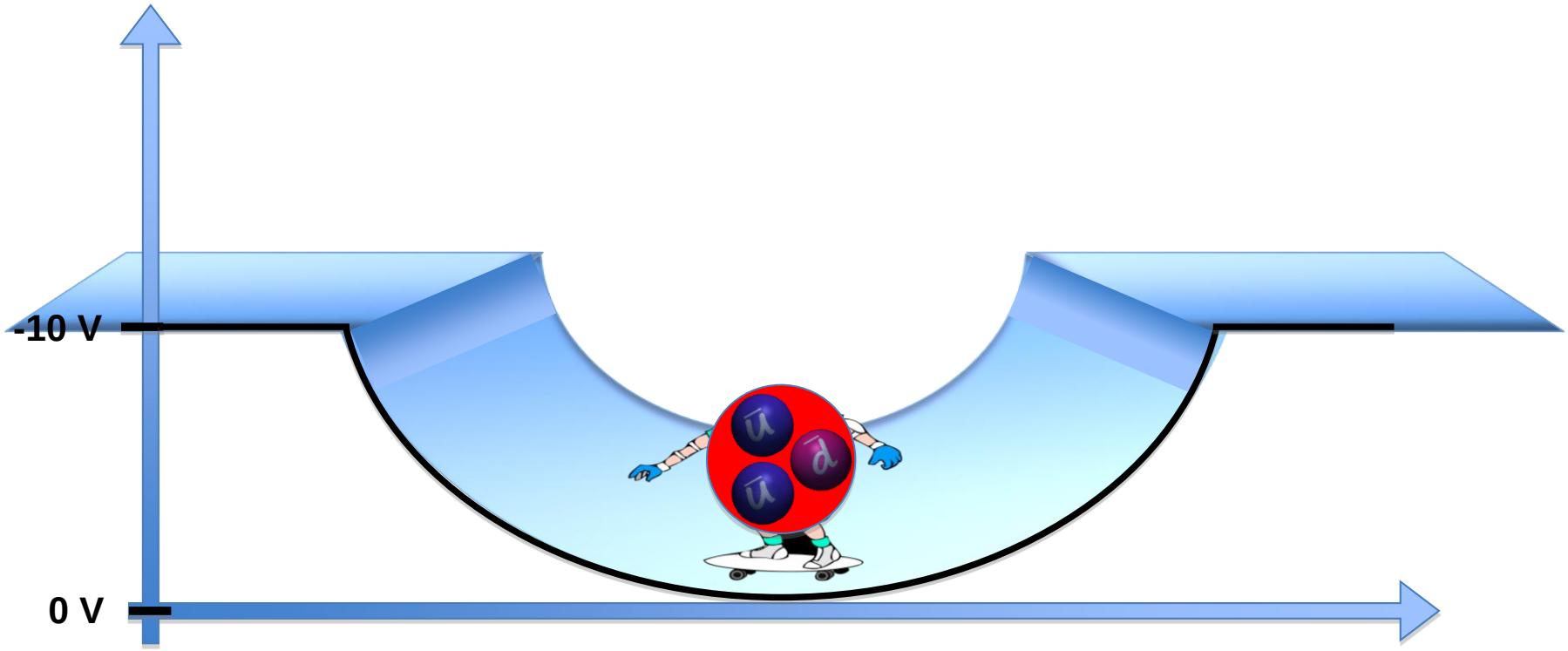

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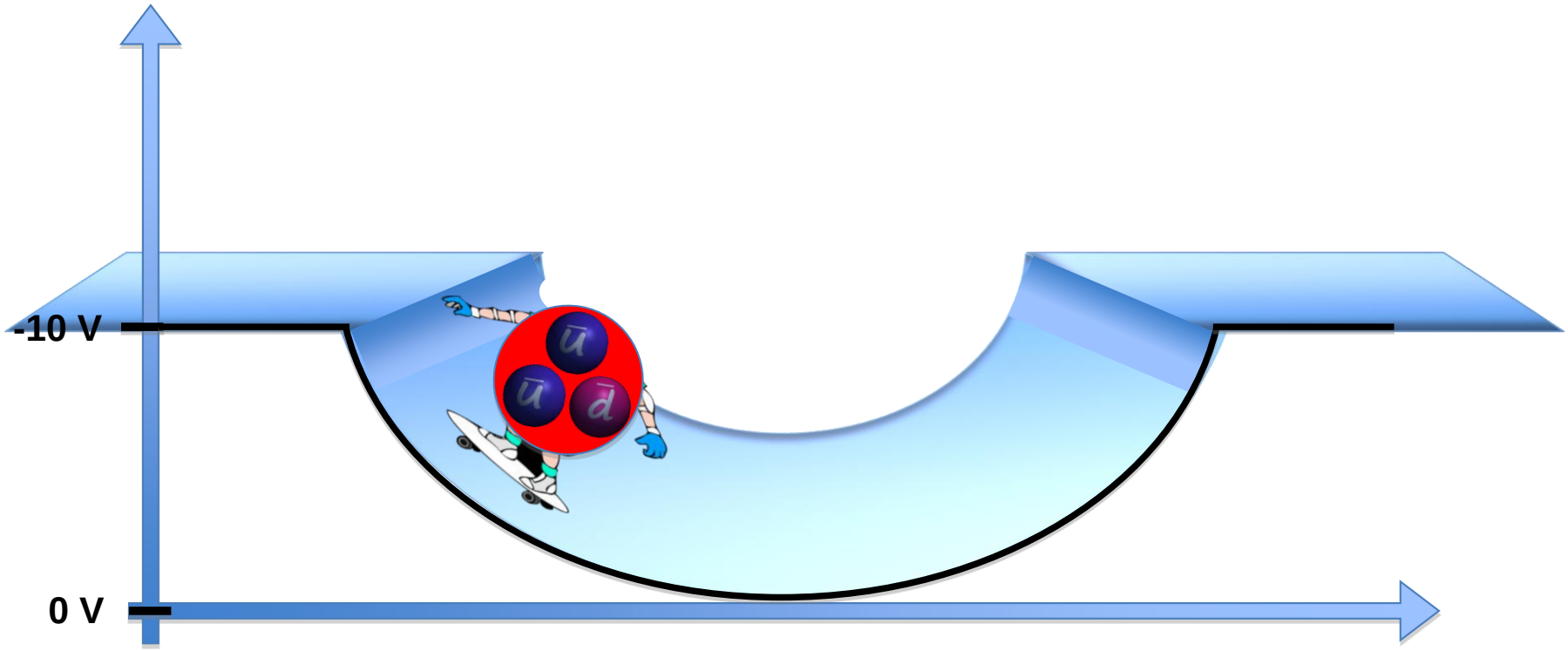

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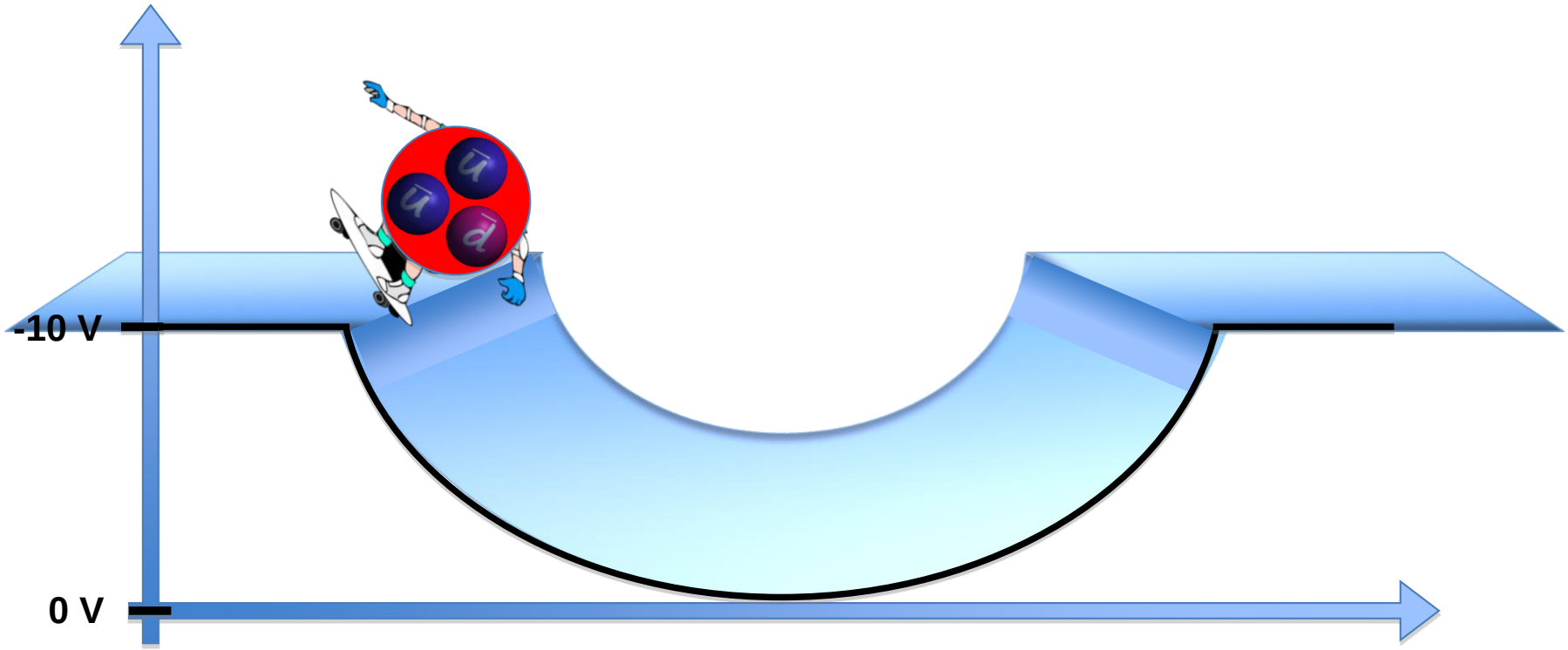

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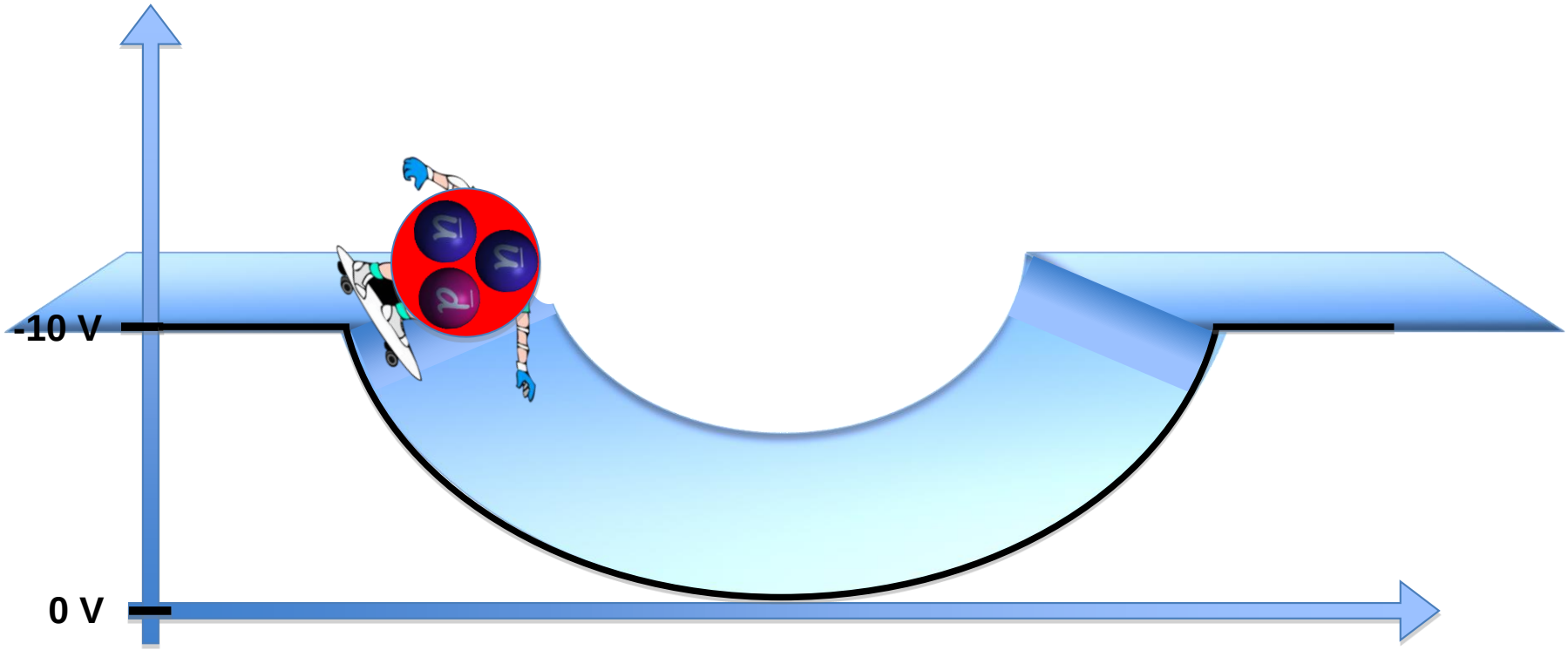

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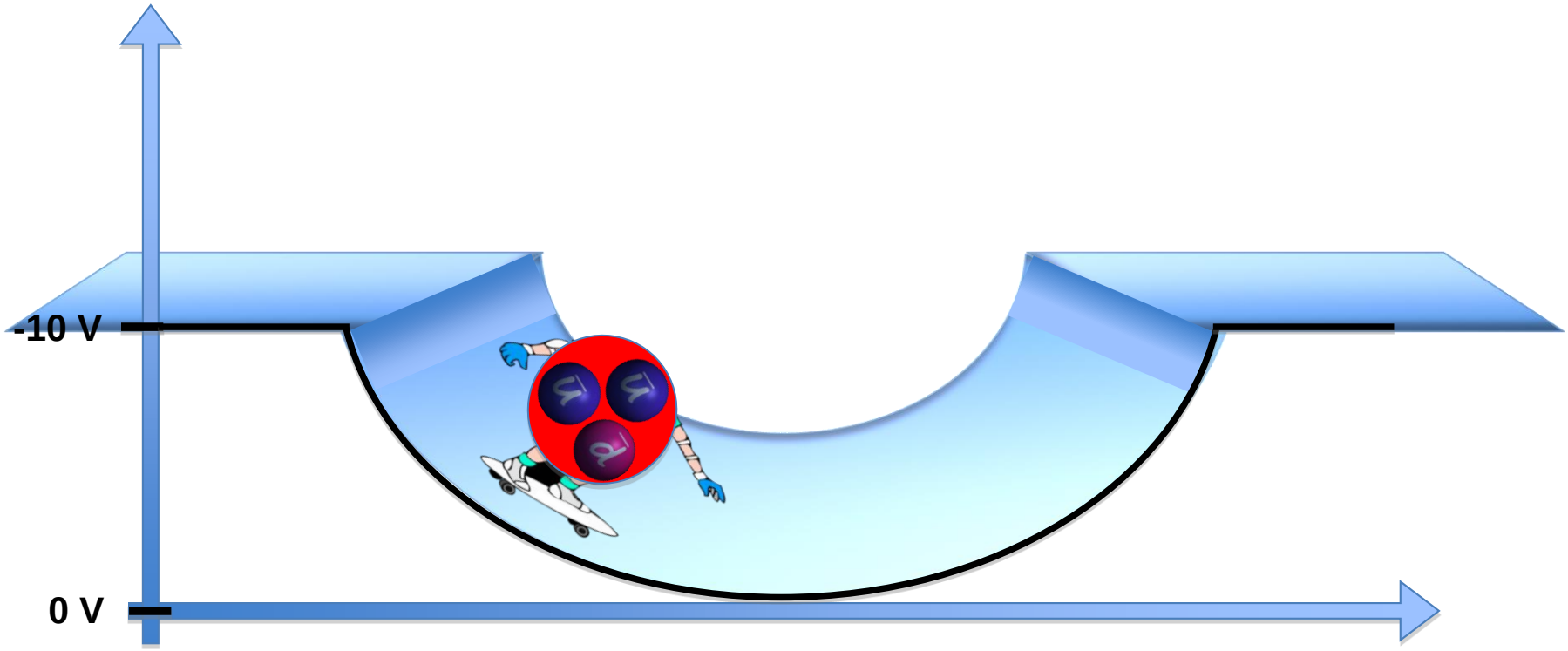

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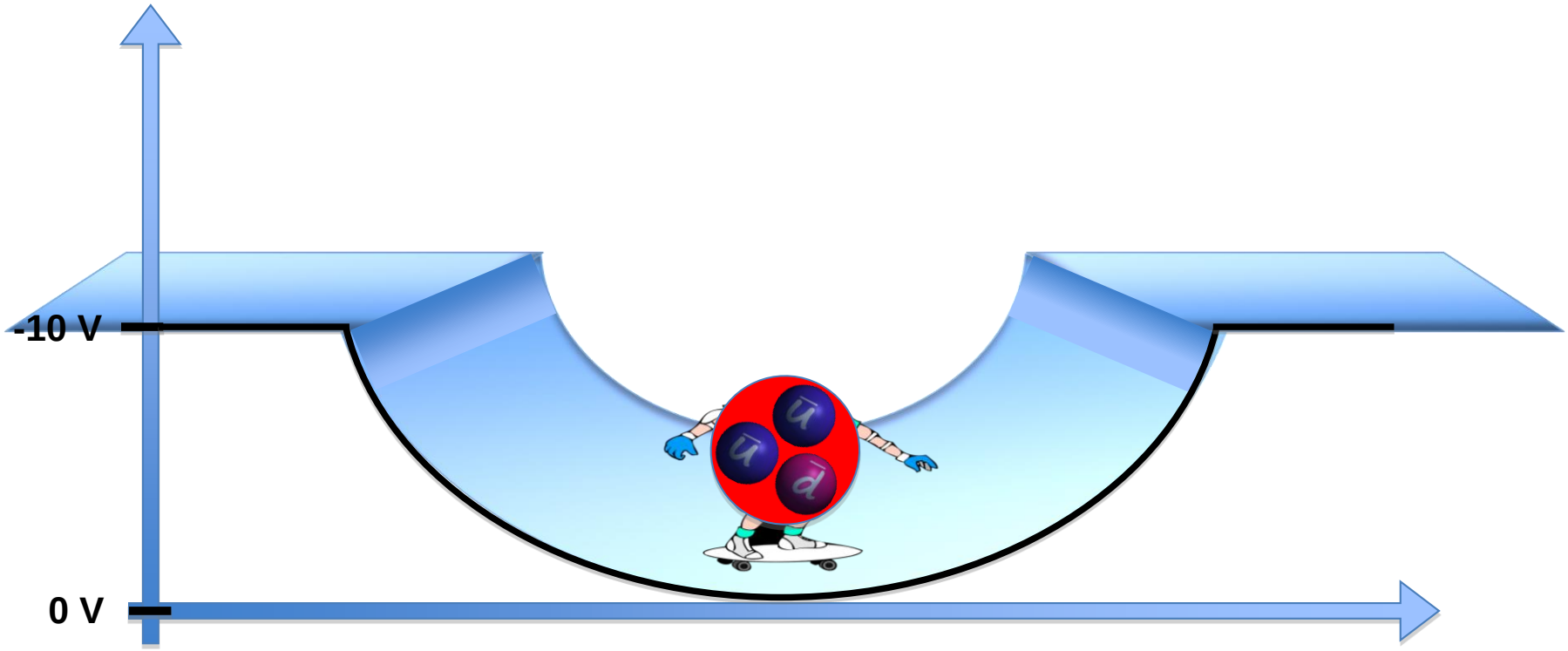

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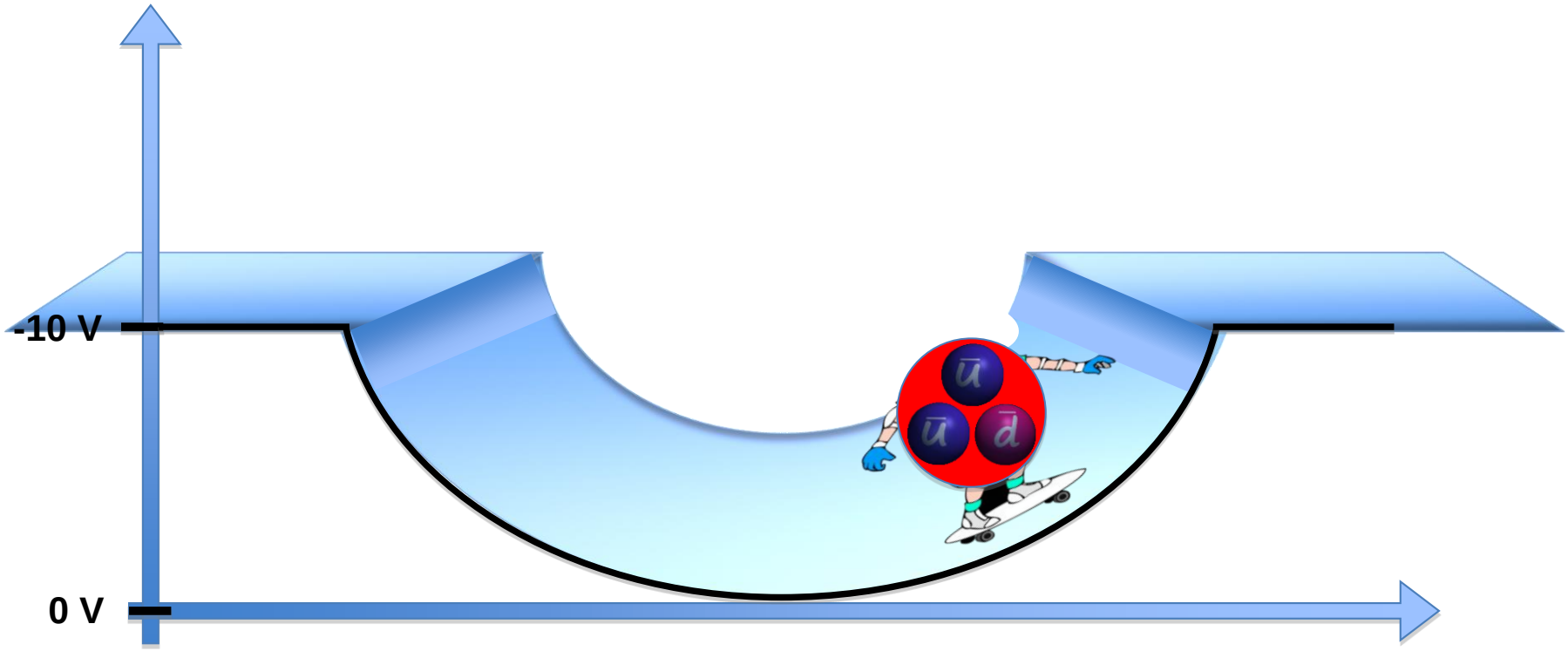

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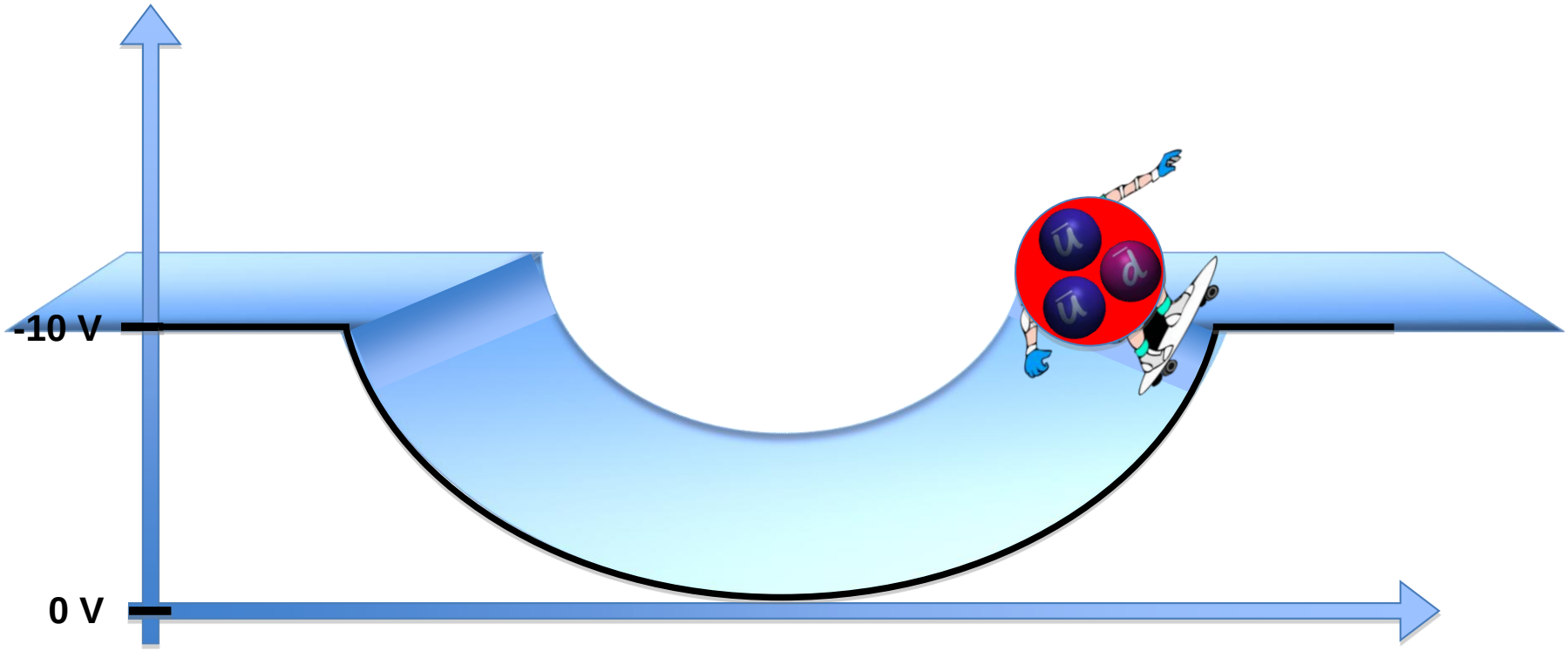

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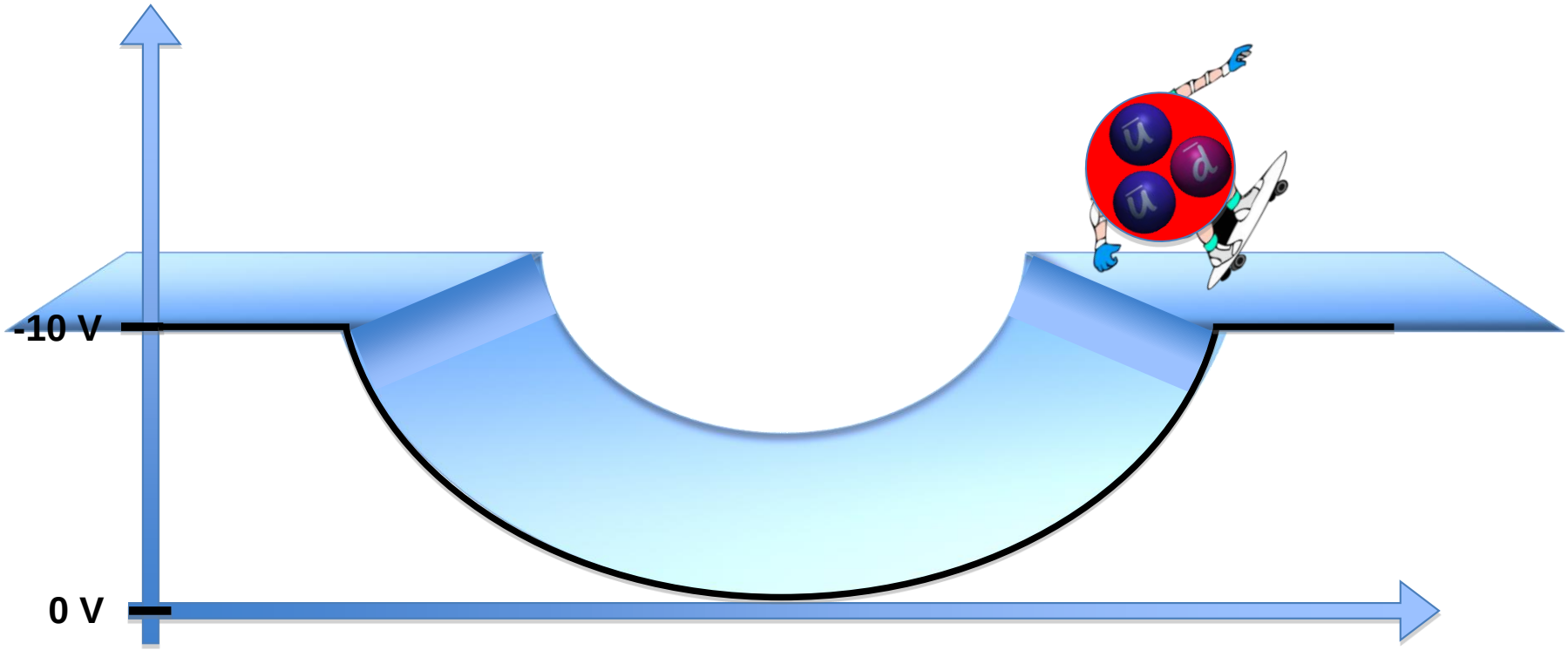

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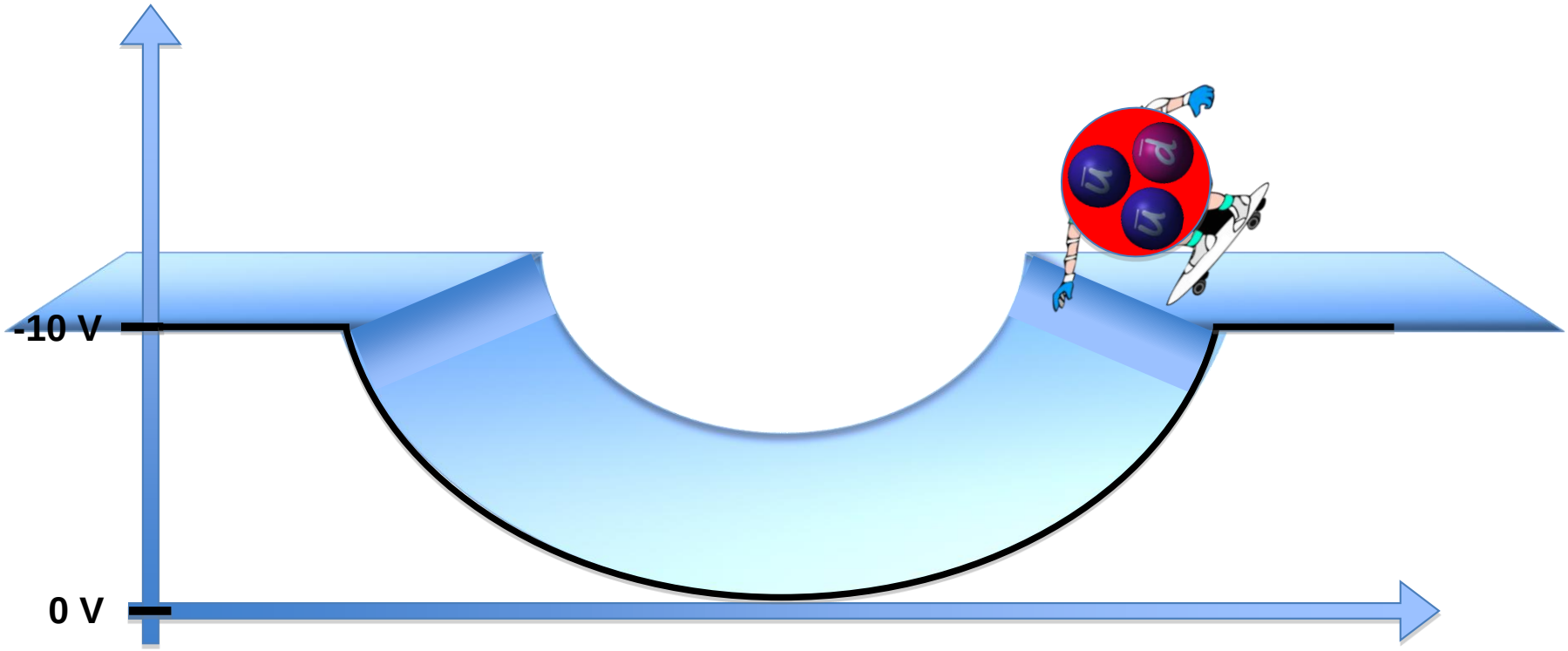

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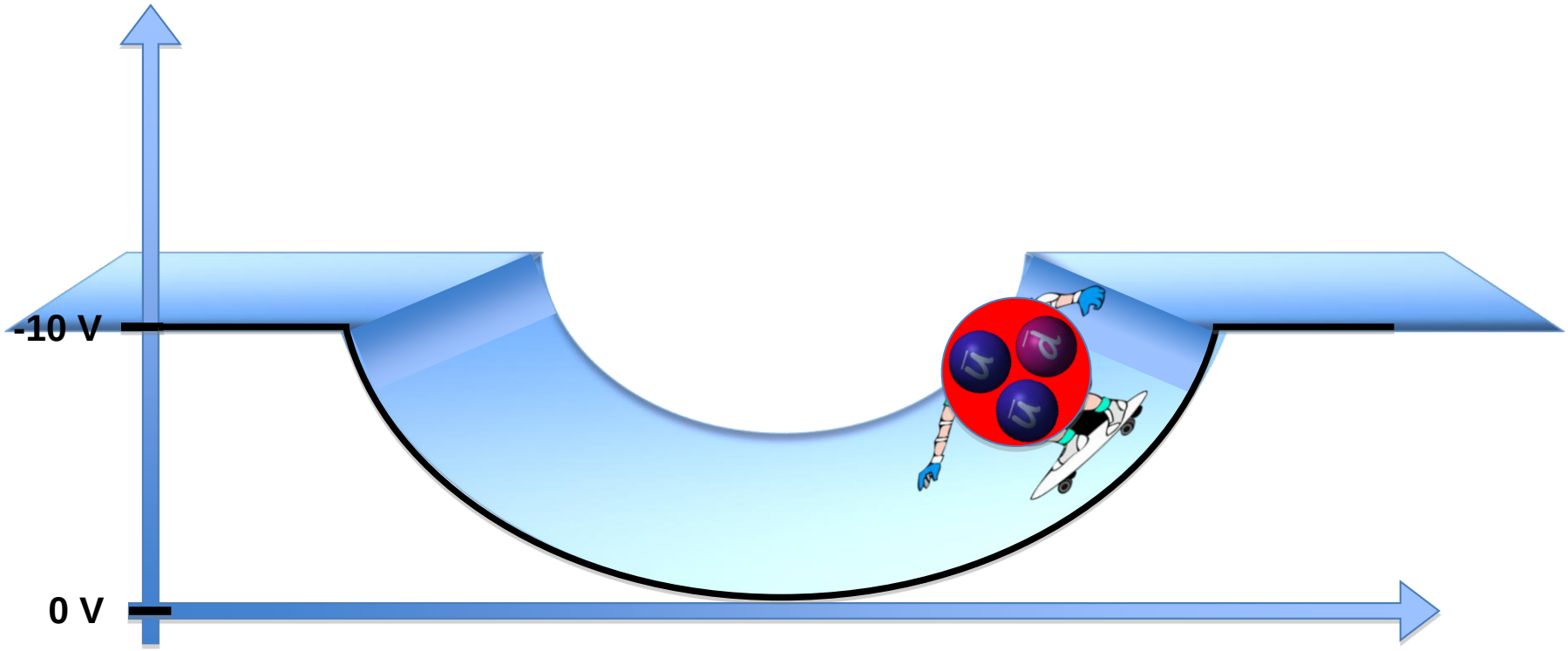

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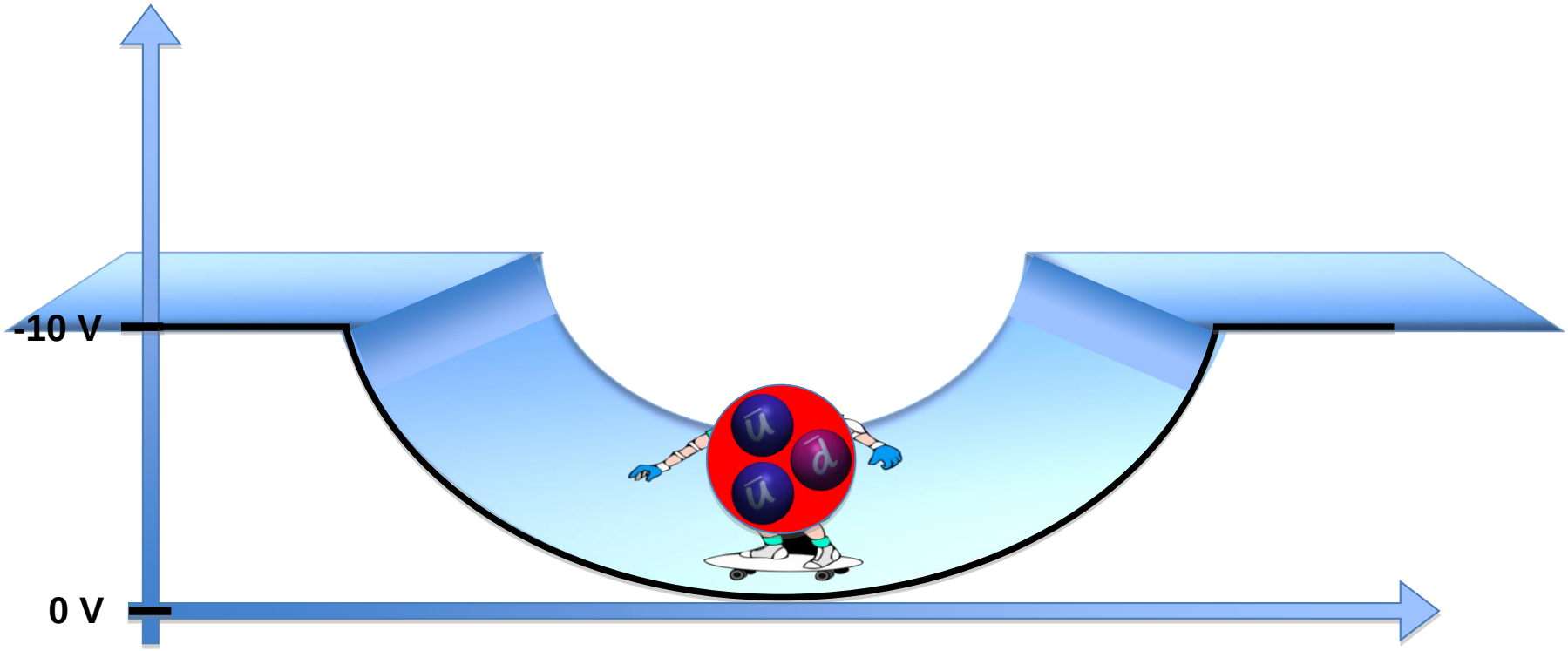

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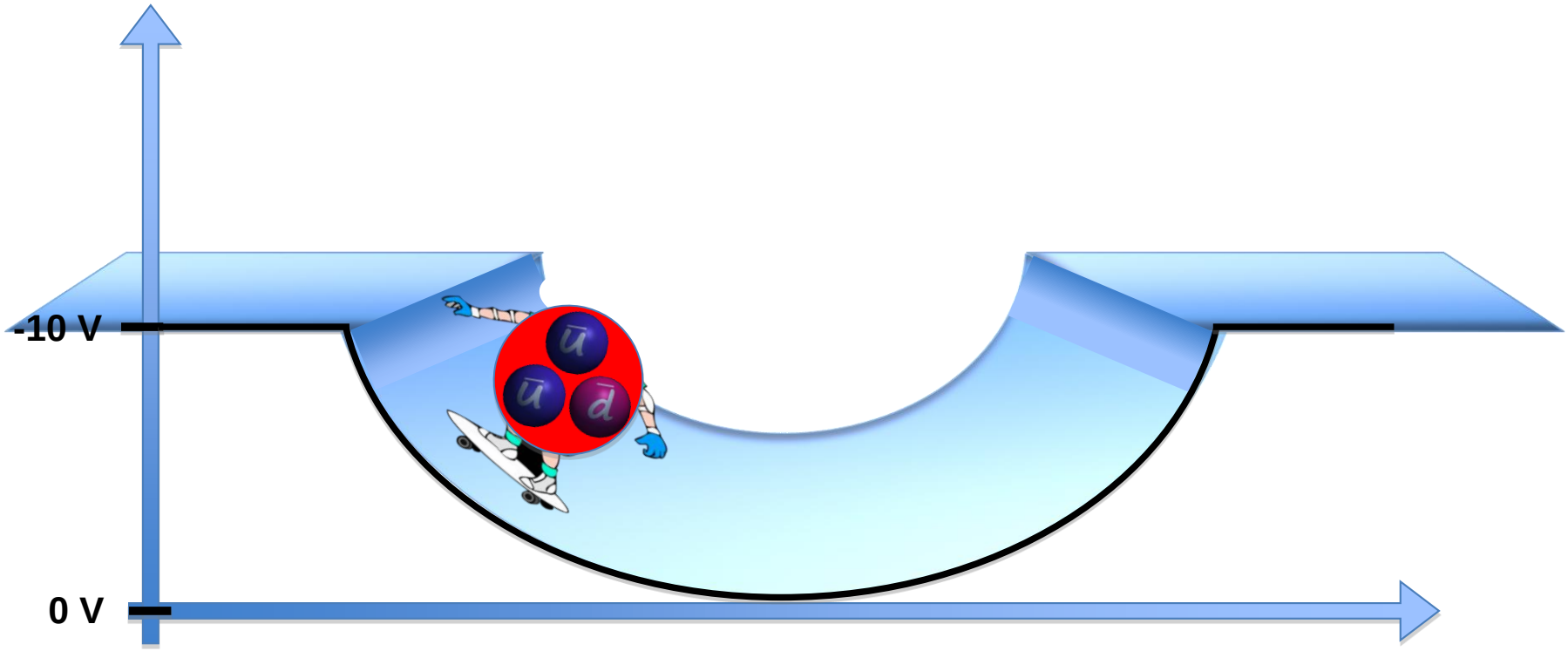

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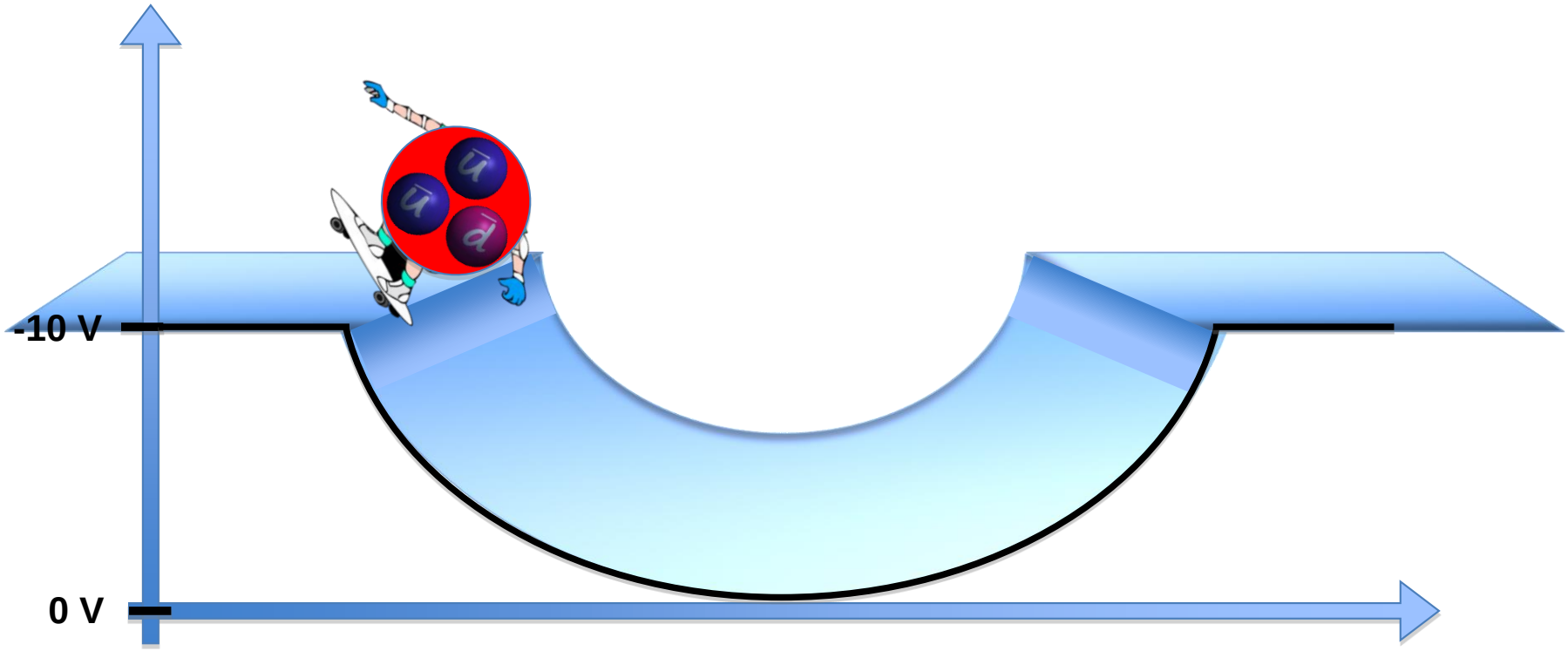

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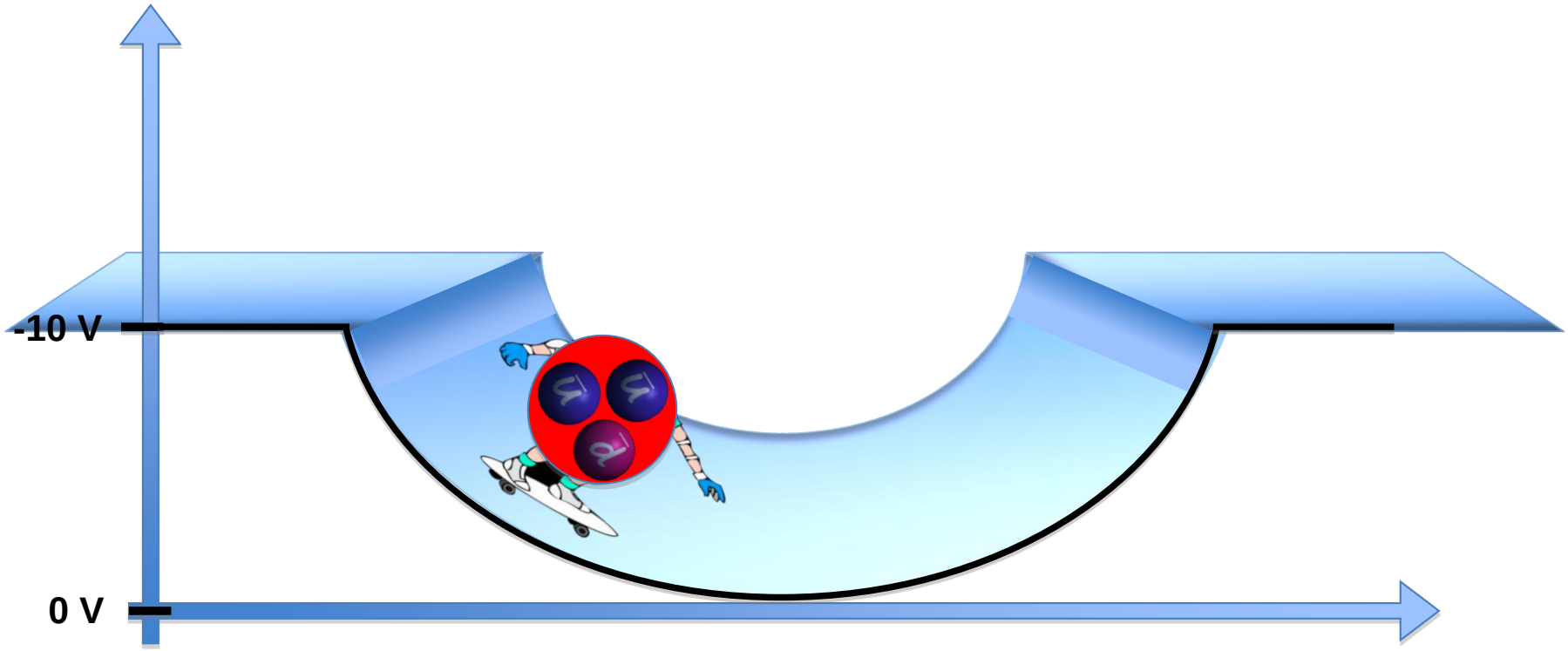

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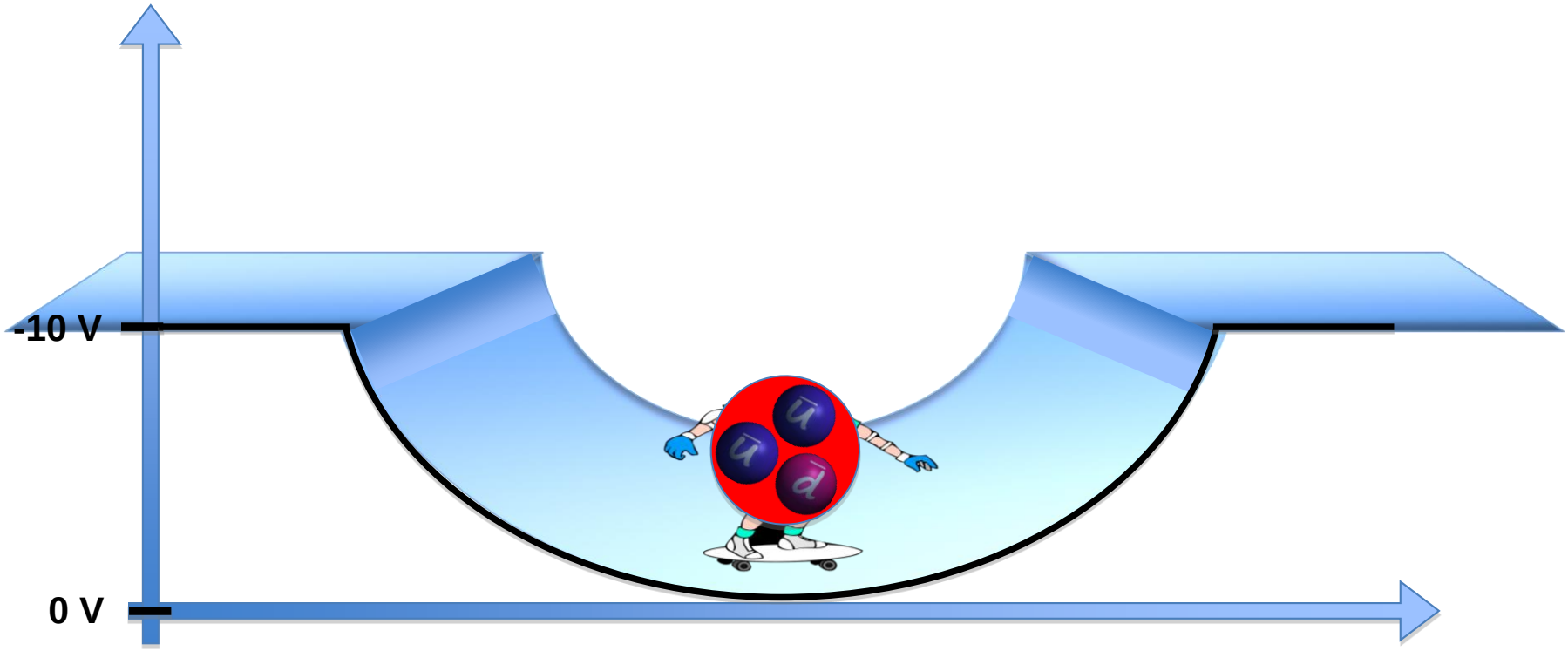

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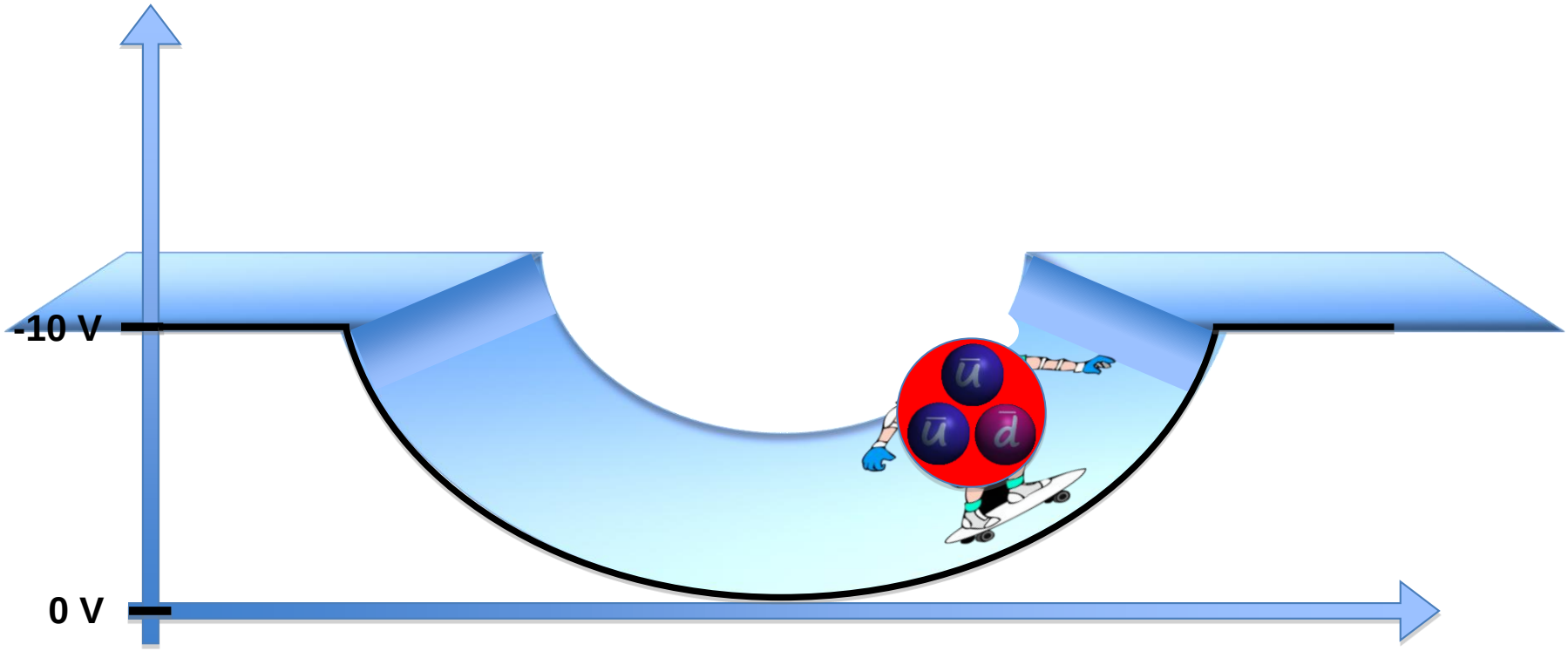

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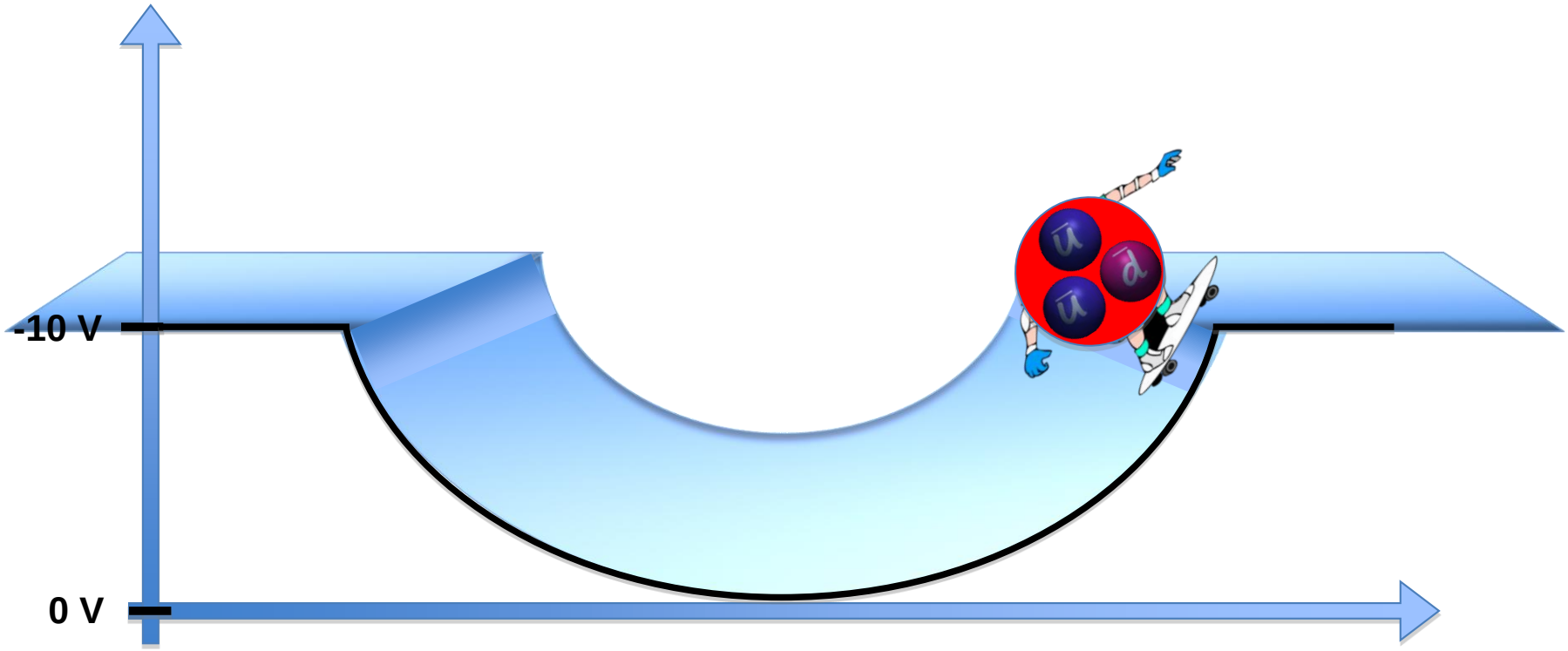

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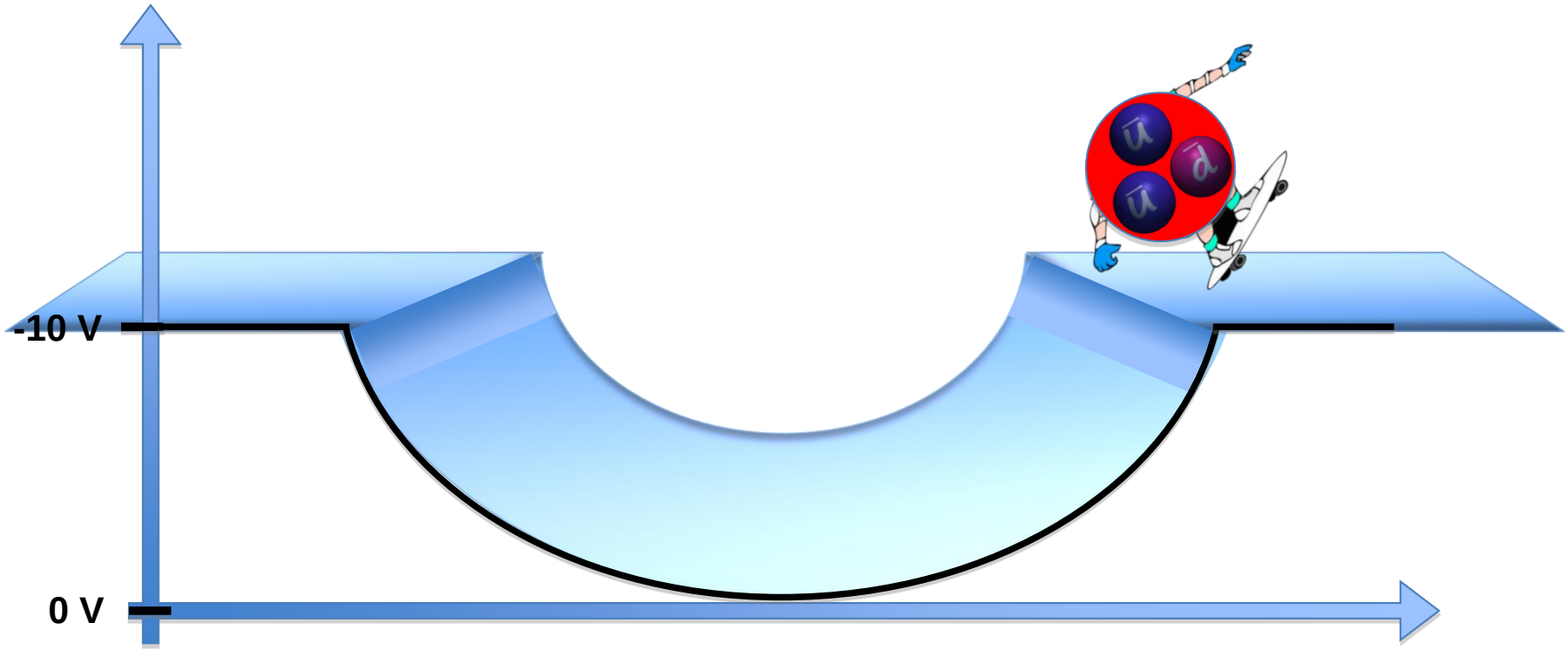

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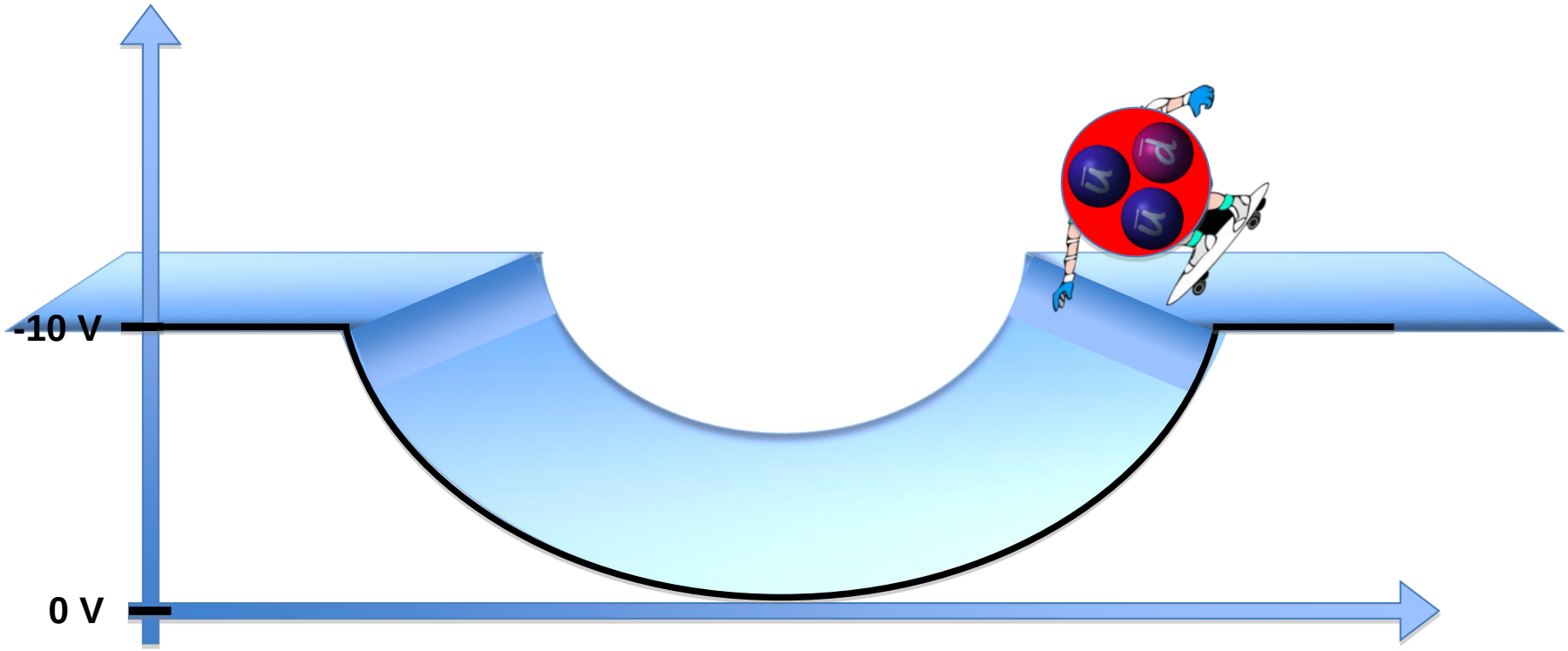
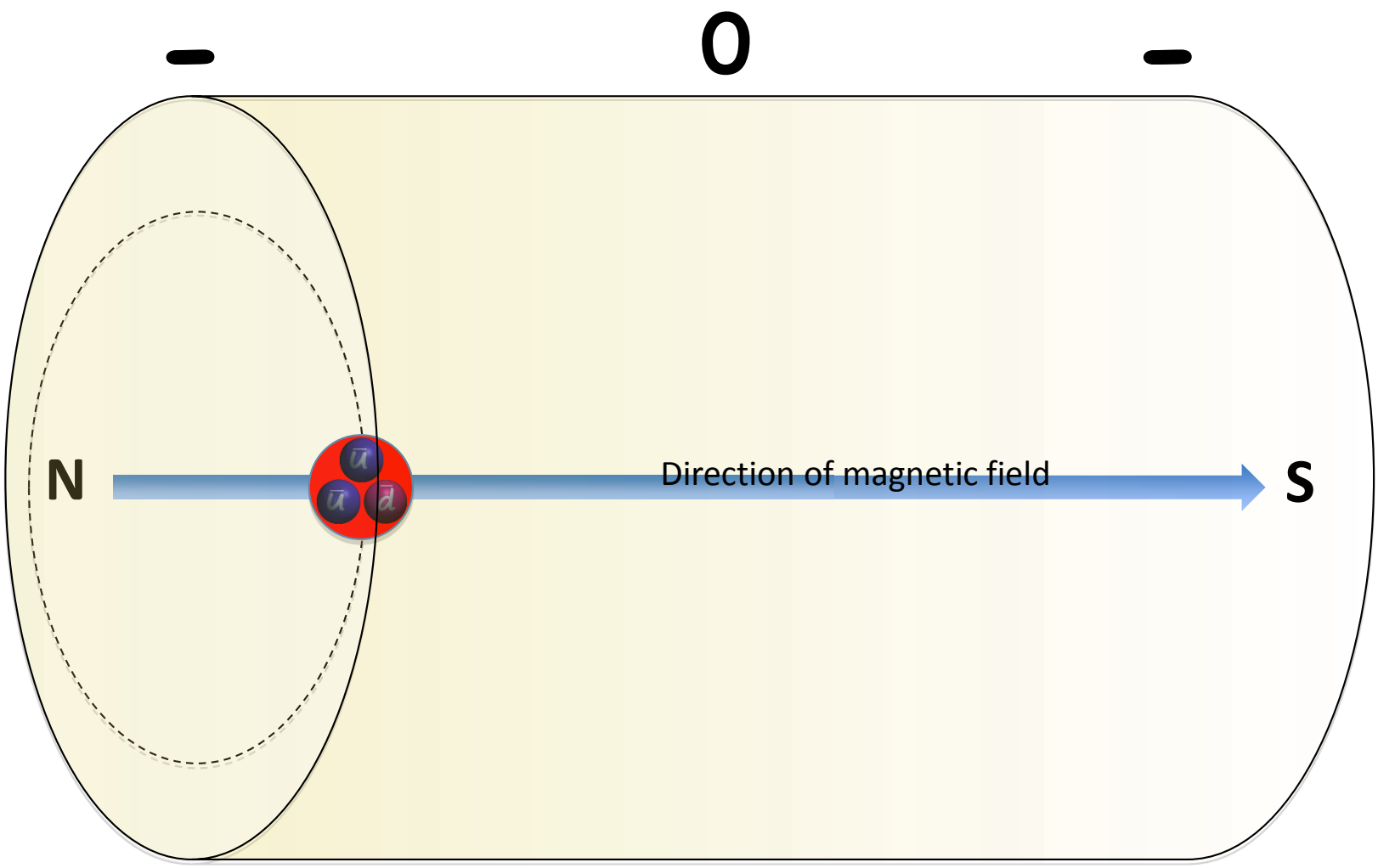


The combined effects of the magnetic and electric fields prevent the antiproton from coming into contact with ALL sides of the cylinder.

The antiproton is now TRAPPED…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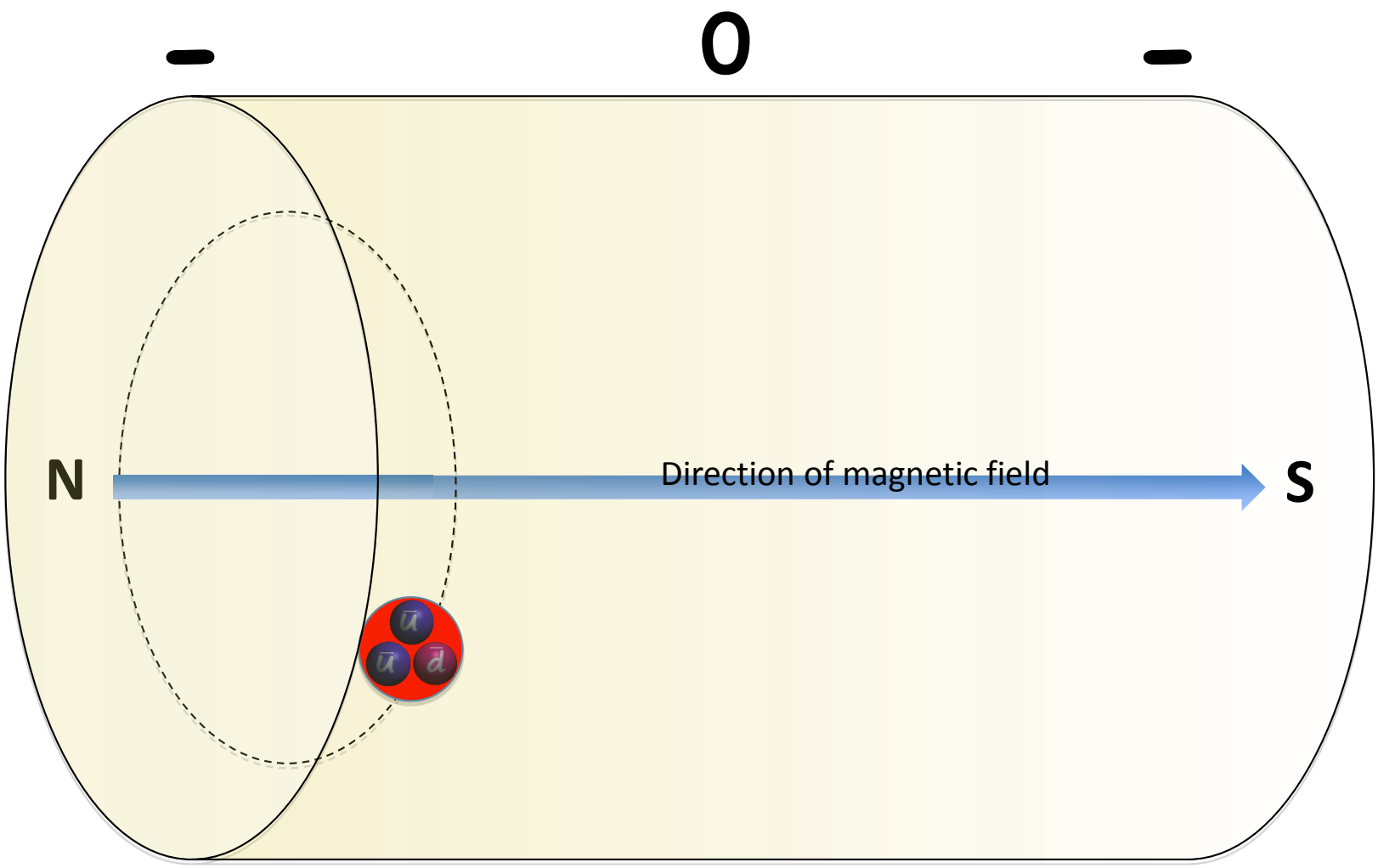
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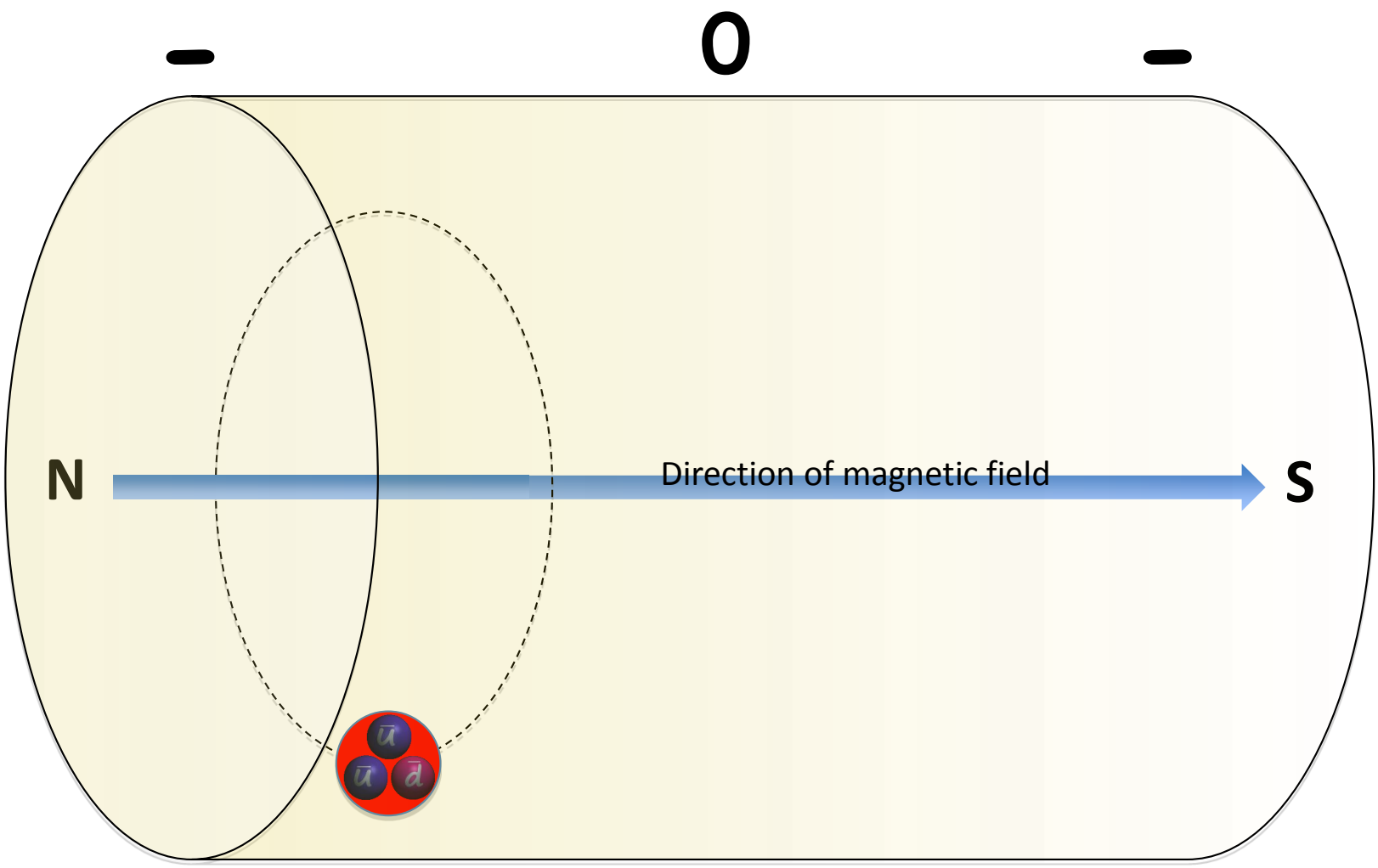
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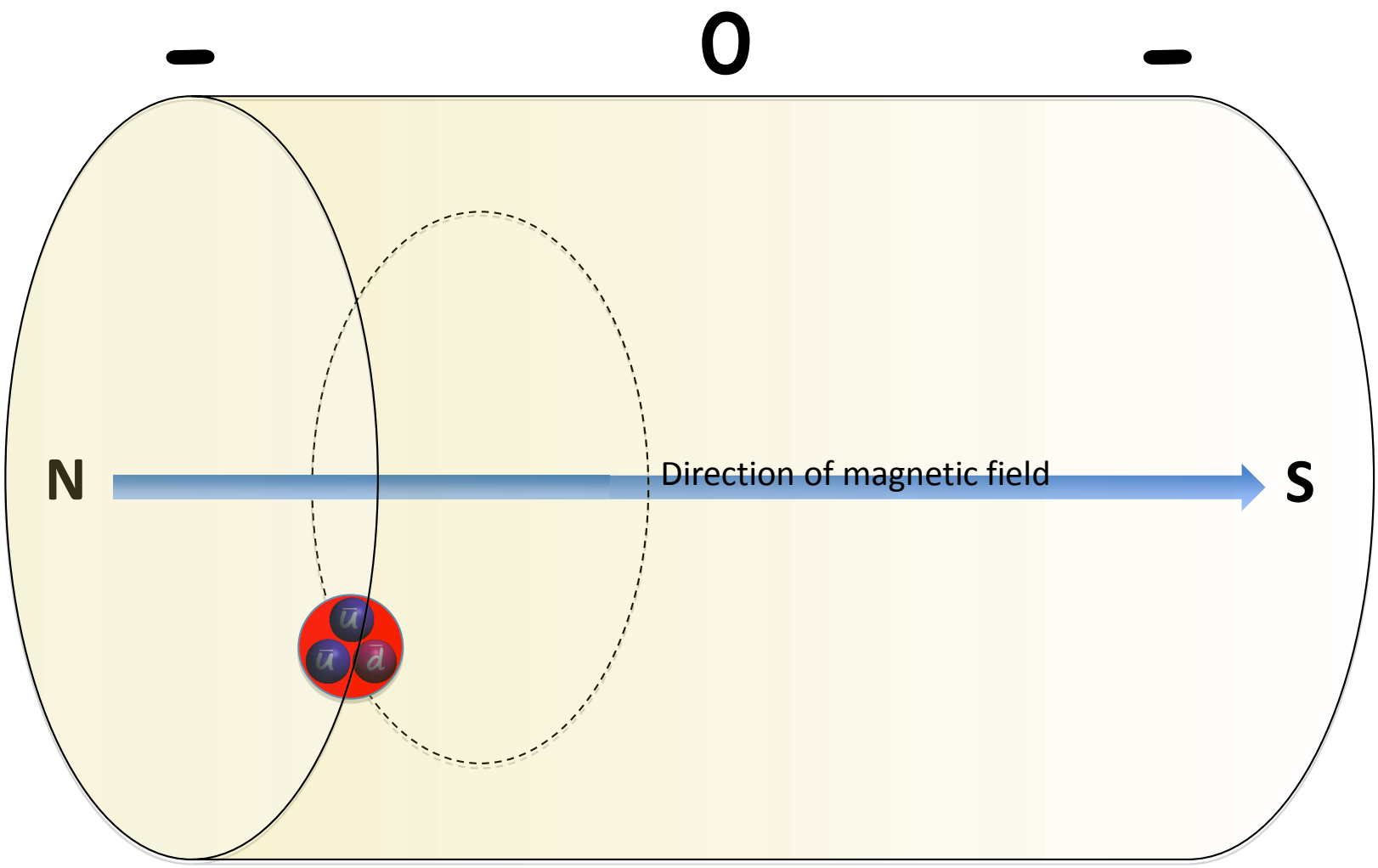
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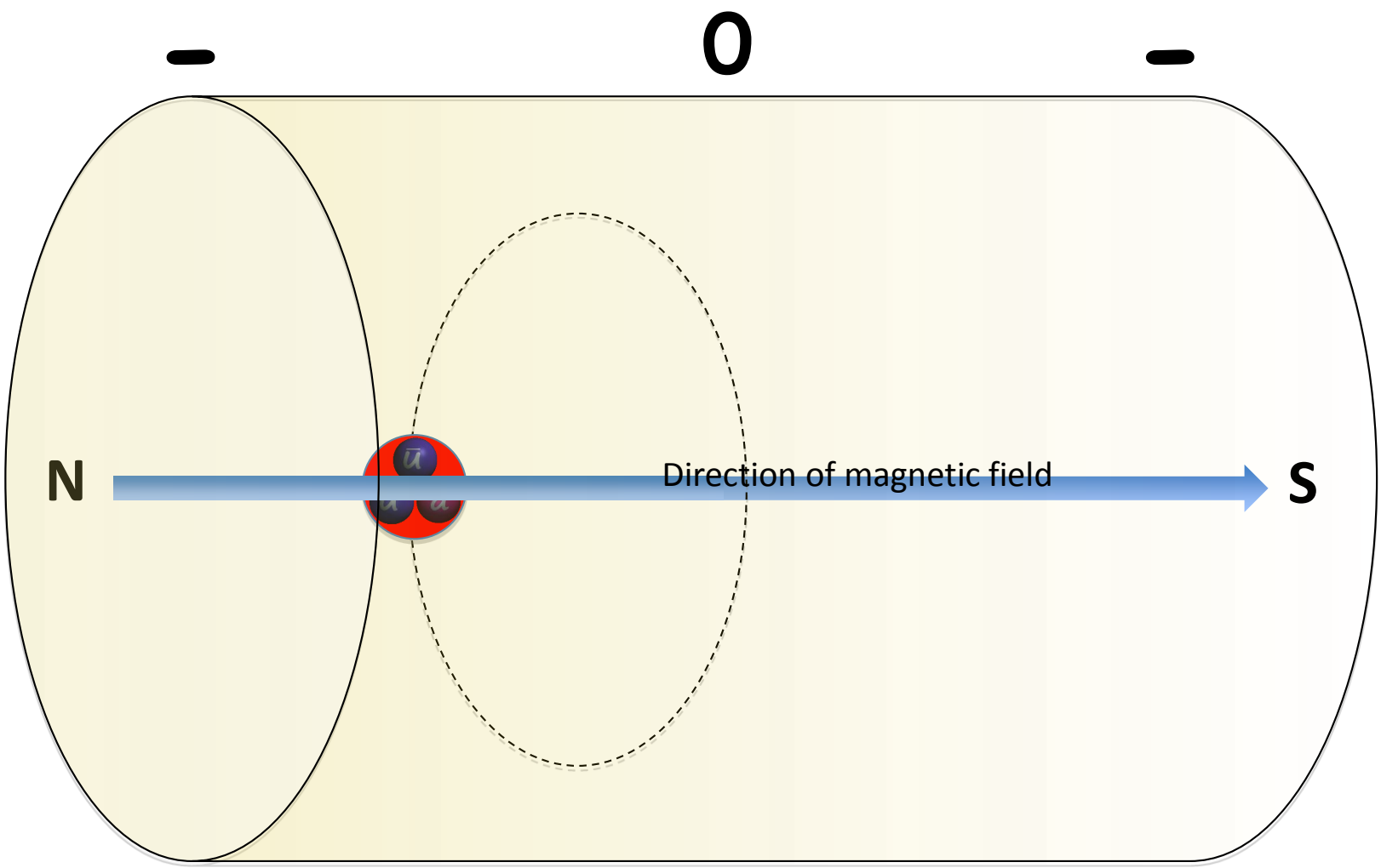
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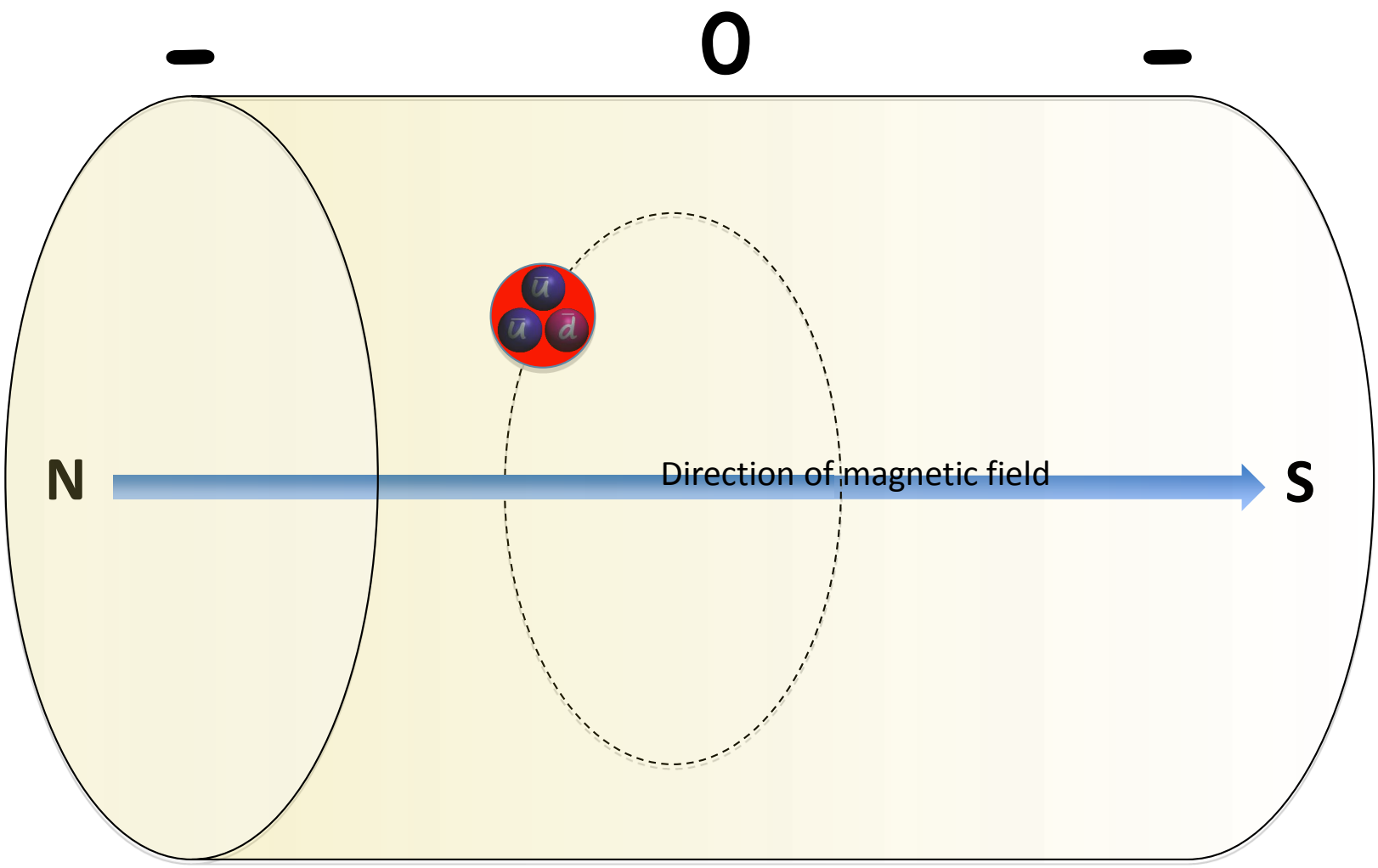
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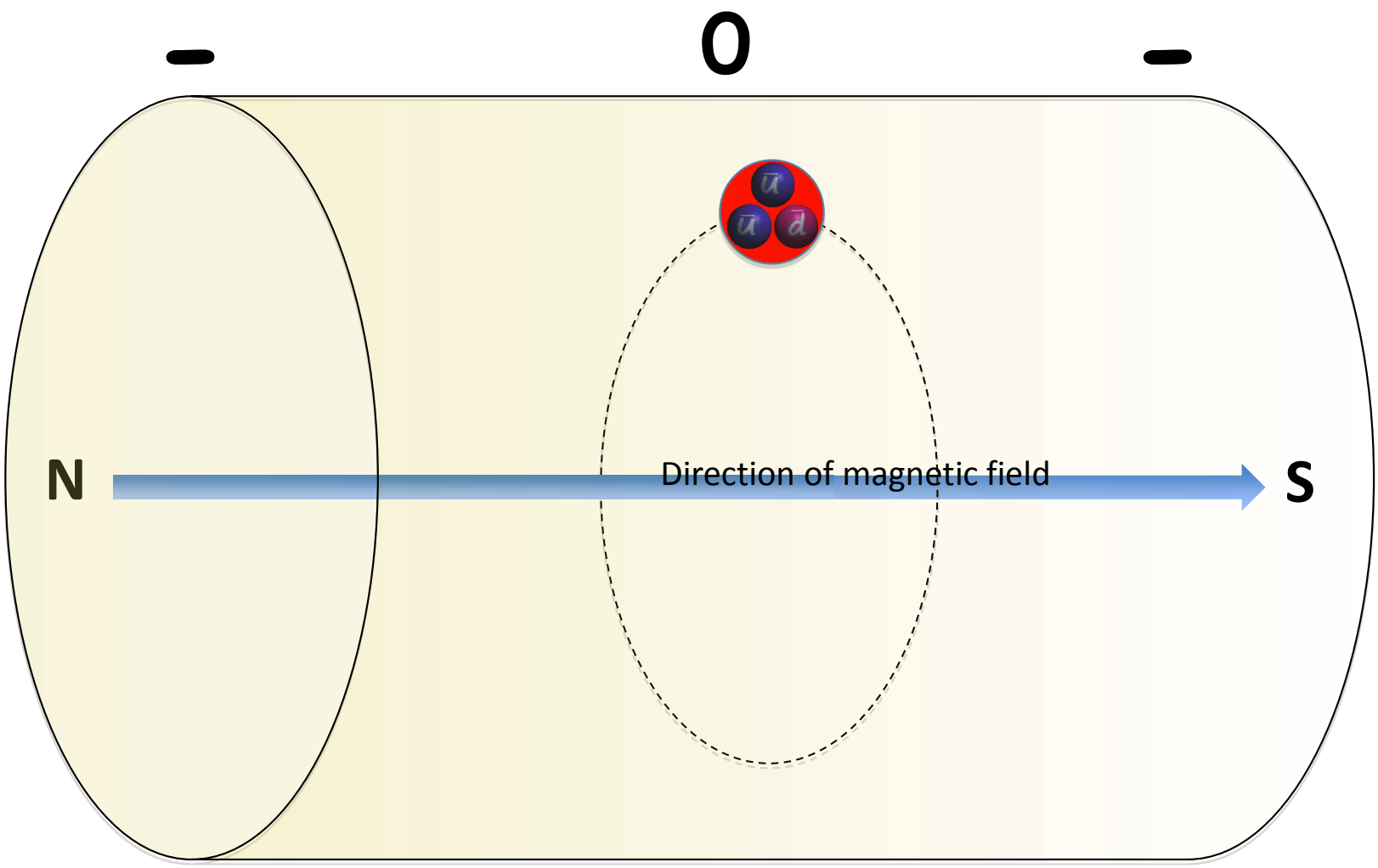
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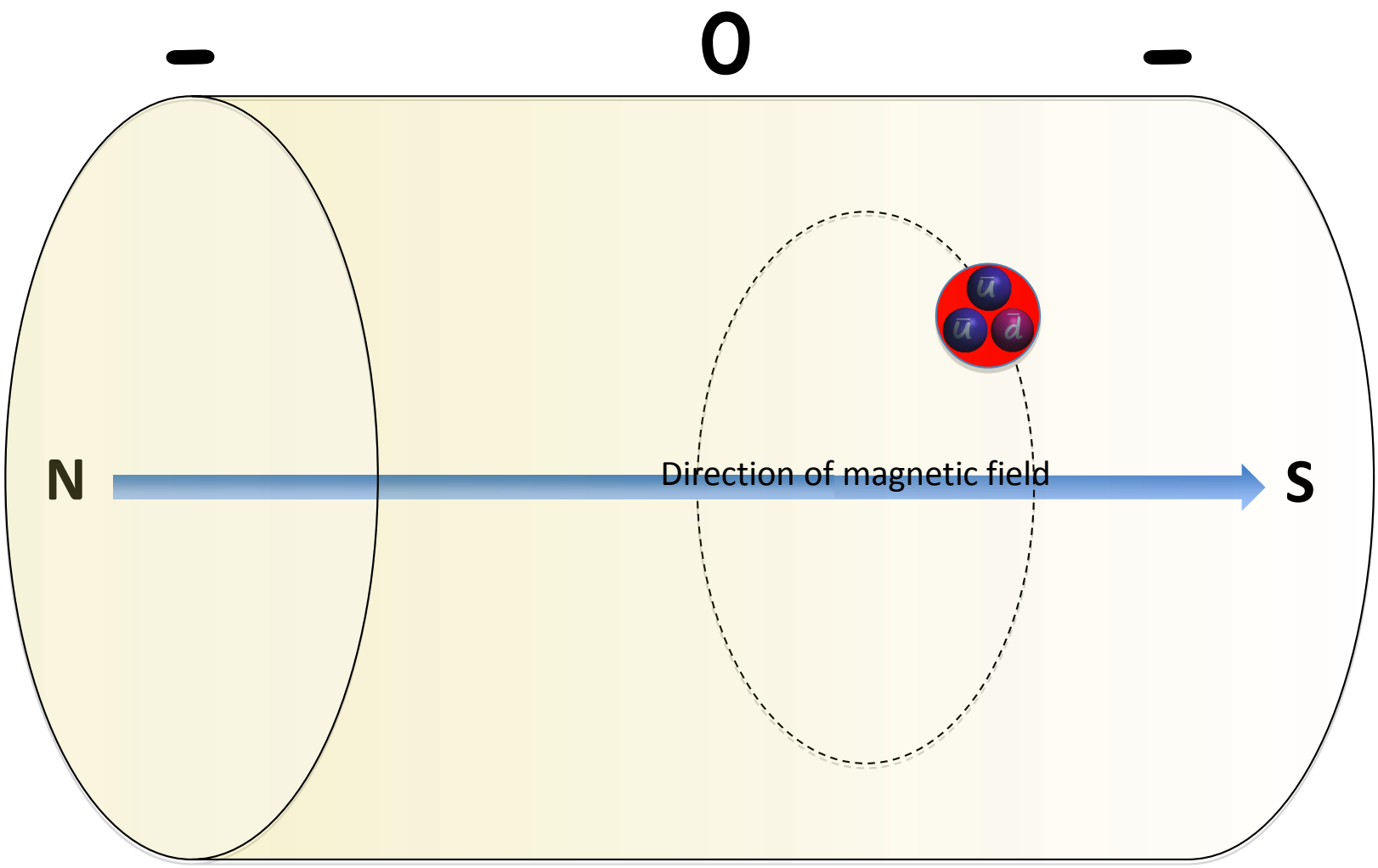
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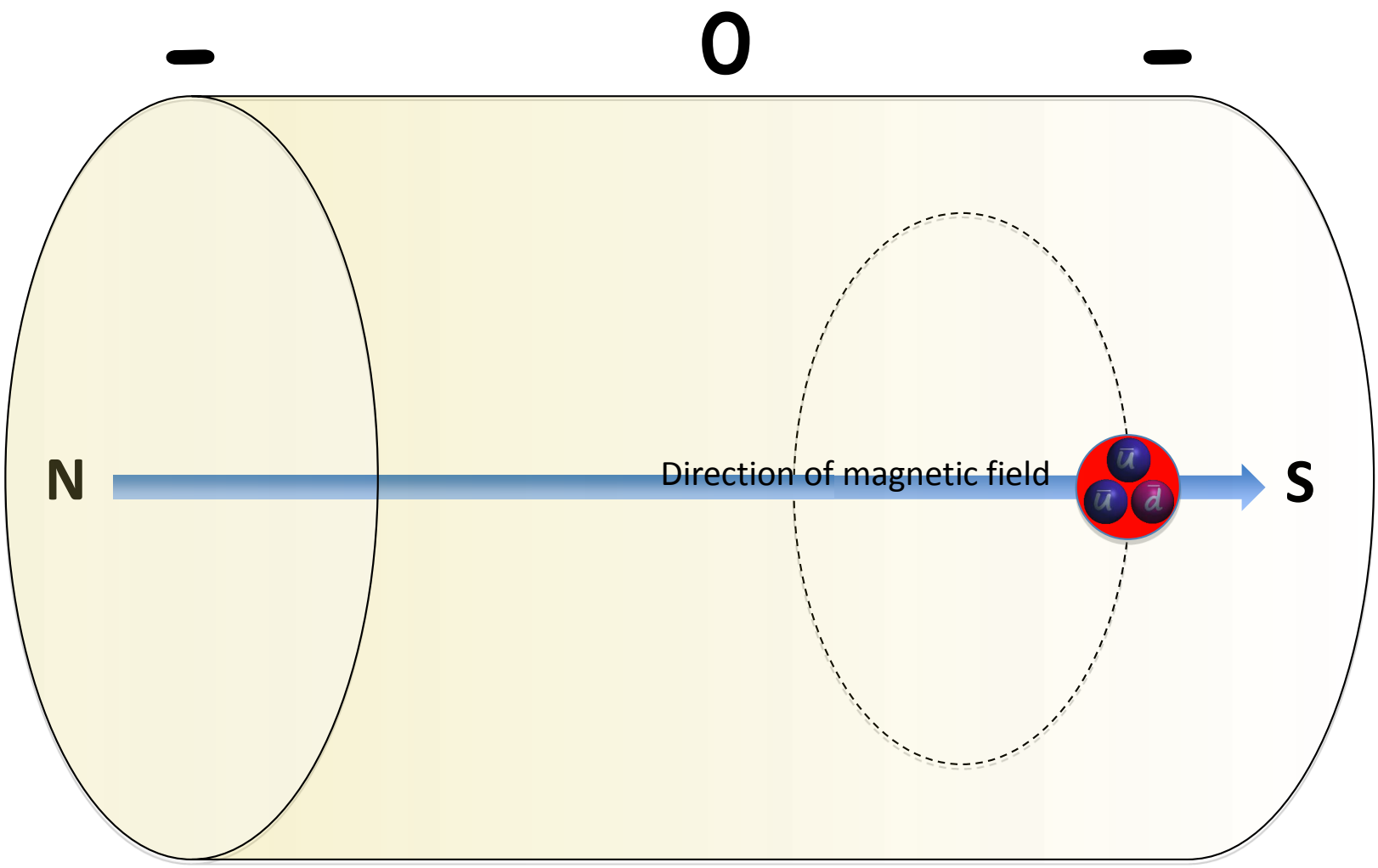
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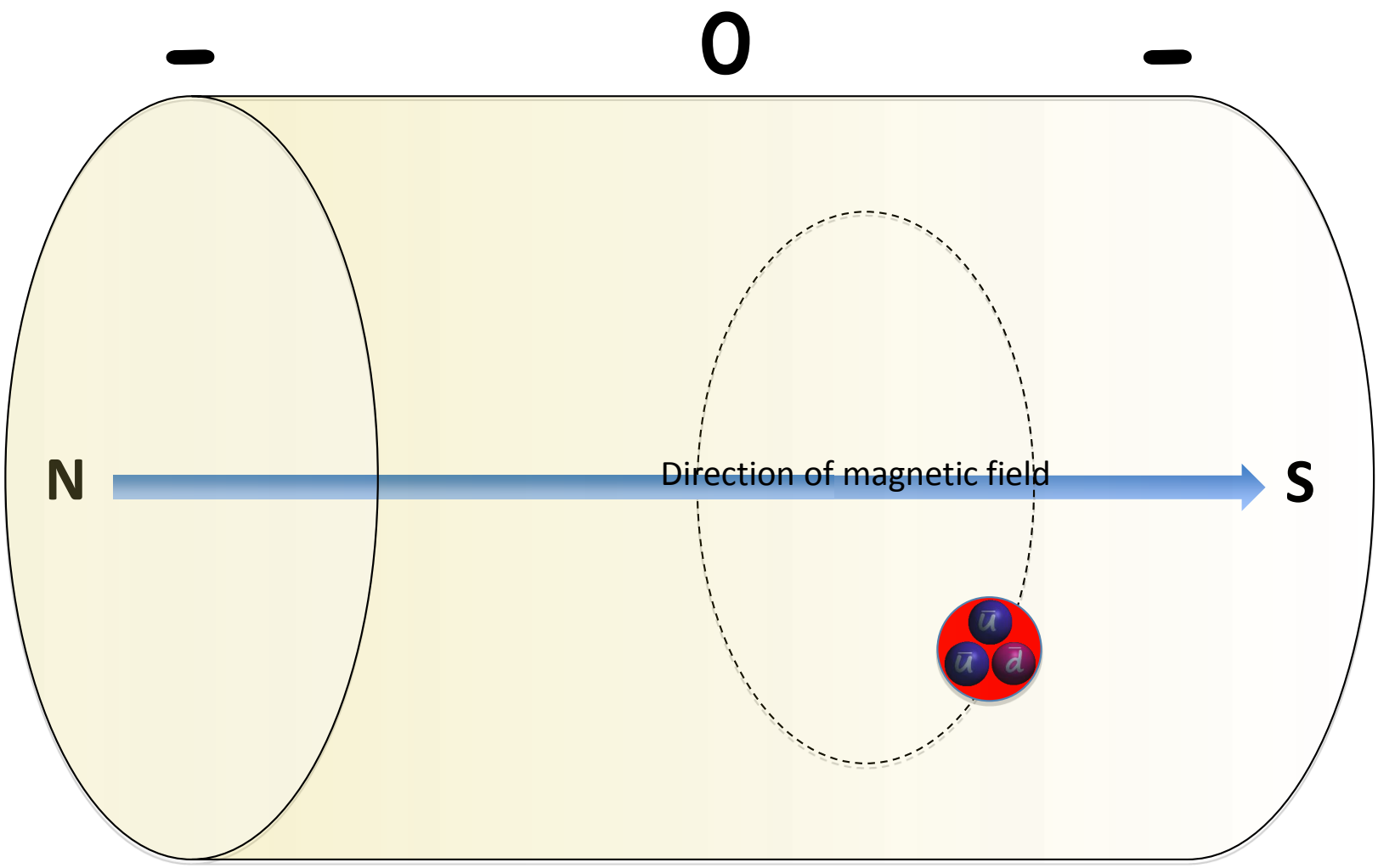
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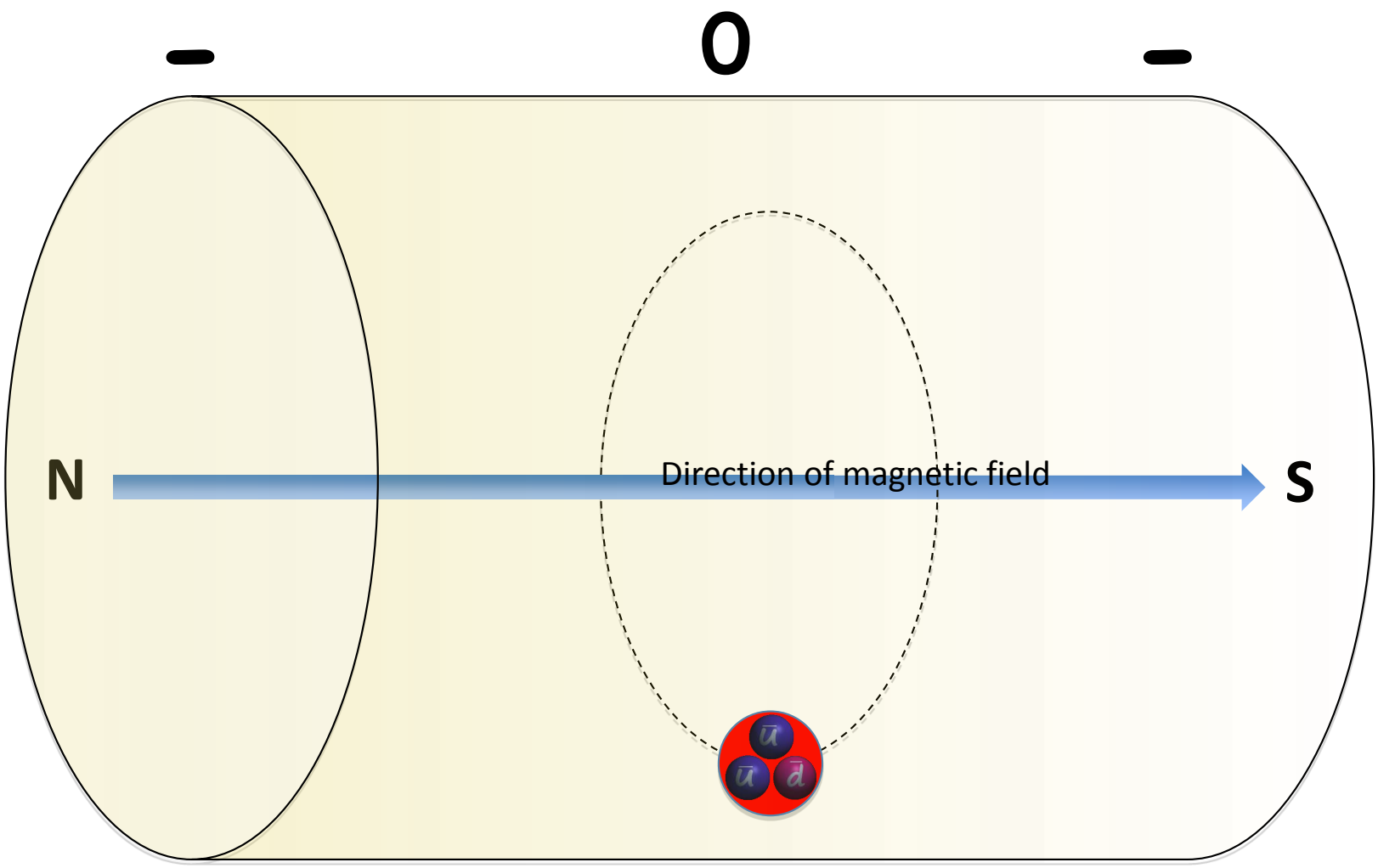
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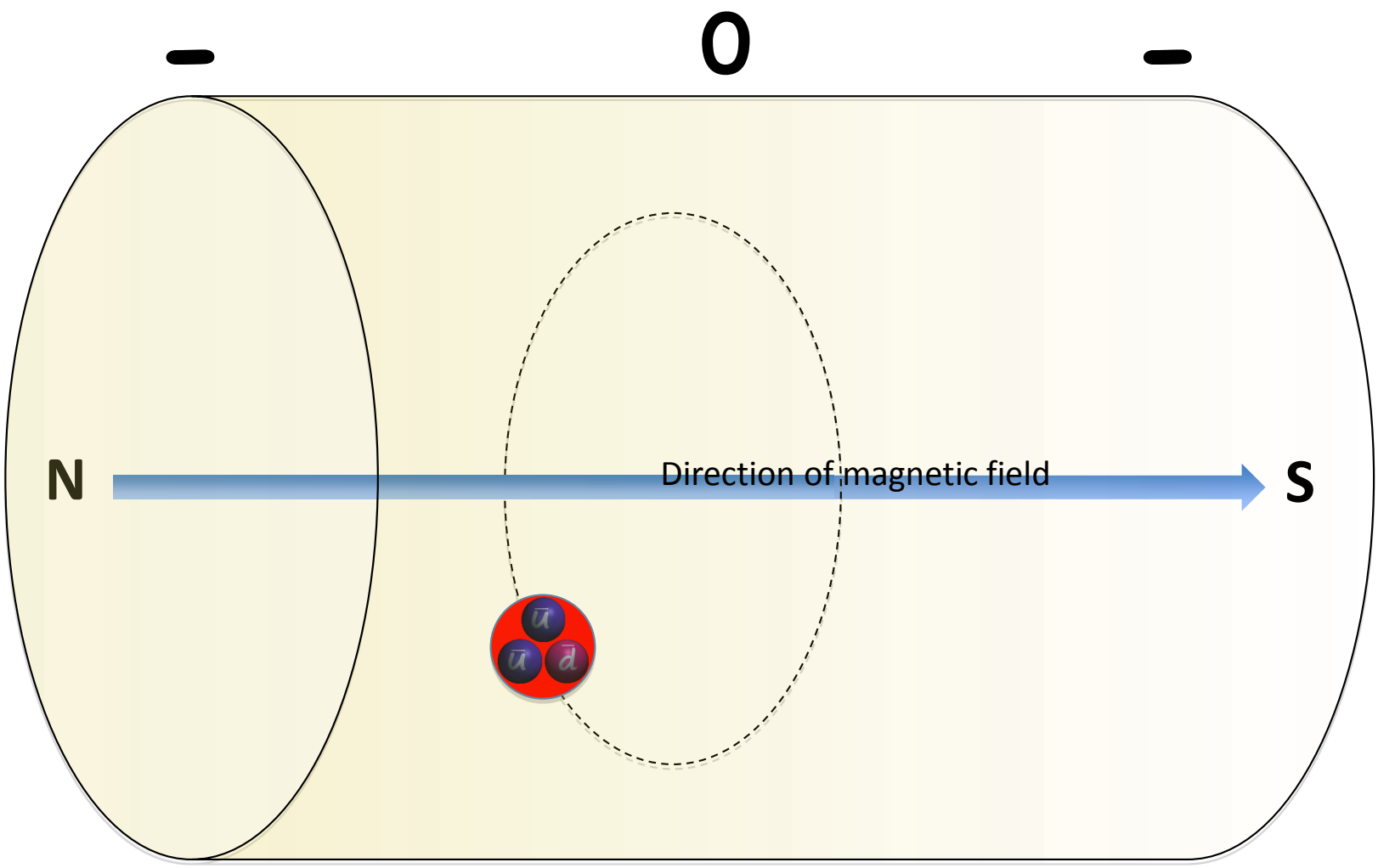
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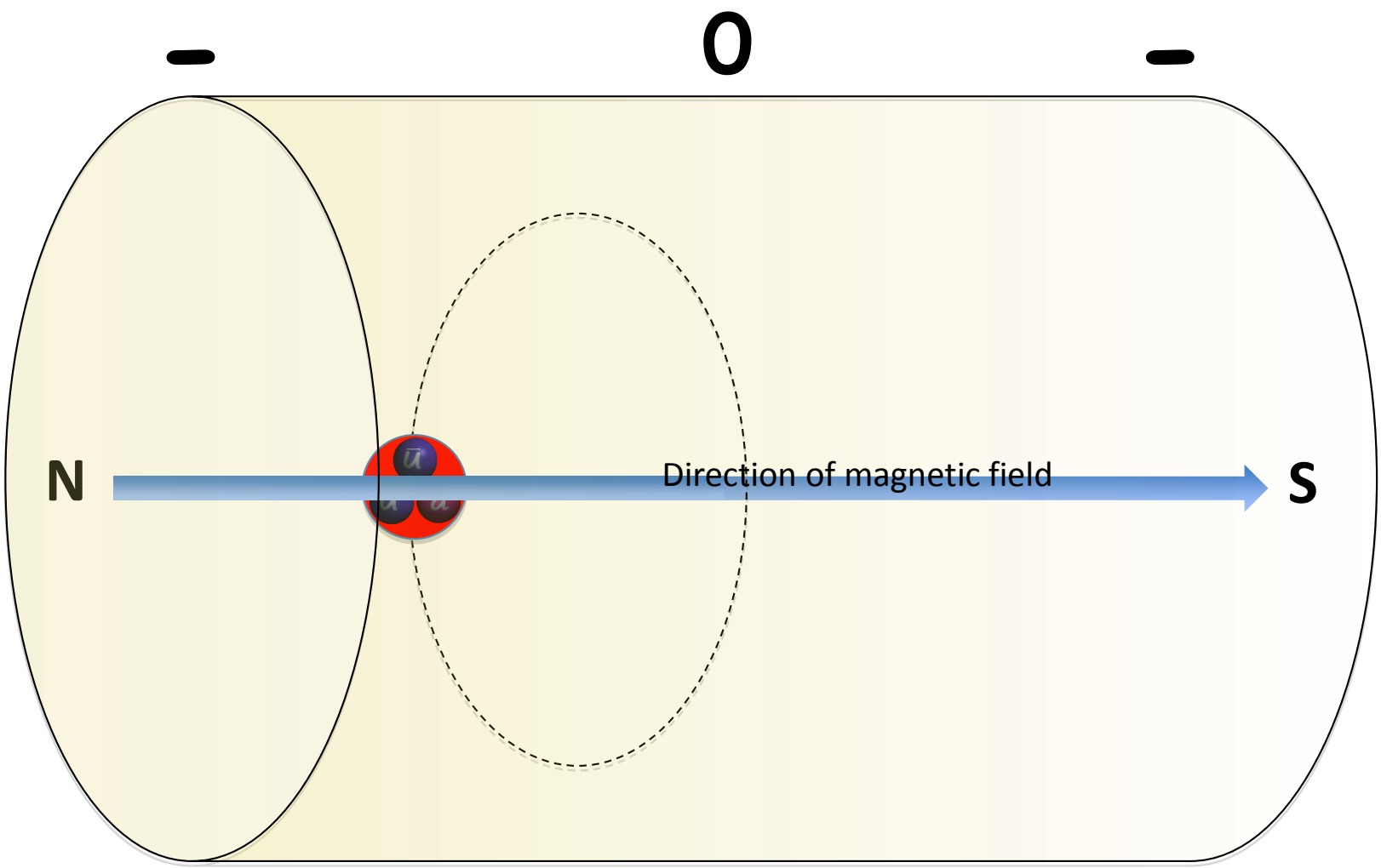
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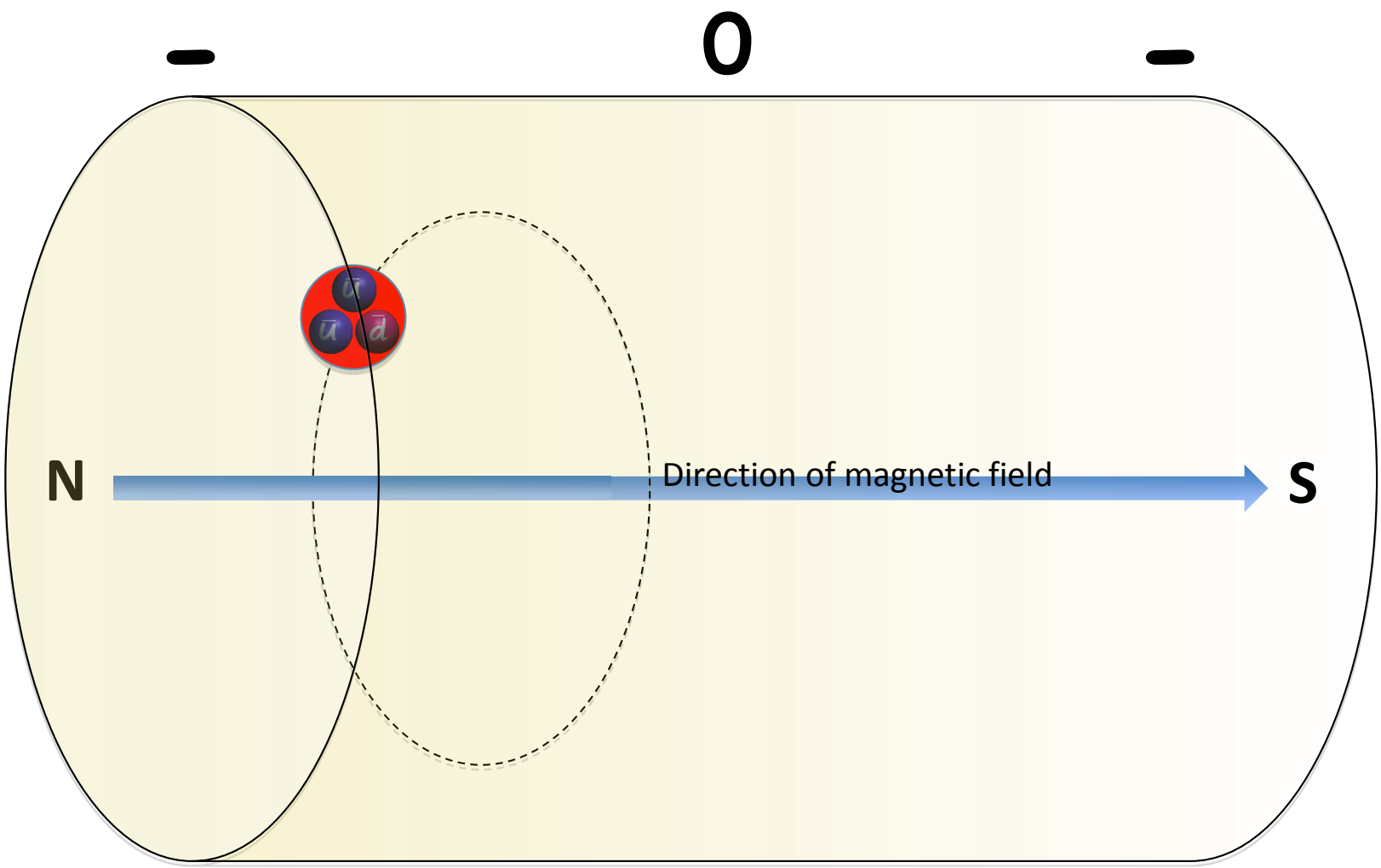
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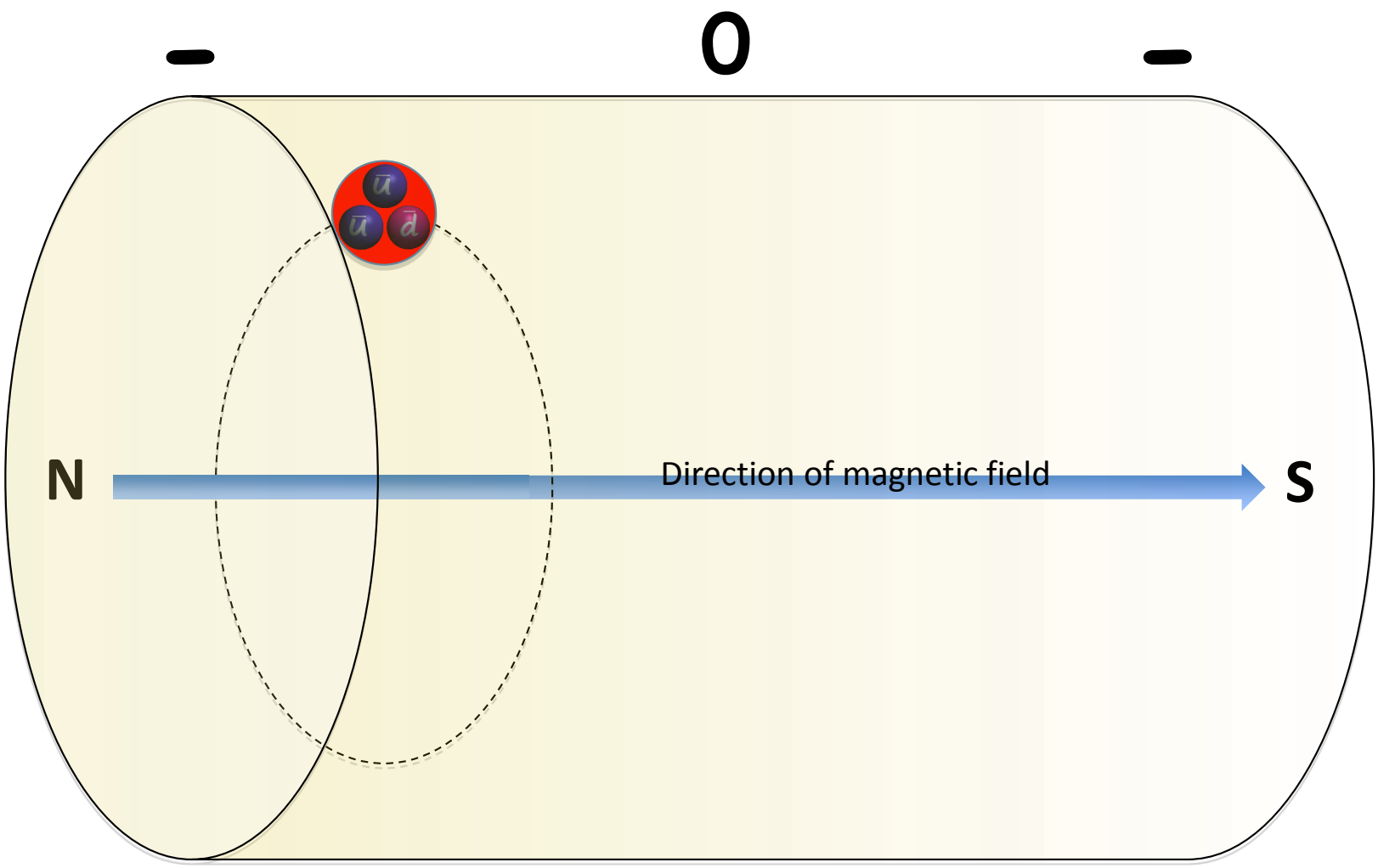
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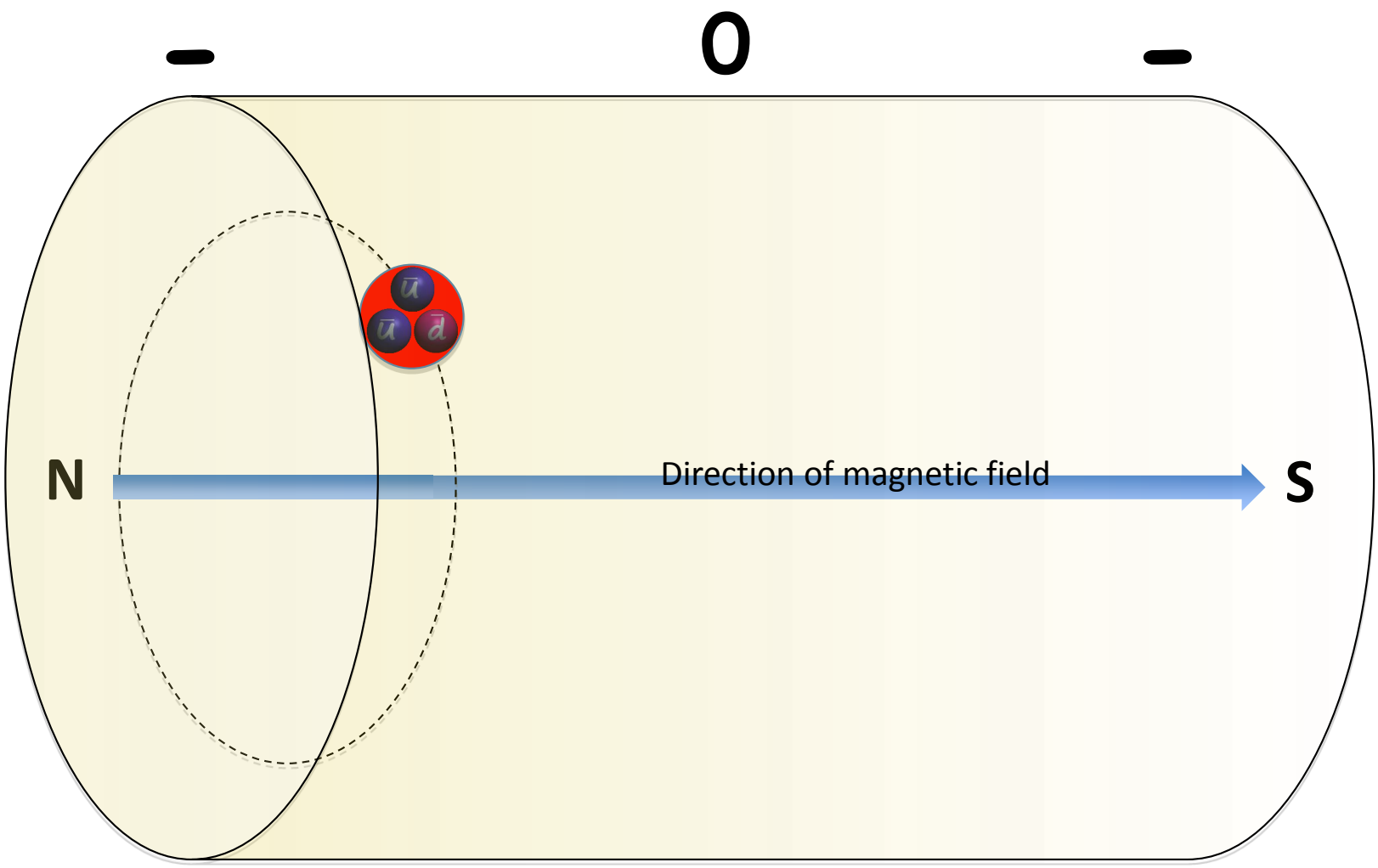
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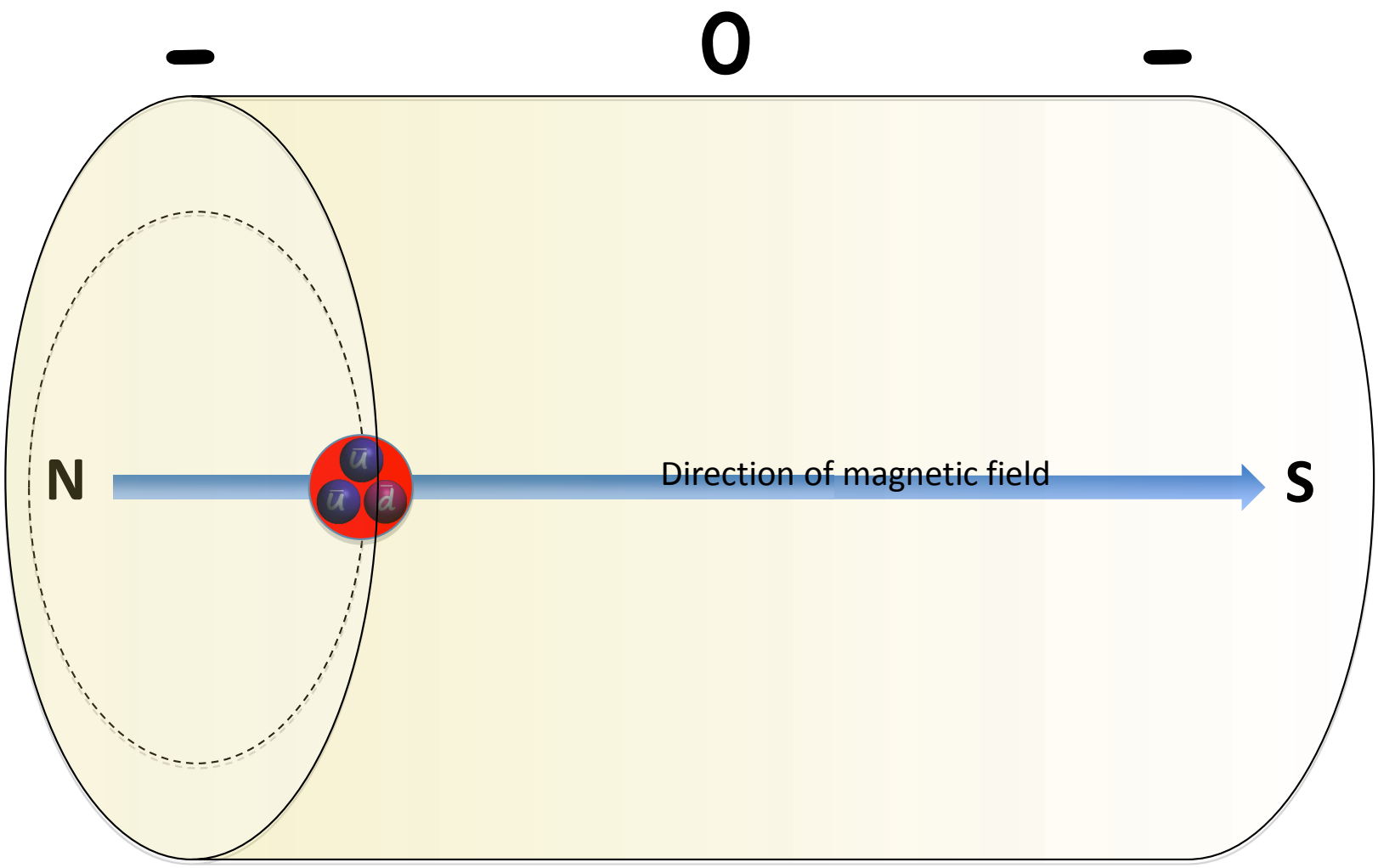
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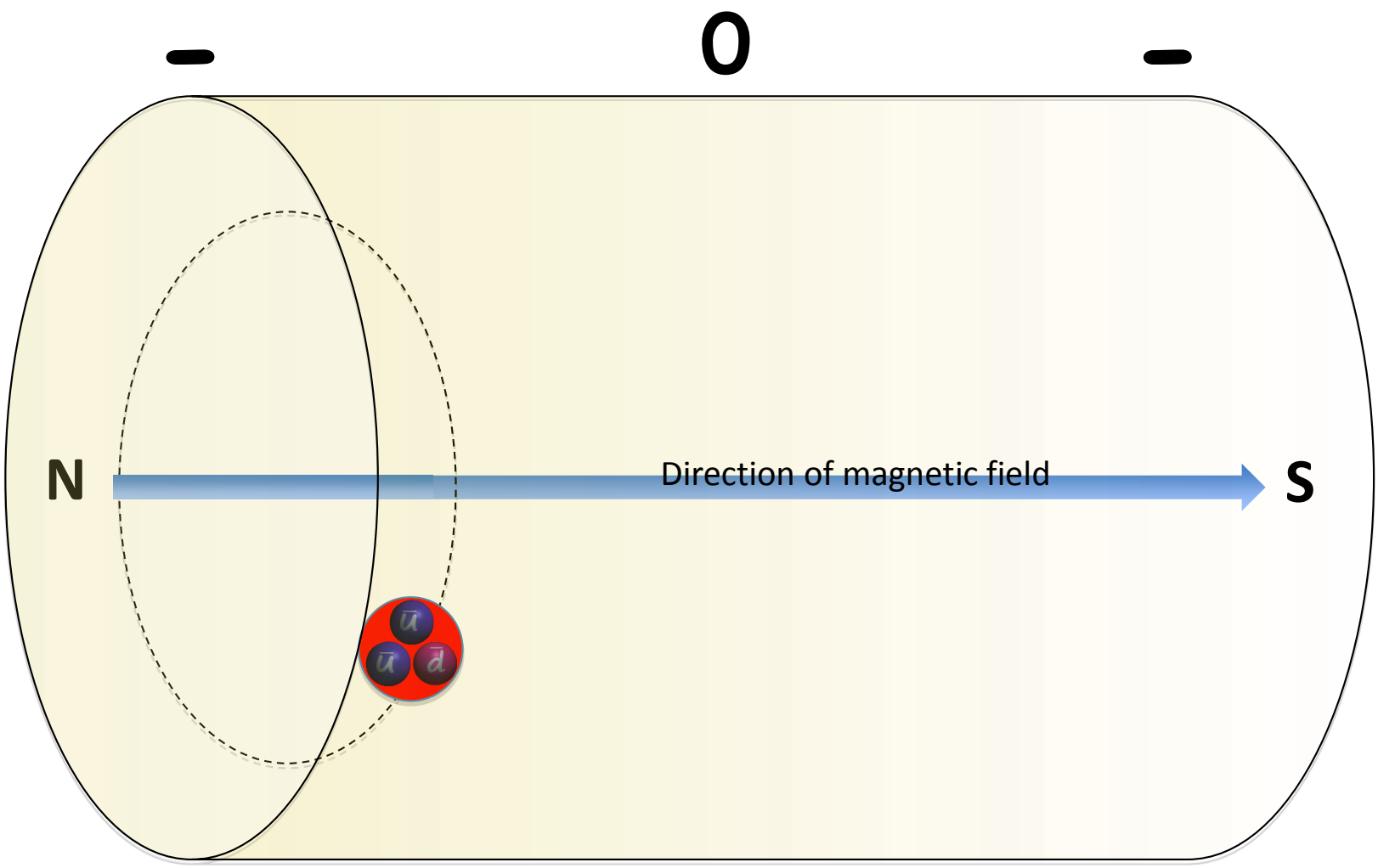
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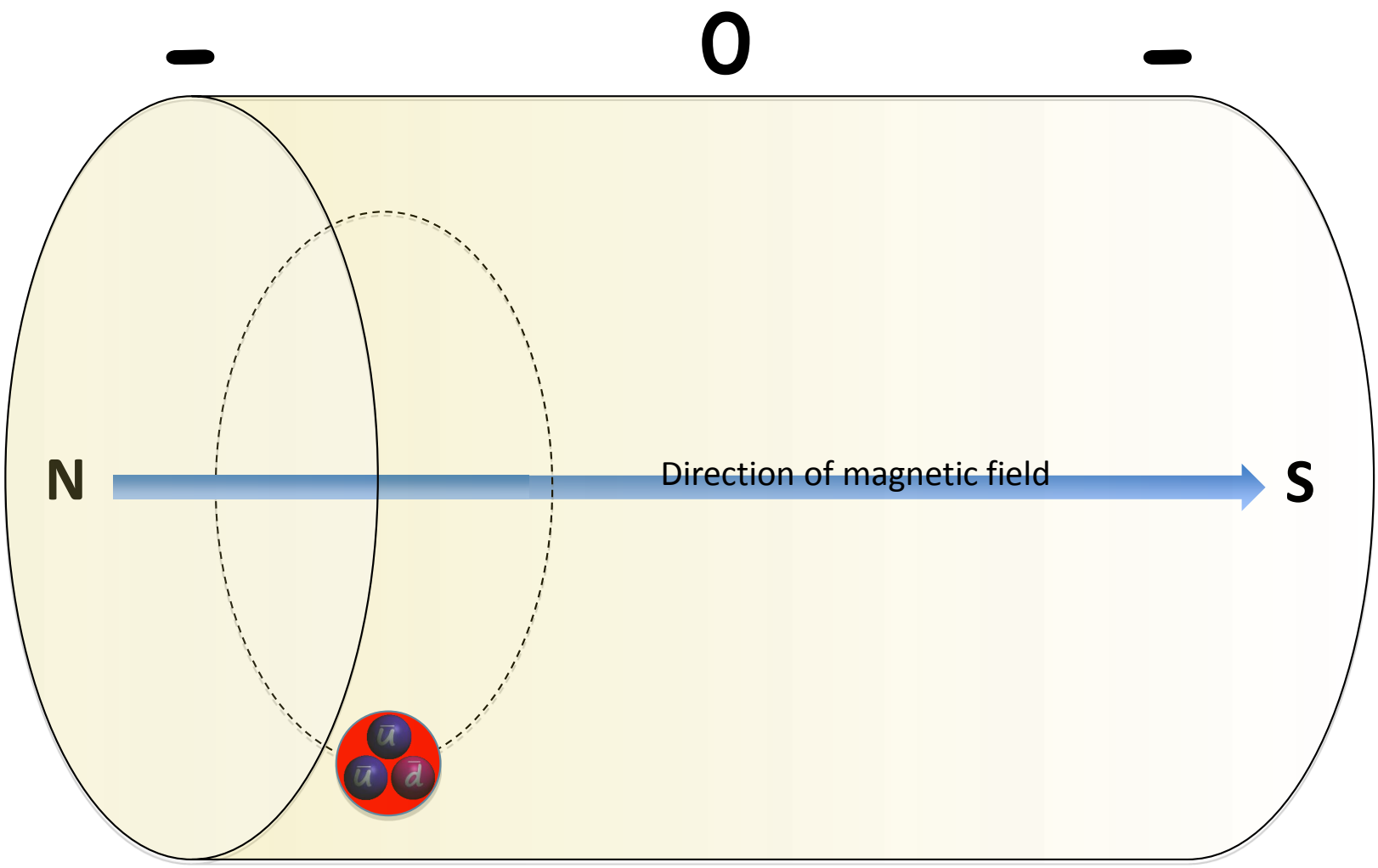
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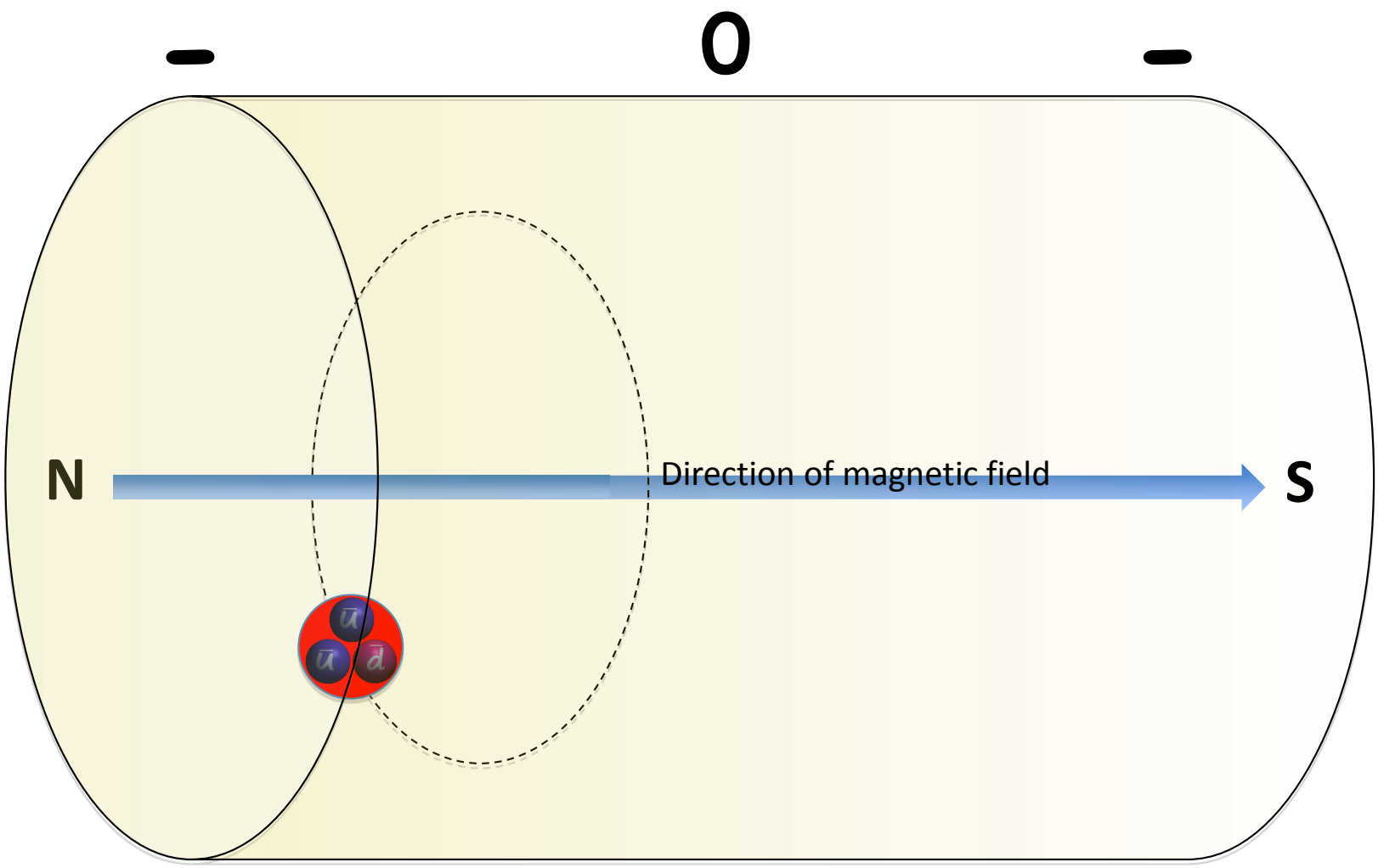
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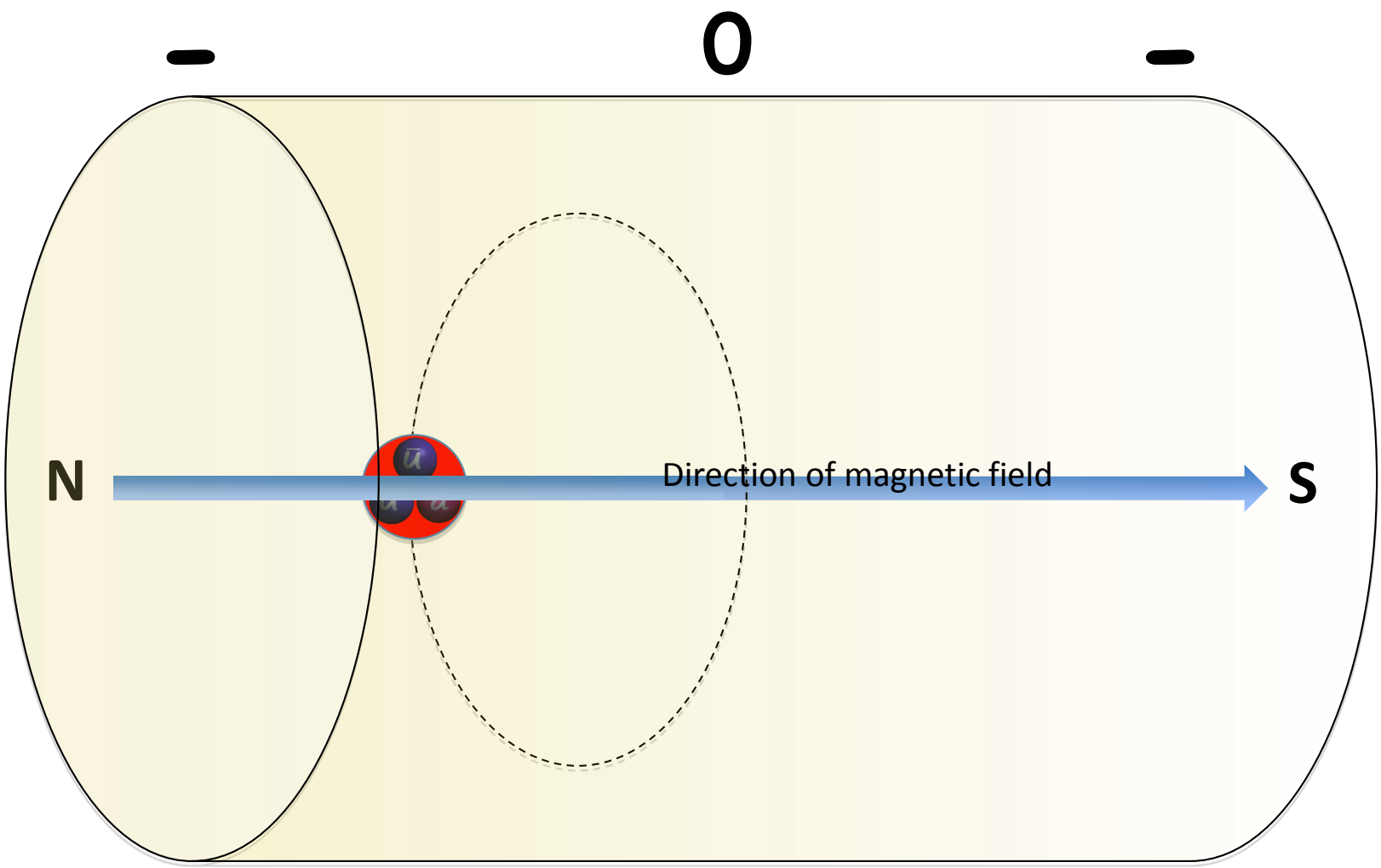
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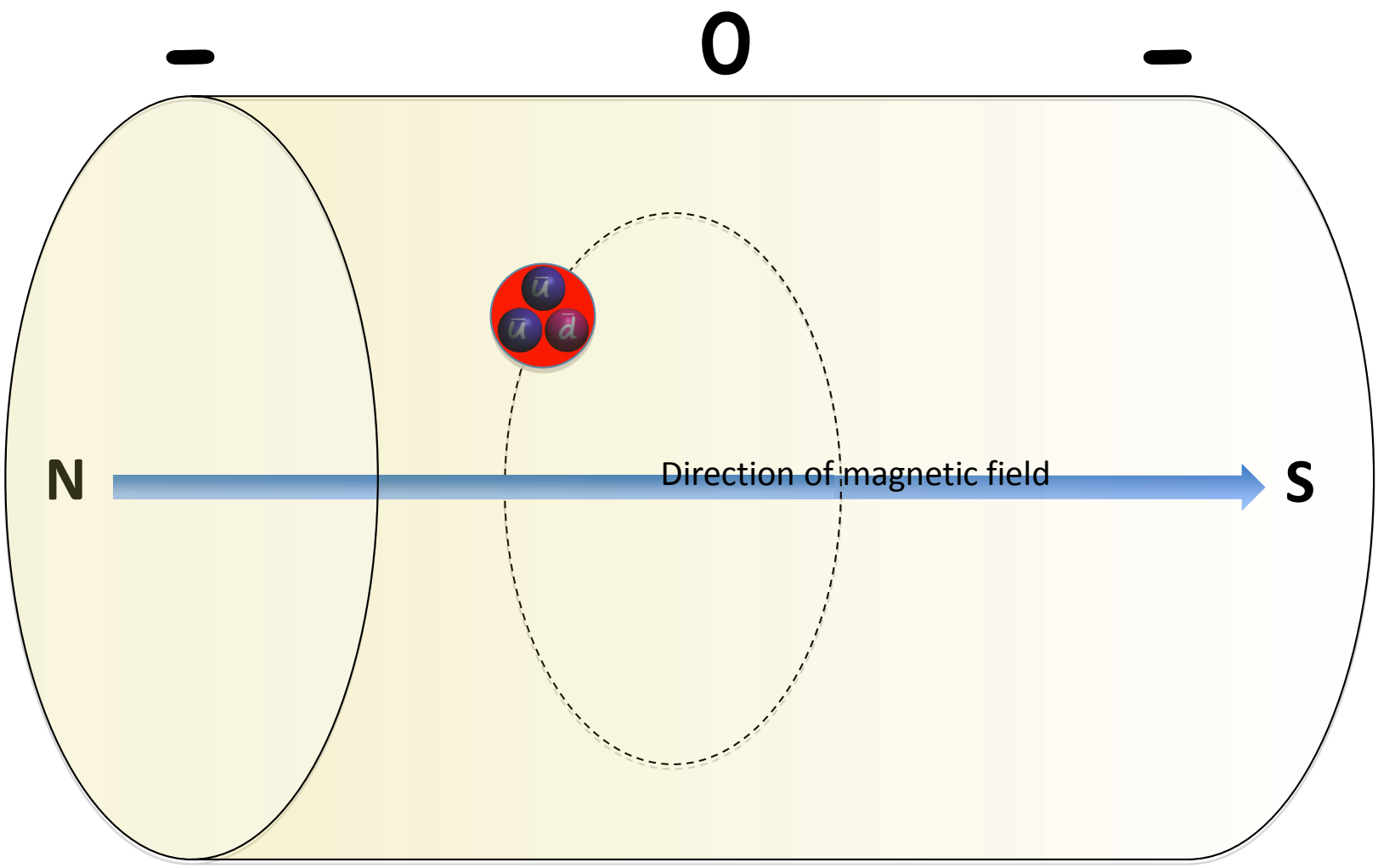
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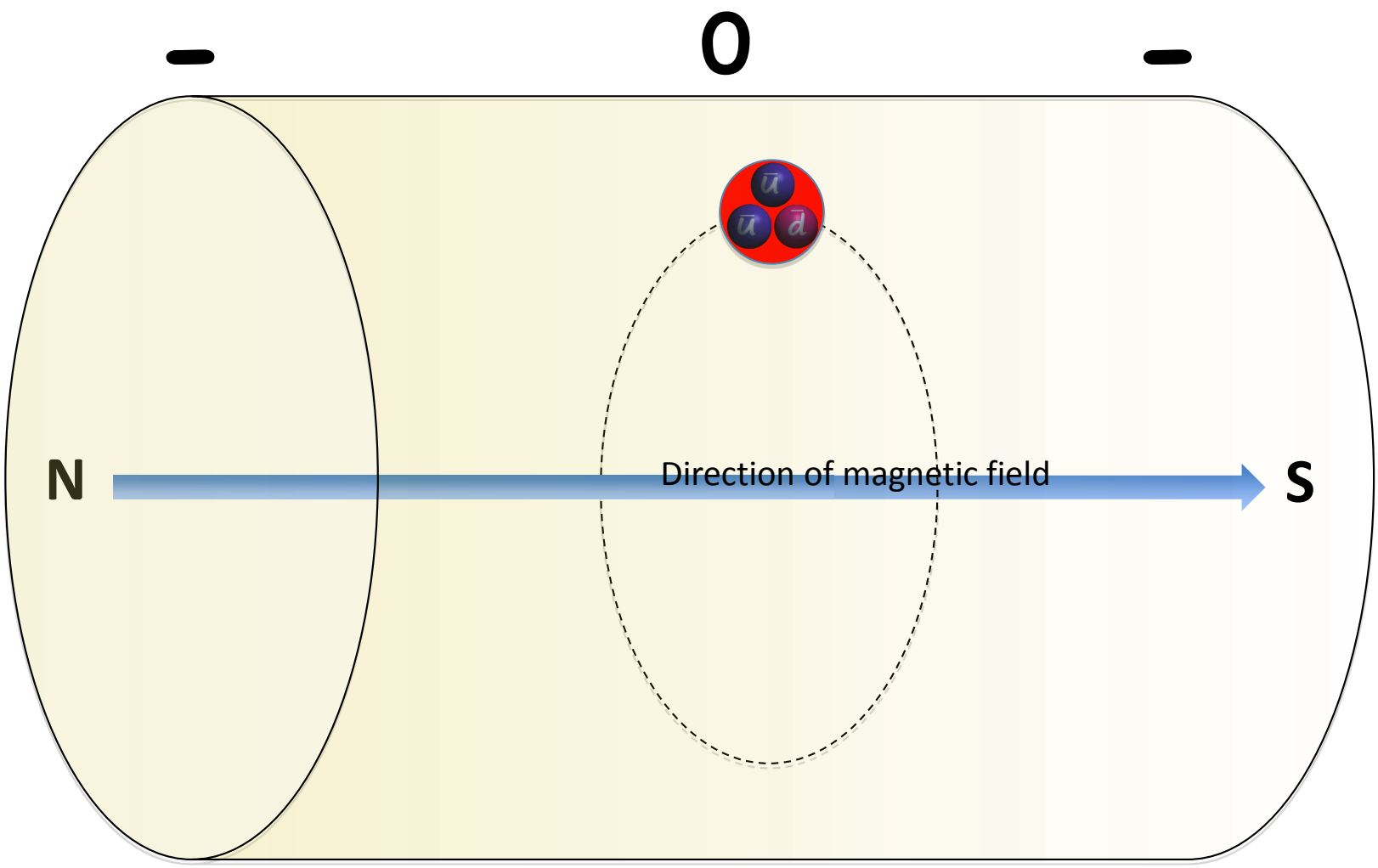
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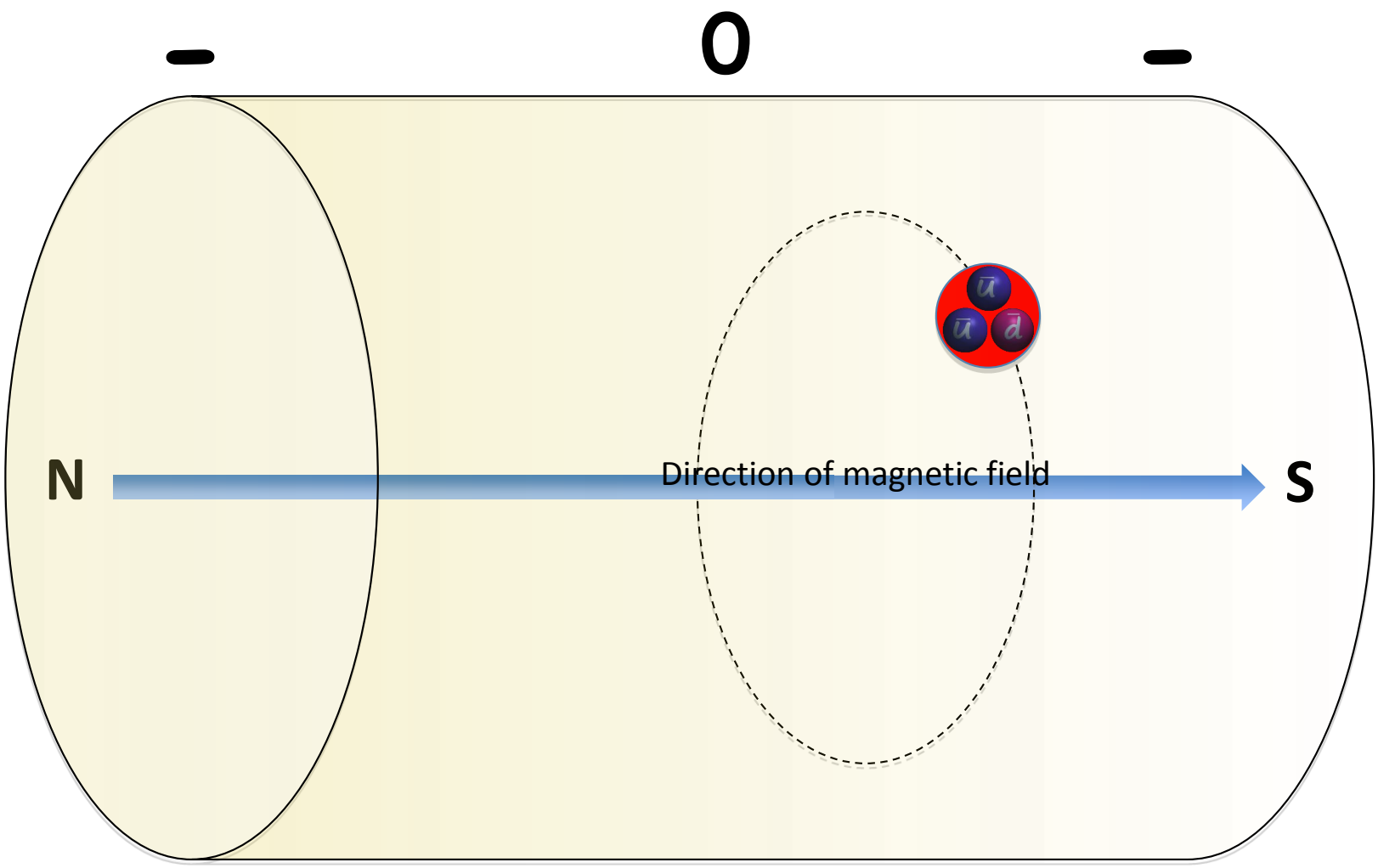
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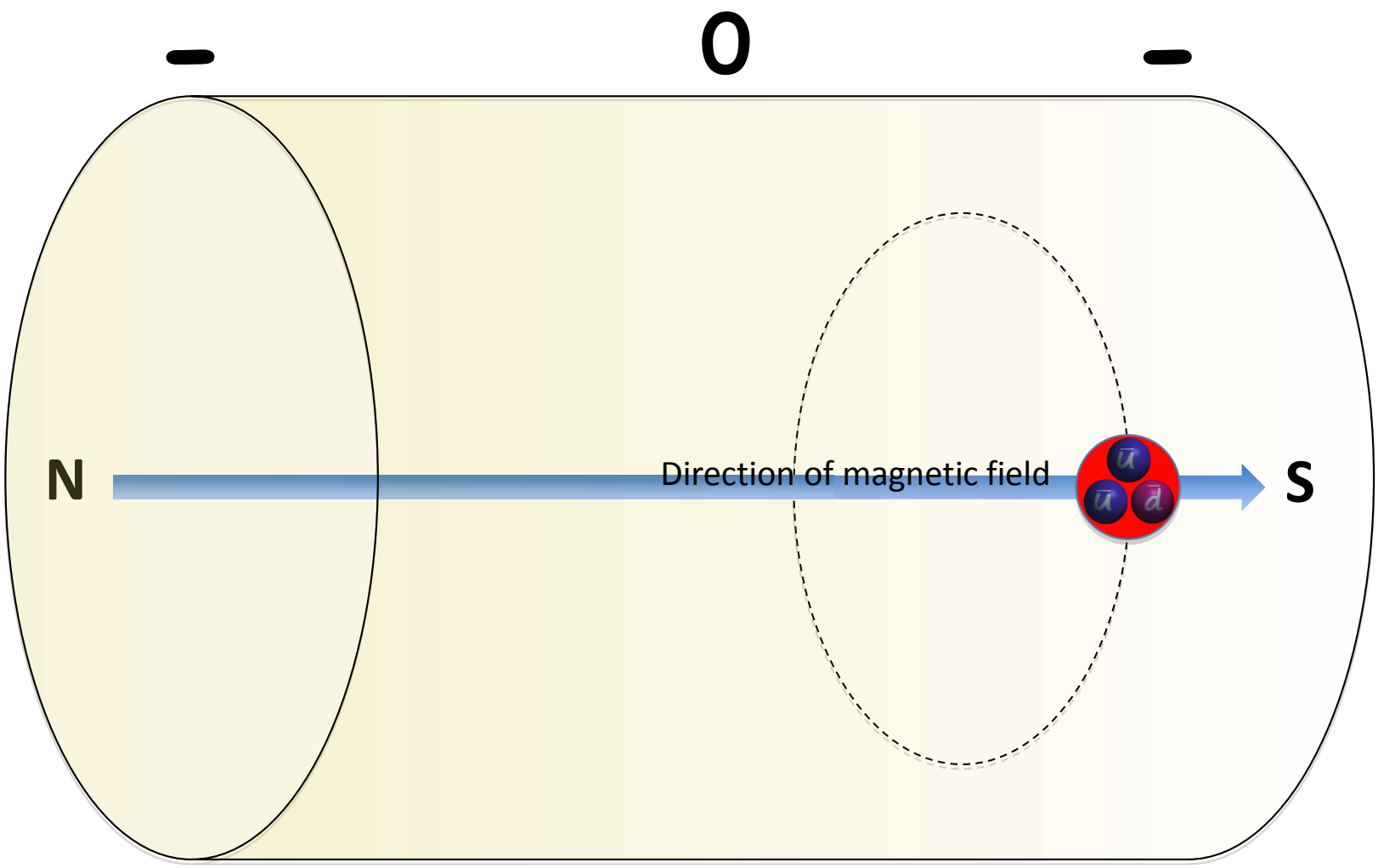
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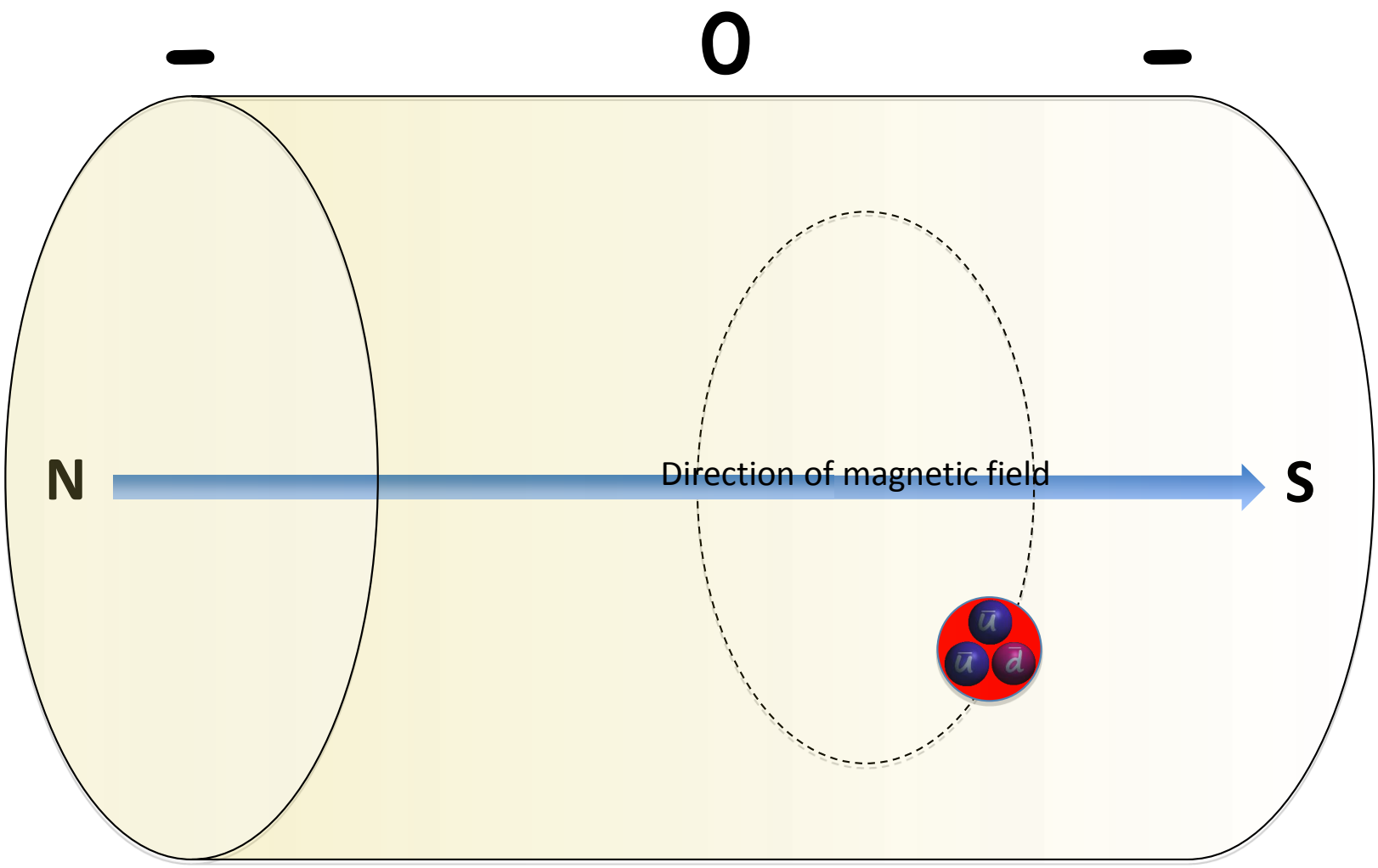
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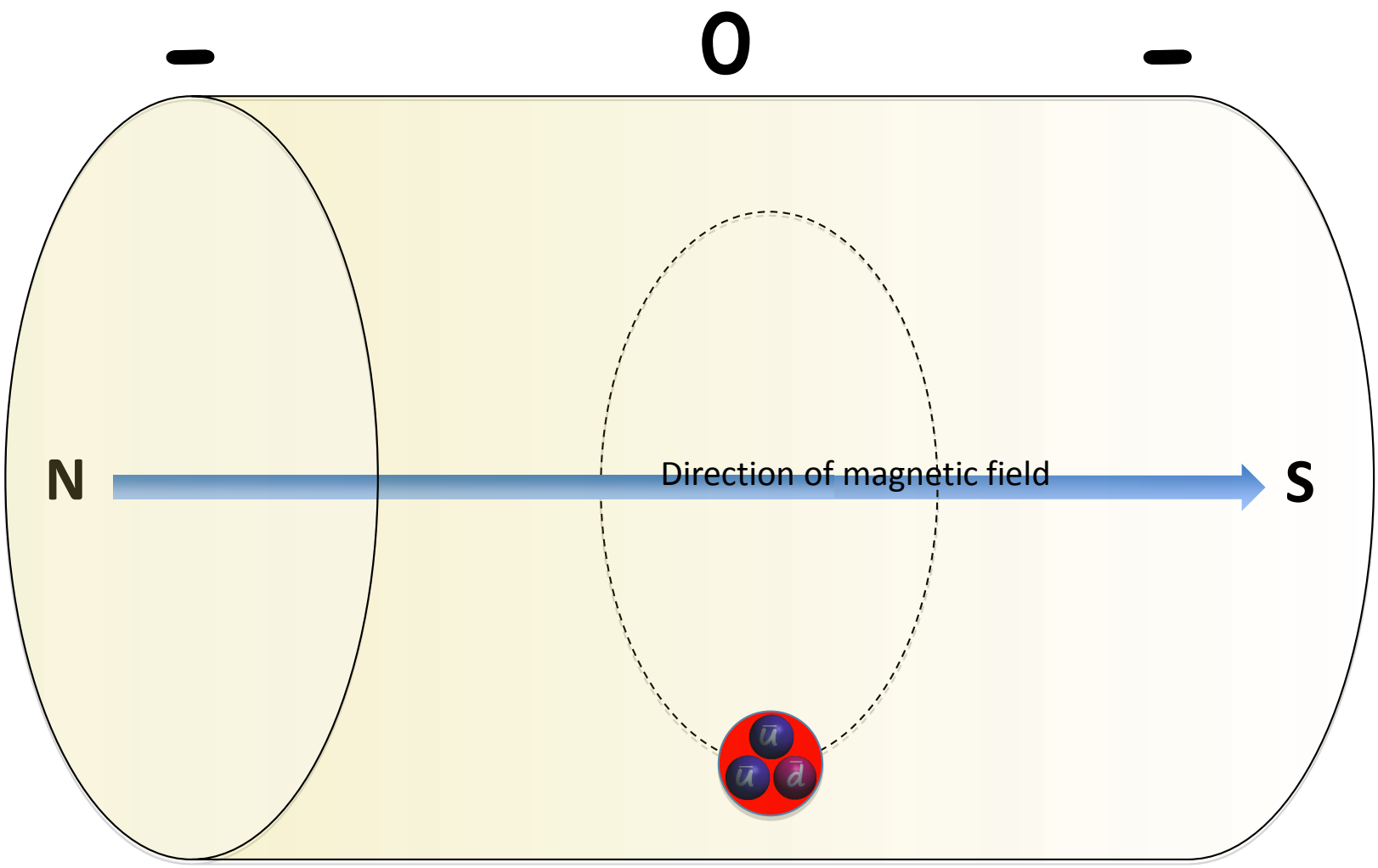
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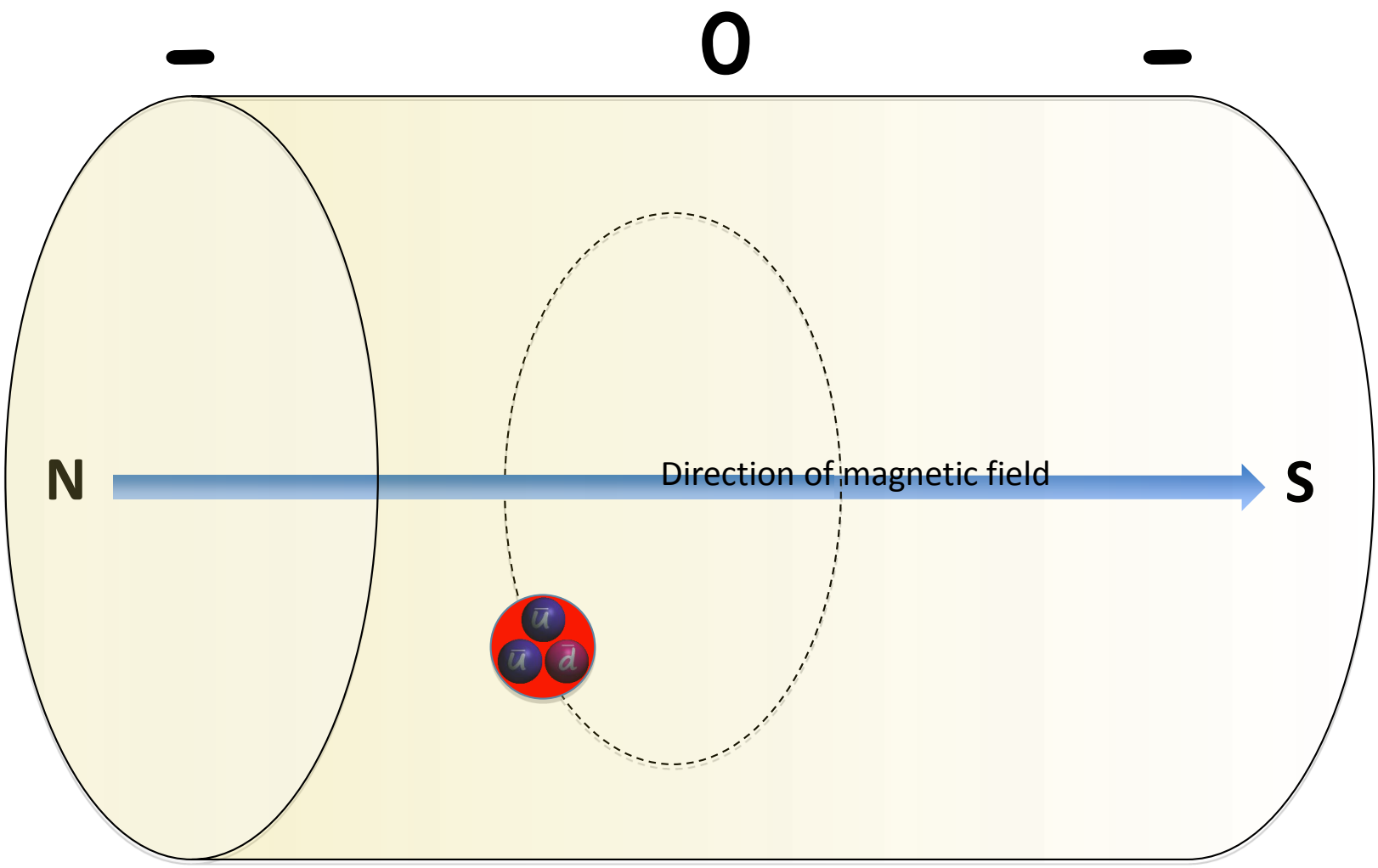
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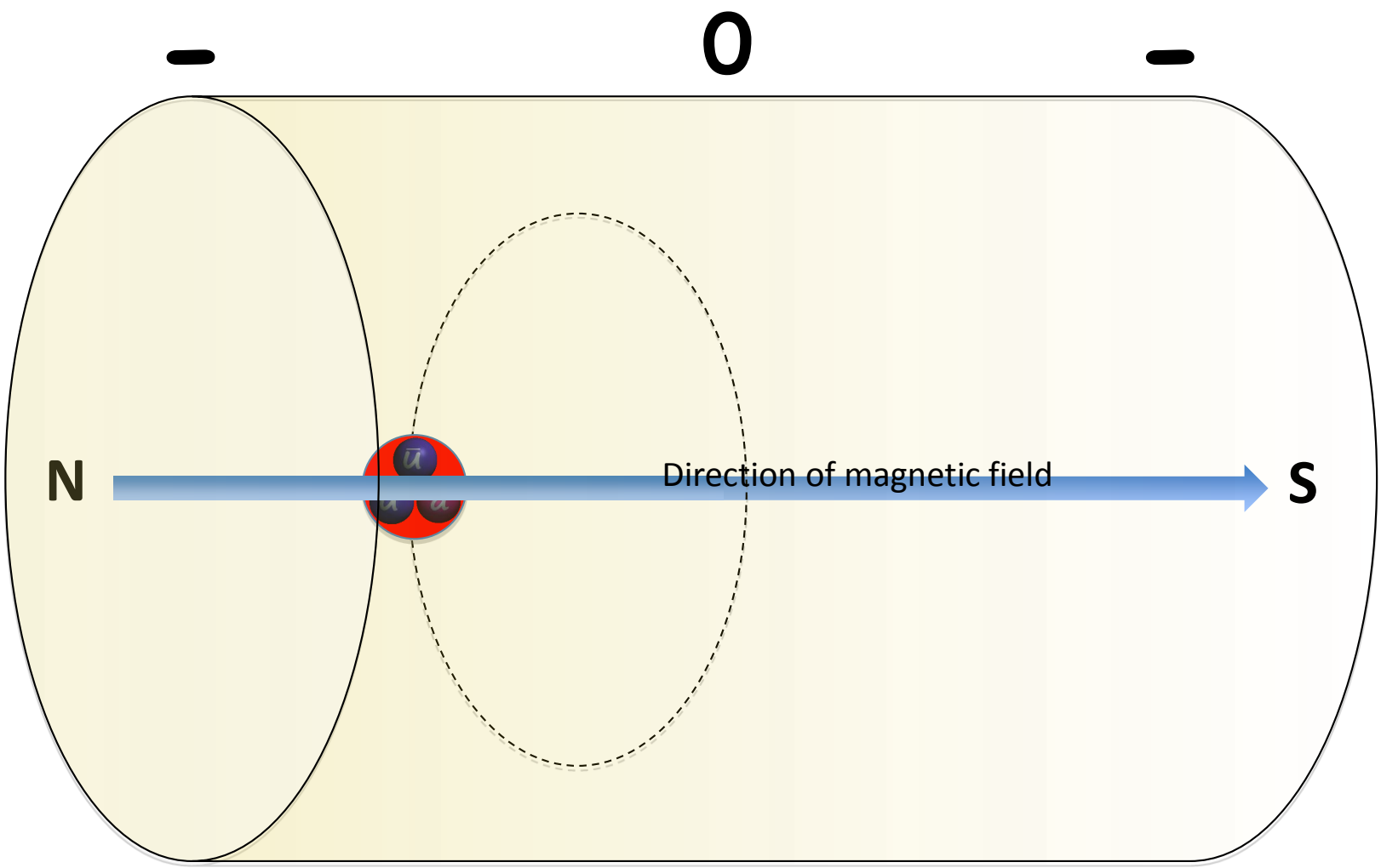
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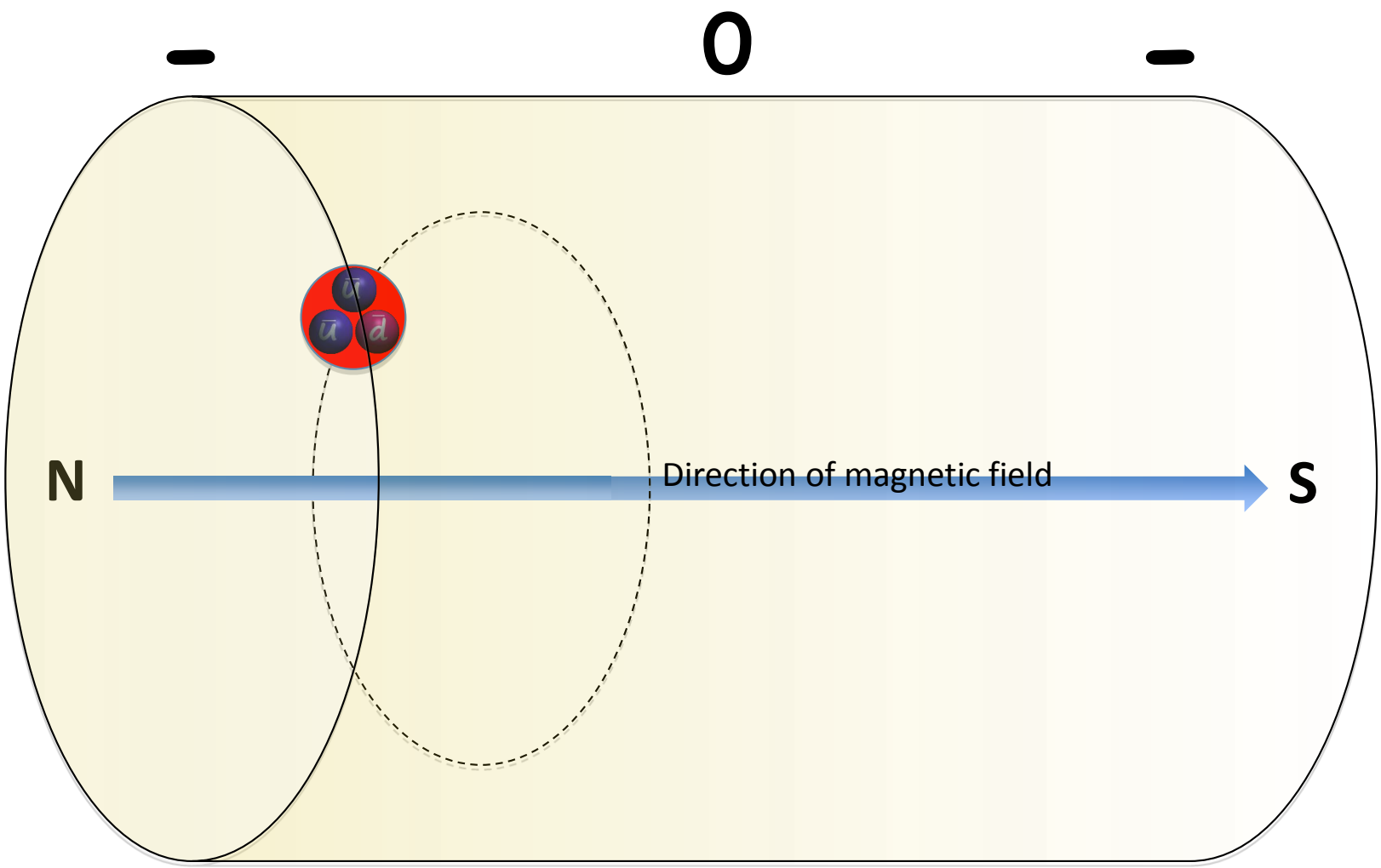
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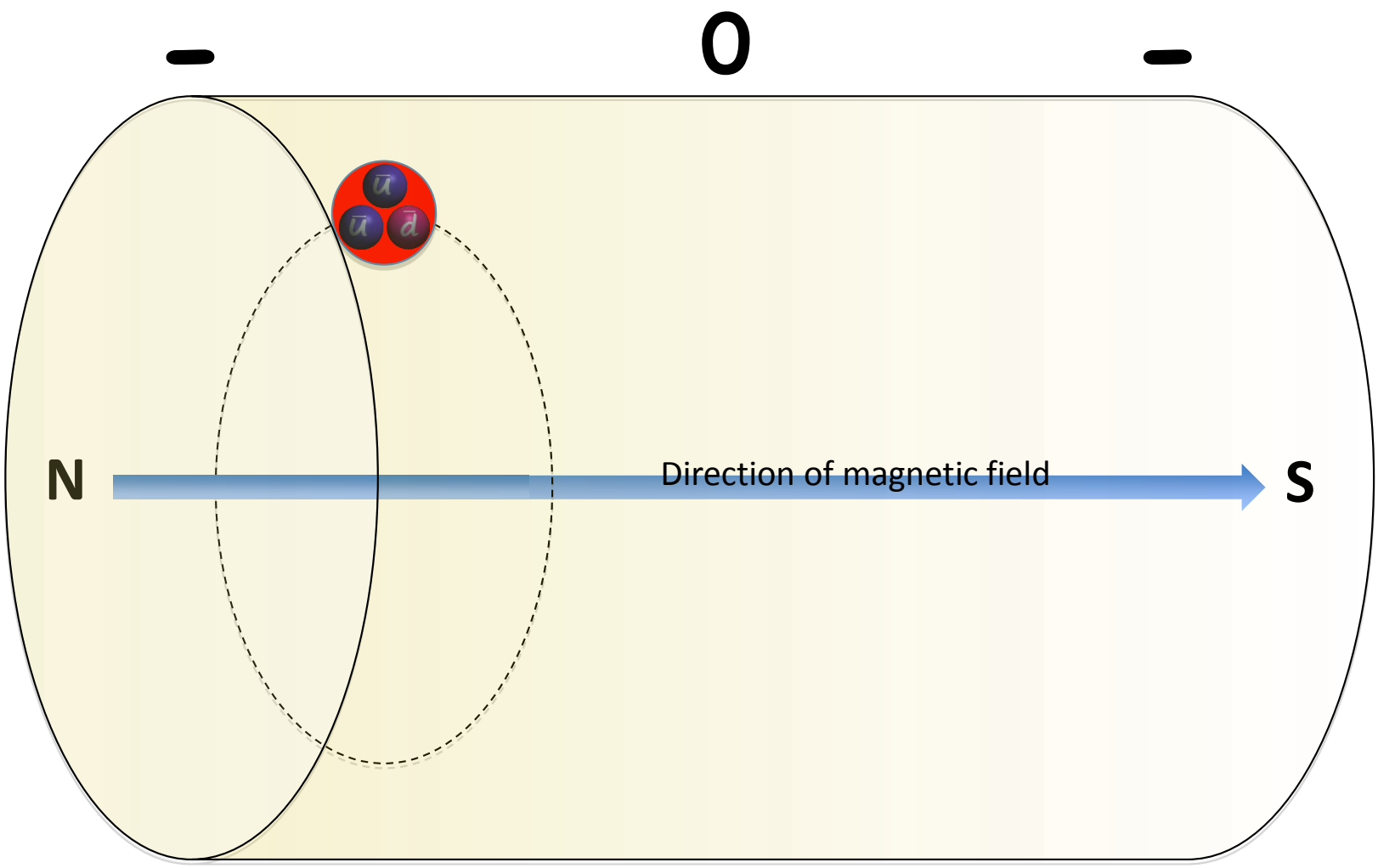
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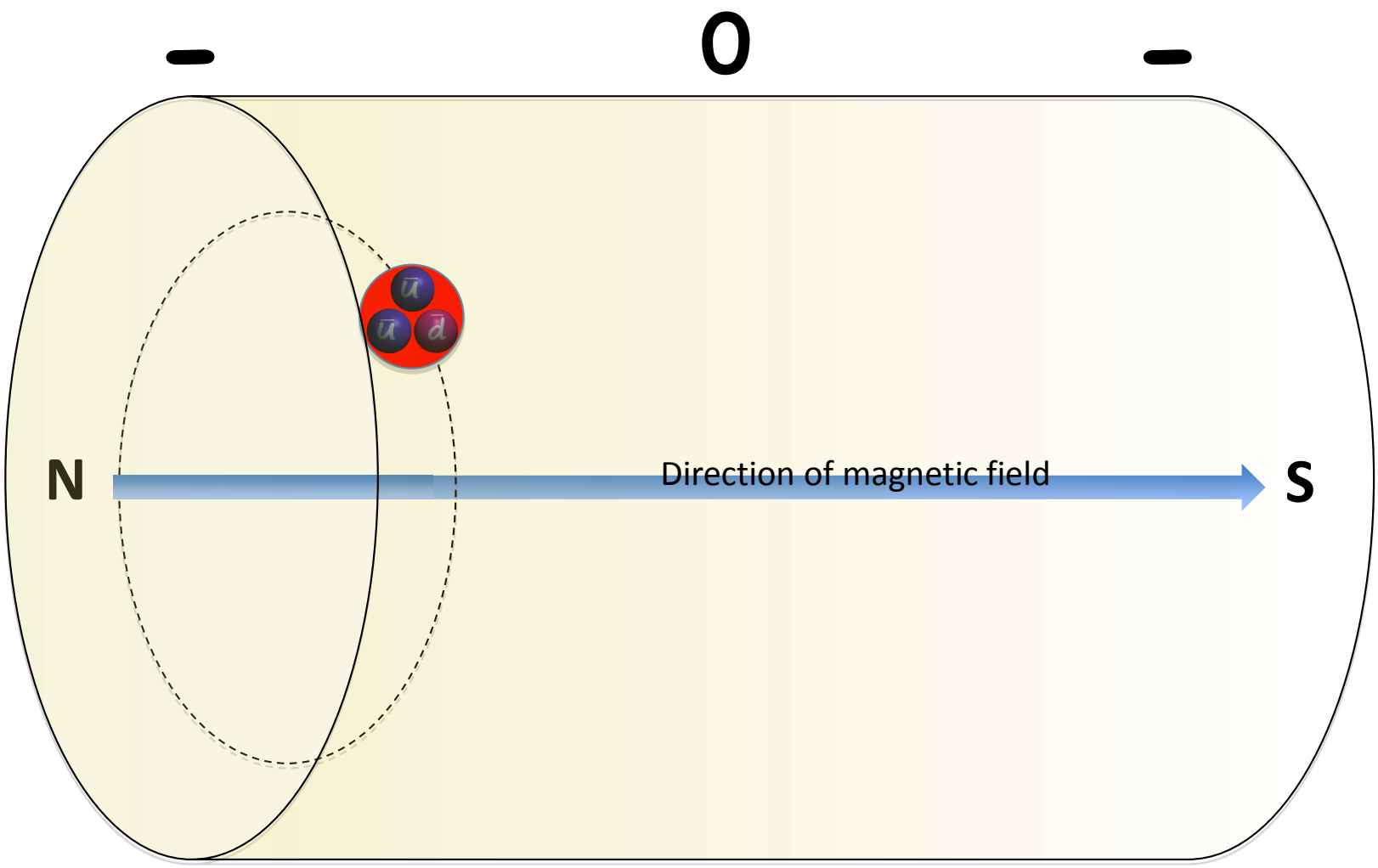
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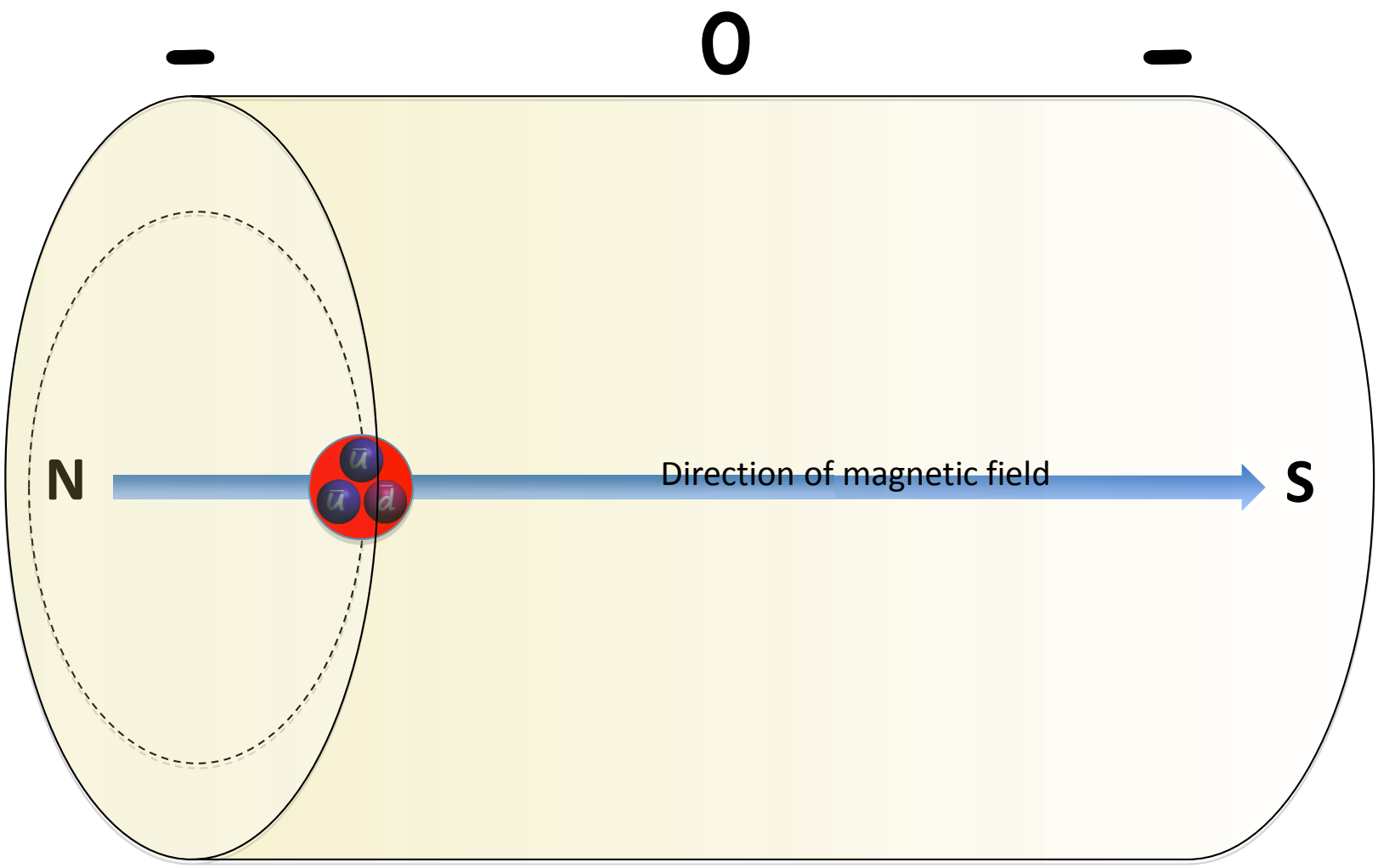
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Positrons can also be trapped in this manner.

As an exercise, think about how you would set up a similar trap in order to contain positrons.

What changes would be necessary compared to the trap used for the antiprotons?

When a charged antiproton is combined with a positron,
the neutral antihydrogen atom is no longer confined
by the fields of the Penning trap.
Alas, the anti-atom is then lost.

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the neutral antihydrogen atom is no longer confined
by the fields of the Penning trap.
Alas, the anti-atom is then lost.

If you would like to know more about how experiments being performed at CERN are trying to solve the antihydrogen containment problem, have a look at the following websites:

http://cerncourier.com/cws/article/cern/30577

http://public.web.cern.ch/public/en/Research/ALPHA-en.html

http://public.web.cern.ch/public/en/Research/ATRAP-en.html