

## Frequently Asked Questions Answered Dec 2020

**Question:** I read that there are hundreds of quarks in a nucleon, and that their extreme fast relativistic speed of these quarks makes up a large percentage of the mass of the proton. And that the extremely large binding energy of the chromodynamic force inside the nucleons also contributes to the overall mass of the proton. Is this right?

**Answer:**  
NO.

Unfortunately, there is much confusion and misinformation about what makes up the mass of a proton and neutron. There is also confusion and misinformation about the number of quarks inside a nucleon. One of the biggest sources of confusion are the sign errors made when accounting for the energy in the proton.

Here is an example of what you might have read concerning the new proton models:

In quantum chromodynamics, the modern theory of the nuclear force, most of the mass of protons and neutrons is explained by special relativity. The mass of a proton is about 80–100 times greater than the sum of the rest masses of the quarks that make it up, while the gluons have zero rest mass. The extra energy of the quarks and gluons in a region within a proton, as compared to the rest energy of the quarks alone in the QCD vacuum, accounts for almost 99% of the mass. The rest mass of a proton is, thus, the invariant mass of the system of moving quarks and gluons that make up the particle, and, in such systems, even the energy of massless particles is still measured as part of the rest mass of the system.

But before we go any further, let's address the questions of what is a gluon? A gluon is a massless particle that bounces back and forth between the quarks, and by doing this, it "glues" the quarks together, binding them inside the proton. The force of this gluon particle field is not like the force of gravity, where the further away you get from a large gravitational mass, the less the force. Rather the gluon force is like the force of a stretchy spring--the more you stretch it, the more it pulls back.

They are not saying that the massless gluons contribute to the mass of the proton. Gluons are massless, and they stay that way. However, gluons have a gluon particle field, and that field has energy. Let us continue to read what they say next about the gluon field.

Two terms are used in referring to the mass of the quarks that make up protons: *current quark mass* refers to the mass of a quark by itself, while *constituent quark mass* refers to the current quark mass plus the mass of the gluon particle field surrounding the quark.

Here they are saying that there are two components that make up the remaining 99% of the mass of the proton:

1. The "current quark mass" is the relativistic mass increase of the quarks as they vibrate around inside the proton at relativistic speeds.
2. The "gluon particle field", is the mass derived from the binding energy created by the gluons. Those massless gluons create a binding energy, and that binding energy has a mass.
3. The constituent quark mass is the sum of those two.

HOWEVER, there is a sign error in this calculation. The gluon binding energy, or binding mass if you will, must be subtracted from the mass of the quarks. Not added. This sign error creates a big problem with what they are saying.

Let us continue to read more about what these new proton models are saying.

As noted, most of a proton's mass comes from the gluons that bind the current quarks together, rather than from the quarks themselves. While gluons are inherently massless, they possess energy—to be more specific, quantum chromodynamics binding energy (QCBE)—and it is this that contributes so greatly to the overall mass of protons (see mass in special relativity). A proton has a mass of approximately  $938 \text{ MeV}/c^2$ , of which the rest mass of its three valence quarks contributes only about  $9.4 \text{ MeV}/c^2$ ; much of the remainder can be attributed to the gluons' QCBE.

The quantum chromodynamics binding energy, abbreviated as QCBE, is the binding energy that holds the quarks in the proton. Unfortunately, as I said, there is a sign error here, which I will discuss next. But here is one more quote about the new models for the protons, to again illustrate the misconceived concepts of these new proton models:

Most of the mass of hadrons is actually QCD binding energy, through mass-energy equivalence. This phenomenon is related to chiral symmetry breaking. In the case of nucleons – protons and neutrons – QCD binding energy forms about 99% of the nucleon's mass. That is, assuming that the kinetic energy of the hadron's constituents moving at near the speed of light, which contributes greatly to the hadron mass, is also part of QCD binding energy.

Regardless of what force we may be discussing—electromagnetic, chromodynamic, nucleon-nucleon, weak nuclear, gravity, or some new weird force that hasn't been discovered yet—if two or more particles are bound together by a force, then the binding energy of that force is subtracted from the sum of the energies of the constituent particles. This subtraction of energy that I refer to here is due to the laws of thermodynamics--specifically, conservation of energy. This subtraction of the binding energy is a rule that is independent of what force you might be talking about. Conservation of energy, and the laws of thermodynamics, cannot be violated, not even by invoking the complex mathematics of quantum physics. It cannot be violated. Period.

The binding energy that occurs as a result of any type of stable bond will put the overall configuration of particles into a lower energy state than the total energy of the individual isolated constituent particles. When particles are bonded together, they are in a lower energy state than when they are separated and isolated.

The binding energy is defined to be positive. However, this binding energy is subtracted from the energy of the unbound constituent parts. Thus, the energy of the bound collection of particles is lower than the energy of the constituent parts. Similarly, the mass of the bound collection of particles is lower than the mass of the constituent parts. The binding mass is not added to the mass of the constituent particles, rather it is subtracted from them. And this is true regardless of the nature force that is holding them together.

For example, consider a moon and large rock, both floating in space, isolated from each other. The binding energy between them is zero. They both have mass and some kinetic energy, and this gives the both moon and rock some energy, let's call that  $E_{\text{moon}}$  and  $E_{\text{rock}}$ . By using the

mass-energy equivalence, we know that the mass of the moon, which includes its kinetic energy, is  $M_{\text{moon}} = E_{\text{moon}}/c^2$ , and similarly,  $M_{\text{rock}} = E_{\text{rock}}/c^2$ . If the rock should wander close enough to the moon, such that it then feels its gravitational field, there will then be a gravitational force on that rock to move the moon and rock closer to each other as a result of this gravitational force. When they do so, they will thereby gain some kinetic energy. The instant before the moon and rock crash into each other, they will have acquired quite a bit of kinetic energy due to the gravitational force. When the rock and moon crash into each other, there will be a release of heat and light caused by the explosion of the crash. In other words, there is energy that is released into space. The rock and the moon will be now bonded to each other by a gravitational bond. When the rock hits the moon, there is a quantity of energy that is released into space as light and heat, call it  $E_{\text{released}}$ .

Throughout this process, the total mass/energy is always conserved. Therefore, there is a difference between the masses of the isolated moon and rock as compared to the masses of the bound moon and rock. This mass difference is the mass of the energy that was released into space as heat and light. As a result, the total mass of the moon and rock has decreased by the amount:  $M_{\text{decrease}} = E_{\text{released}}/c^2$ . As a result of their gravitational bond, the moon and the rock are now in a lower energy state. In other words, energy was released when they collided, and because of the released energy going into space, the moon and rock are now at a lower energy. And, correspondingly, they have less mass. That released energy is equivalent to the binding energy that holds the moon and rock together. In other words, the binding energy between the moon and the rock is equivalent to the released energy,  $E_{\text{released}} = E_{\text{binding}}$ . And that binding energy (or if you will the binding mass) is subtracted from the mass of the moon and rock before they collided. The rock and the moon are at a lower energy, and at a lower mass, than they were initially. Conservation of Energy. Thermodynamics. Cannot be violated.

Now if that rock were to lift off the surface of the moon and then fly out into space, some sort of external energy would be required to do that; some sort of “work” would have to be done on the rock in order to separate it from the moon. That externally applied work must be equal to or greater than the binding energy,  $E_{\text{work required}} \geq E_{\text{released}}$ . As always, for a process like this, mass-energy is always conserved.

Let me give a second example. Consider a proton and a neutron, isolated from each other, and there is no binding energy between them. If they get near enough to each other, they will bond, via the nucleon-nucleon force, to form  ${}^2\text{H}$ . This force is not like the gravitational field, nor is it like a stretchy spring, but rather it is like a snap. If they touch each other, they snap together, forming a strong bond. And when the proton and neutron bond, they released energy into the environment in the form of gamma radiation. For a neutron and proton forming  ${}^2\text{H}$ , this amount of released energy is 2.224 MeV.  $E_{\text{released}} = 2.224 \text{ MeV}$ . There is a binding energy between the neutron and proton of 2.224 MeV keeping them together,  $E_{\text{binding}} = E_{\text{released}} = 2.224 \text{ MeV}$ . Mass-energy is always conserved.

It would require 2.224 MeV or more of externally applied work to pull them apart, supplied by an external force. In other words,  $E_{\text{work required}} \geq E_{\text{binding}} = E_{\text{released}} = 2.224 \text{ MeV}$ . Because of the 2.224 MeV of released energy when the neutron and proton came together, the mass of the  ${}^2\text{H}$  is now less than the previous  $M_{\text{proton}} + M_{\text{neutron}}$ , by the amount of  $2.224 \text{ MeV}/c^2$ . Energy is

conserved, and the mass of the  ${}^2\text{H}$  is less than the masses of the isolated neutron and proton. Conservation of Energy. Thermodynamics. Cannot be violated.

Let me give a third example. A few instants after the Big Bang, three isolated quarks—two with a mass of .214% of the proton and one with a mass of 0.510% of the proton—come together and they bond. The quarks are now stuck inside the proton and it would require a very large amount of externally applied energy to release them. This is simple conservation of energy. If it requires a certain amount of energy, or work, to unbind the quarks, then the mass of the three initial quarks is decreased by that same amount of energy. Compared to the initial mass of the unbound quarks, the net mass of the three bound quarks is less.

It doesn't matter if that chromodynamic force is caused by massless virtual gluons flying around inside the proton, it is still incorrect to assume that these massless virtual gluons create a binding energy that adds to the mass of the proton. It doesn't matter how the force is generated--by fields or by gluons or by photons. If the proton is stable, the binding energy is subtracted from the mass of the three constituent quarks, and overall net mass is less than the rest mass of the three isolated quarks. Conservation of Energy. Thermodynamics. Cannot be violated.

Quantum physics can not to claim that since there is quantum "uncertainty", that conservation of energy can be violated. Quantum uncertainty can only violate conservation of energy for a very short amount of time, and then it has to give back any energy it took. Yes, what I said here is right--quantum uncertainty still has to abide by conservation of energy. Thus, it cannot be claimed that quantum uncertainty is allowed to forever make the proton more massive, in violation of conservation of energy.

Quantum forces or not, it doesn't matter. There is a decrease in the overall total energy of the bound configuration of particles, and that is because energy is released into the external environment. And an externally applied amount of work is required to separate them. Since mass-energy is always conserved, there is a decrease in the mass of the collection of bound particles. Quantum or not, this is a fact of thermodynamics and energy conservation.

How does this relate to the new models about protons that you read about?

If there are three isolated quarks, at rest, and the total sum of their isolated rest masses is only 1% of the mass of the proton, then we cannot use binding energy to increase the mass of the proton. Since these quarks are bound together inside a nucleon, held together by the extremely strong binding energy of the chromodynamic force, the resulting collection of three quarks is less massive than the mass of the three isolated quarks. Not more massive.

Unfortunately the new proton models are adding the binding energy rather than subtracting it. They are saying that this binding energy increases the mass of the proton, such that a significant portion of the proton mass is due to binding energy. However, as conservation of energy insists, binding energy is subtracted, not added. And the corresponding binding mass is subtracted, not added. That is the sign error I mentioned earlier. These models may try to claim that because it is quantum physics, and there is a lot of complex mathematics involved, and there is quantum uncertainty, and the chromodynamic force is different from other forces, and there are gluons,

and because of all this complicated quantum theory, that they are therefore allowed to violate conservation of energy. No. Quantum forces or not, it doesn't matter. There is a sign error in their model.

Thus, the mass of the proton is not coming from the binding energy of the chromodynamic force.

Another idea for adding mass to the proton is to add more non-valence quarks into the proton, hundreds of them, in fact. However, in order to keep the net electric charge at zero, they must be added in three's, by adding two down quarks and one up quarks. But they also have to keep the spins of the non-valence quarks at a net zero, so the quarks must be added in six's. In other words, three quarks to give a net charge of zero and a spin of  $\frac{1}{2}$ , and three more quarks to add a spin of  $-\frac{1}{2}$ , to get the net spin of the valence quarks to be zero. So additional non-valence quarks can only be added in groups of six.

The problem is that every one of these additional hundred or so quarks violates Pauli exclusion principle. This, however, is a fact that is conveniently ignored by the new proton models.

All of these hundreds of quarks also violate the Copenhagen Interpretation of the Heisenberg Uncertainty Principle. Again, this violation is also not something the new proton models tend to mention. Thus, the addition of hundreds of non-valence quarks into the proton now violates two of the foundational stanchions of quantum physics.

Removing the violation of the Pauli Exclusion Principle is easy, we simply say there are more than three colors in the proton. Problem is resolved. However, in order to fit within the confines of the Copenhagen Interpretation of the Heisenberg Uncertainty Principle, doing the math, we find that each quark must be 12.4% of the mass of the proton, or more. So we inflate the mass of the quarks relativistically, and then we can add 5 more quarks to get 8 quarks total inside the proton. And we conveniently add five more colors, for the Pauli Exclusion Principle. Now all the eight quarks just barely fit into the constraints of the Uncertainty Principle. But recall, we must add these non-valence quarks in groups of six--not five, not four, not three. So if we add six more quarks instead of five, either we're over budget for the mass of the proton, or we violate the Heisenberg Uncertainty Principle. So this doesn't work at all. Not to mention that we would have to rewrite the entire chromodynamic theory to add more colors. Let's just stick with three quarks and three colors, so we don't have to re-write chromodynamics.

Another idea is to make the three quarks vibrate super fast, such that they inflate their mass relativistically and become much more massive, enough to account for the 99% of the missing proton mass. This super fast speed increases the mass of the quarks so much that the Copenhagen Interpretation of the Heisenberg Uncertainty Principle is no longer violated. Good.

However, if we want this relativistic mass to be 99% of the mass of the proton, then this mass increase must be a factor of 99 times more than their rest mass. The problem is, in order to get this much relativistic mass, they need to go 0.99995 times the speed of light. And if they are going that fast, they would instantly explode from the proton. In other words, the added kinetic energy needed to get the relativistic mass increase, and the inertia of their motion, will instantly hurl them out of the proton. Unless the binding energy is stronger than this inertia.

Thus, in order to prevent the quarks from exploding out of the proton, we need a binding energy that is stronger than this relativistic kinetic energy. In other words, the relativistic kinetic energy is in direct conflict with the binding energy. Here is yet another sign error on the part of these new proton models.

These new models of the proton are trying to say, quite erroneously, that this relativistic kinetic energy contributes to the binding energy. No, that is absolutely incorrect. This kinetic energy opposes the binding energy, rather than contributes to it. In order for the proton to be stable with quarks vibrating back and forth inside it at relativistic speeds, the binding energy of the chromodynamic force would have to be stronger than the relativistic mass increase. So if we use relativistic speeds to increase the mass of the quarks by a factor of 99, then in order for the proton to be stable, the binding energy must reduce that mass by at least that much.

The relativistic kinetic energy does not contribute to the binding energy, rather it competes with binding energy in a tug-of-war. And if the quarks are to be bound inside the proton, then the binding energy has to be more than their kinetic energy. Conservation of energy insists that if the proton is to be stable, then the relativistic mass increase due to kinetic energy cannot be more than the mass decrease of the binding energy. In other words, the mass of the bound three constituent quarks must have a overall net decrease--a decrease which is caused by the binding energy being greater than the kinetic energy. Said another way, the net mass of the three quarks inside a proton cannot be increased by kinetic energy more than it is decreased by the binding energy--if we want a stable proton.

Hence, we are back to square one, and having 99% of the mass of the proton still unaccounted for.

There are sign errors in the new models of the proton, errors that are made when trying to account for the various energies and masses. Also there are violations of Thermodynamics, Energy Conservation, Pauli Exclusion Principle, and the Heisenberg Uncertainty Principle. Thus, these new proton models are not very impressive at all. And they are definitely NOT correct.

References:

<https://en.wikipedia.org/wiki/Proton>

[https://en.wikipedia.org/wiki/Quantum\\_chromodynamics\\_binding\\_energy](https://en.wikipedia.org/wiki/Quantum_chromodynamics_binding_energy)