Classical Thinking: Why Does It Fail?

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1 Some Preliminary Words

One consequence of Einstein's relativity causes serious problems for most classical pictures of the subatomic world. Exactly how this consequence comes about is best covered in a session on relativity, and therefore will not be covered here. All we need is the consequence itself so that we can apply it: **Nothing, not even information, can travel faster than the speed of light.**

There is also one mathematical rule that comes into play quickly: **It is forbidden to divide by zero.** Dividing by smaller and smaller numbers leads to bigger and bigger ratios. (i.e. if you divide by 2, you get a bigger answer than if you divide by 3. Divide by 1/2, and it gets bigger yet. Divide by 1/1000, and it is like you just multiplied by 1000. The closer to 0 your divisor gets, the bigger your answer. If you divide by zero, you have just made the answer infinitely large.)[1]

It's also important to state that this first chapter is not about answering questions. Rather, it is about finding the right questions to ask to help us realize that we need to have some sort of bizarre looking theory to explain the seemingly mundane world we inhabit. The answers come later, often followed immediately by even more questions.

[1] Dividing by fractions is often hard to picture, frequently due to the verbiage used to establish division in elementary school. If we have 6 objects, and we divide by 3, we are often told to "divide them into three groups" or "divide them into groups of three." Though not wrong, this verbiage makes it unclear what we are doing when we divide by fractions. Think of "divide 6 by 3" as "these 6 objects represent 3 groups; how many are in a single group?" instead. We still naturally arrive at 2 objects per group. However, when dividing by fractions, "6 divided by 1/2" then becomes "these 6 objects represent half a group," and grasping that there are 12 items in a single complete group becomes much easier, and far more natural.

2 Classical Pictures

The classical picture of an atom presented in most public school systems is based on the solar system. Protons and neutrons are, somehow, stuck together in the middle like a sun, called a nucleus and perfectly spherical electrons orbit around this centre like planets through the electromagnetic forces. It's clean, it's familiar, it's easy to picture, and it's completely wrong.

2.1 Sphere Problems

Imagine that electrons, protons, and neutrons are, in fact, small spheres. In that model, one could take a handful of electrically neutral and indivisible particles[2] and line them up in a row, as with the beads in a Newton's cradle. Much like the Newton's cradle, you could smack one end and the particle on the other would move. With solid, structureless spheres, that leads to a conceptual problem.

Now imagine you had ten such particles in a row. They would all be identical, including their diameters. Now, let us examine the information transmitted in this process. When you push on the first particle in the line, the information about that push is immediately transmitted to the next particle it is contact with. (A structureless particle is an incompressible particle. Push it on the left, and the right side moves instantaneously.) How quickly is this information transmitted?

The speed of anything is the distance covered divided by the time elapsed. When you push the particle on one end of our line, information about this push is transmitted ten diameters down. So, the information travels a distance of 10 diameters. However, *this information travels instantaneously.* That means 0 time elapsed. The speed would be ten diameters divided by zero, and division by zero is forbidden. The speed would be infinitely high, and that's a whole lot faster than the speed of light.[3]

If nothing can travel faster than light, then we cannot use this picture of particles. Two options present themselves. In one possibility, the particles we are dealing would have to have some sort of internal structure. This works well enough for a storebought Newton's cradle, but not for quantum mechanics: at some point, we need to boil things down to the basic building blocks of matter,

[2] To most people, this means neutrons. These people would be wrong, but that's a topic for next week.

[3] The Newton's Cradle you can buy in a store doesn't have this problem because the balls are compressible, and because there is a time delay between hitting one end and the ball responding on the opposite end. The balls aren't *very* compressible, and the time delay is very small, but both effects are enough to get information transmission under the light speed limit.

and that means particles without structure. The other option is to get the physical distance traveled by the information down to 0 as well. Due to this, all indivisible particles, called *elementary* particles, would have to have zero volume. Only then does instantaneous information transfer become consistent with relativity.

That poses a new problem: if all matter is made up of particles that have no volume, then why does matter take up space at all? Why doesn't it all collapse to a point? How can particles bind together so consistently that we can define a specific density for a specific material, keep particles from falling together on each other, and also keep them from getting so far apart that the material collapses? Furthermore, why do we experience any kind of contact forces? Why can we feel a table instead of putting our hands through the table entirely? How do particles with no volume interact at all?

2.2 Interaction Problems

Orbits imply interactions. Planets are held in place through interactions involving gravity. When dealing with protons, neutrons, and electrons, gravity is not even remotely strong enough to hold the batch together. There is only one other force in nature that we observe at the macroscopic level, and that's the electromagnetic force. This seems to work for establishing orbits, as electrons and protons would be attracted to each other. Pick the right set of distance scales, and you would think this would work for building atoms out of the nucleus and the electrons.

There is a major and fundamental problem with this picture, too. What the heck holds the nucleus together? neutrons have no electric charge, so there seems to be no way to hold them in place. Protons would actually repel each other. As they would also be packed in tightly, the repulsion between protons should be much stronger than the attraction to electrons. The nucleus should, by classical understanding, tear itself asunder long before complex molecules could form. Clearly, complex molecules such as DNA not only exist but can remain stable for long periods of time, so there is a flaw in this model. We have to have at least one other force in play, and this force must greatly exceed the strength of the electromagnetic force trying to pull the nucleus apart. This leads to yet another problem: if there is at least one other force in nature that is significantly stronger than the electromagnetic force, then why haven't we seen it in the macroscopic world?

We have another problem with this model. Why is every nucleus made from protons and neutrons only? Why don't we ever have electrons in a nucleus as well, or instead of protons? Why can't an atom have electrons and neutrons in its nucleus and protons in orbit?

2.3 Nucleus Mass Problems

In 1932, James Chadwick discovered the neutron. He discovered that two nuclei with the same number of protons could still have different masses, and realized that a nucleus must contain more than one type of particle, one of which was electrically neutral. Classical thinking dictates that all particles of a given type are identical, and experiments bear that out: when studied in isolation, all protons have identical properties to all other protons, all neutrons are identical to all other neutrons, electrons to electrons, and so forth. Thus, if you measure the mass of the proton, and the mass of the neutron, you can then predict and calculate the masses of all combinations of protons and neutrons. (i.e. a nucleus composed of two protons and two neutrons would have a mass identical to the combined masses of two protons and two neutrons.) It's a simple idea, which follows from our natural instincts, and which one would expect from identical, indivisible particles combining in different ways.

Too bad it's wrong.

Experiments have shown that the total mass of a nucleus does *not* match the combined masses of its component parts. Now, one could propose some sort of glue that is holding the particles together, which would increase the combined mass. This would make sense, except the mass of a stable nucleus is *invariably* less than that of its component particles. Either the glue has a negative mass, or something entirely different is going on. To make matters worse, nuclei that have more mass than the particles they are made out of have a nasty habit of releasing energy, not mass, and then finding themselves with a lower mass as a result.

That leaves us with two problems: why does energy transmission change a particle's mass, and what is gluing these particles together to form nuclei?

2.4 Information Transmission Problems

We know of ways to transmit information without wires. Radio waves broadcast music and cellular traffic constantly. Wi-fi networks keep us connected to the Internet throughout homes and coffee shops worldwide. However, the methods we use all involve the input of energy, usually electrical power. That energy must come from somewhere; after all, classical physics dictates that energy is always conserved, meaning the sum total of all energy in the universe does not change. It may change form,[4] but the energy is always around here somewhere.

The same is true every time information is transmitted in all of its forms.

[4] One form energy can take is mass.

If we have an electron orbiting a nucleus, then that electron "knows" of an opposing electrical charge in the nucleus. In other words, information about that charge has been received. In order to manage that, energy needs to be transmitted away from one or the other. Where does that energy come from? How much energy does each particle have to transmit? How does the transmitted energy get replenished? It cannot balance in a direct exchange between the two particles; if that happened, that could only mean that *every* transmitted piece of energy is exactly balanced by an incoming piece of information. This, in turn, would imply that *every* transmitted piece of information reaches a destination. That is only guaranteed if the information is *only* transmitted towards particles ready to receive that information. In that case, then the transmitting particle would *already* "know" where to find the receiving particles. This creates circular logic: in order to transmit information between two particles while conserving energy, information about the two particles must already be known to both particles.

Nonetheless, information *does* get exchanged between particles, and yet violations of energy conservation have never been observed in an experiment. This seems to be a logical inconsistency that will need to be sorted out.

2.5 Particle Creation Problems

The final problem comes not from the observations of the very small particles in quantum mechanics, but in the observations of the very large cosmological entities. Early in the 20th Century, it was discovered that the Universe is expanding outwards in all directions. This implies that it was packed in together far more tightly in the past. The question is, how tightly? In a world of absolutes, where particles are immutable and indivisible, the particles also become invincible. Every massive particle that exists now has always existed and always will exist. This means that the entire Universe would have once been packed into a single, small space with such density that gravity could not be ignored. That much mass in one place could not have catalyzed a Big Bang to create the Universe. Thus, we could not have had all of the particles that exist today around at the time. So, what was there? How did it spark? How did all of these particles get created? The last question can be answered in the realm of quantum mechanics. Any scientific studies of the remaining questions belong in cosmology.

3 What Comes Next

Next week we answer the questions regarding the mass of a nucleus, and end up with more questions to ask.