Questions — PS 303 — Fall 2010

1. **If a muon hits a nitrogen atom what happens?**

   Lots of things can happen. The nitrogen atom is made of protons and neutrons (in the nucleus) and electrons. (The most common isotope of nitrogen is nitrogen-14, which has 7 protons, 7 neutrons, and of course, 7 electrons. It is 99.63% of all nitrogen on Earth.) The muon can act like a billiard ball, knocking the particles and breaking the atom apart. If it has enough energy, it can split the nucleus, although this is not so common with a light particle like a muon. For example, a muon has a rest energy of 105 MeV, and the typical muon discussed in class created by cosmic rays, with $\gamma = 30$, has an energy that is 30 times that, or 3.15 GeV. In principle, therefore, if the muon is annihilated in a reaction, it can "create" any other particle whose rest energy is less than 3.15 GeV (for example, a proton, whose rest energy is ≈ 1 GeV). Of course, momentum must also be conserved in any such reaction. It is therefore also possible that electrons can be created by such a collision, although it is more likely that the muon will decay into an electron (plus some neutrinos).

   Another interesting reaction is that of a neutron colliding with a nitrogen atom. (Neutrons are also commonly created by high energy cosmic rays.) The following nuclear reaction might occur

   $$n + {}^{14}\text{N} \rightarrow {}^{14}\text{C} + p,$$

   and the carbon-14 radioactively decays via

   $${}^{14}\text{C} \rightarrow {}^{14}\text{N} + e^- + \bar{\nu}_e.$$

   These two reactions represent the production and loss of carbon-14 in the environment, and its presence leads to the possibility of "carbon dating" objects that are no longer living.

   — David Roffman

2. **What is your opinion on String Theory?**

   I think string theory is a very beautiful, very mathematical theory, but it has yet to predict the outcome of any experiment. This means that so far it is not scientifically useful. In order to be scientifically useful a theory must make predictions that can be confirmed or denied by experiment. The goal of string theory is an attempt to marry quantum physics and gravity (i.e., general relativity). All other forces have been quantized, so this is one of the final steps toward a "theory of everything."

   Definition of string theory from Wikipedia:

   > String Theory is a developing theory in particle physics that attempts to reconcile quantum mechanics and general relativity. It's the first candidate for the theory of everything (TOE), a manner of describing the known fundamental forces and matter in a mathematically complete system. String theory basically posits that the electrons and quarks within an atom are not 0-dimensional objects, but rather 1-dimensional oscillating lines ("strings").

— Jessica Steinman

3. **What if an object was spinning at near relativistic speeds?**

   If a cylinder was rotating such that the surface was moving relativistically, the radius would remain the same length (i.e., not be Lorentz-contracted) because it is perpendicular to the motion. However the circumference would appear to be larger. Why? Because a meter stick on the edge parallel to the circumference would appear Lorentz-contracted, meaning one could fit more meter sticks around the edge. This would imply that

   $$C > 2\pi\, r.$$

   This result means that the space-time is represented by a non-Euclidean geometry, specifically a hyperbolic (or Lobachevskian[1]) geometry. This curious fact is known as "Ehrenfest's paradox," and is discussed in detail on the web site:

   `http://physics.ucr.edu/~wudka/Physics7/Notes_www/node93.html`

   — Ryan Harrington

4. **On CNN, it was noted the differences between the two isotopes of uranium. How do they enrich uranium?**

   The two isotopes of uranium are ^{238}U and ^{235}U. They each have 92 protons in the nucleus, but a different number of neutrons (146 and 143, respectively). Another difference is that ^{238}U has a half life of 4.468 billion years, and ^{235}U only has a half life of 704 million years (a bit less than 1 billion years). Due to this fact, out of all the uranium on Earth, only 0.72% of it is the ^{235}U isotope. When the Earth was created there was approximately the same amount of each, but ^{235}U decayed more rapidly, and hence there is less of it today. The reason that ^{235}U is used in weapons is because it is more fissionable than ^{238}U.[2]

   To enrich uranium, which means to separate out the less massive isotope, there are essentially three methods:

   (a) Centrifuge — Just spins repeatedly and the heavier matter is taken off at the end.

   (b) Diffusion — The heavier parts are caught on a membrane

   (c) Mass-Spectrometer — Uses a magnetic field to separate the two isotopes.

   All three methods were used in the Manhattan project, and the diffusion method was used for most of the weapon's uranium. However, currently new technology has allowed the centrifuge method to be the easiest, and it is what is used by North Korea, for example. What is left of the uranium is called "depleted" Uranium and is used in Kevlar and shielding.

   NOTE: Only the Hiroshima bomb (*Little Boy*) was a uranium bomb. Both the test at Trinity, New Mexico, and the Nagasaki bomb (*Fat Man*) were made of plutonium.

[1] Nikolai Ivanovich Lobachevsky, 1792-1856.

[2] The atom bombs used on Japan in World War II had uranium collected from Africa, specifically the Shinkolobwe mine in what was then the Belgian Congo.

SECOND NOTE: Reactor grade uranium requires that it be enriched so that about 3%-4% of it is ^{235}U. Nuclear weapons, on the other hand, work due to a chain reaction of nuclear fission events, which means that about 80% must be ^{235}U. This is called "highly enriched."

— Ty Clayton

5. **How is the physics behind 2012 wrong?**

   The movie postulates that neutrinos from the sun (specifically a solar flare) are heating up the Earth's core.

   Neutrinos are fundamental particles and interact only *weakly* with other particles since they have such a small mass and no electromagnetic charge, likewise no strong charge. They do interact via gravity which is in itself very weak. This leaves only the weak nuclear force, which, by definition, is weak. In fact, it would take a piece of lead 1 light year thick to stop a neutrino.

   How are neutrinos produced by the Sun? The main source is fusion reactions in the Sun's core, where H fuses into He with neutrinos as byproducts. The net reaction is

   $$4\text{H} \rightarrow \text{He} + 6\gamma + 2\nu_e,$$

   where γ signifies a photon. When they leave the solar surface, the photons illuminate the Earth. However, they get absorbed and re-emitted many times on their way from the core to the surface so that it can take, on average, about 100,000 years for them to make it out of the Sun. This means that if solar nuclear reactions turned off right now, we wouldn't know it for years. The neutrinos, on the other hand, pass right through the Sun and the Earth and don't interact at all, so there is no way for them to heat up the Earth's core, although there are a lot of them so they have a lot of energy.

   For the Sun to be as bright as it is, it requires that about 10^{38} of the above reactions occur every second. This means that 2×10^{38} neutrinos are produced each second, and they are emitted in all directions. At the distance of the Earth, about 6×10^{14} neutrinos pass through a square meter every second, which means that about 100,000,000,000 neutrinos pass through your thumbnail every second.

   The final answer is that billions of neutrinos pass through the Earth with no effect, and the theory in the 2012 movie can thus be considered incorrect.

   — Logan Dahle

6. **What would be the next step for physics if someone were to solve the problem of quantum gravity?**

   This is more of a philosophical question than a physics one. One does not really know what will happen with physics if someone were to solve this problem. There have been other times in the past when it was thought that all of physics was completely "solved." Most notably, in the late 1800s it was assumed that all that was left for physicists to do was to increase the accuracy of their measurements, but not learn any new physics. Then came the 20th century, and relativity and quantum mechanics, the subjects of this course.

There is no way to know what it is that is unknown. If you knew it was unknown, it wouldn't be unknown! However, in some sense we realize that the current best theoretical structure is incomplete. This is because we cannot describe events that occur on very short spatial scales or very large energy scales. For these, it appears (although we are not sure) that we need a quantum theory of gravity. The reason it looks like this will be necessary is that this technique (quantizing a classical field theory) has worked extremely well with quantum electrodynamics (QED), the most accurate physical theory that humans have invented. It has also worked well with quantum chromodynamics (QCD). We hope (pray?) that it will work well with "quantum gravito-dynamics."

Another reason that physicists suspect that our current picture is incomplete is that we don't know why any of the fundamental constants have the values that they do. These constants include G and c as well as the masses of the elementary particles (m_e, m_p, etc.). A quantum theory of gravity should (?) be able to predict these values. On the other hand, they may be completely free parameters, and the creator of a universe may have complete choice with regard to these parameters. We don't know....yet.

— Mike Sola

7. **What is the one electron universe theory?**

This theory posits that antiparticles (for example, the positron, or anti-electron) can be viewed as traveling backward in time. Therefore, when an electron and positron interact, that interaction can be thought of as the electron simply changing it's "direction." This would mean that the reason why all electrons have the same charge and same mass (i.e., they are indistinguishable) is because they are all the same electron! And the same goes for the positrons. Of course, this does not seem to be consistent with the fact that there are more electrons than positrons, but there have been (complicated) suggestions to get around this fact.

A very nice description of this theory can be found in Paul Davies's book *About Time*. In addition, Richard Feynman discusses this in his Nobel lecture here: `http://nobelprize.org/nobel_prizes/physics/laureates/1965/feynman-lecture.html` (search for "same electron"). To learn about the standard model of particle physics, with it's zoo of matter particles and anti-matter particles, a good place to start reading is here: `http://en.wikipedia.org/wiki/Quark`

— Amy Williams

8. **Why can't two objects occupy the same space at the same time?**

For example, when you place a water bottle on a table, why doesn't it fall through? Why can't you walk through walls?

Well, humans, and all other "solid" objects, are mostly empty space. The reason is that atoms, which make up humans, are mostly empty space. The radius of an atom's nucleus is on the order of 1 femtometer (10^{-15} m), compared to the size of the atom (i.e., the electron cloud surrounding the nucleus), which is roughly a half angstrom (0.5×10^{-10} m). This means that the nucleus is 20,000 times smaller than the atom.

However, two objects cannot occupy the same space because the electrons in the surfaces of the two objects repel each other due to the Coulomb force.

An example in which two objects *can* occupy the same space is during galactic collisions. In a galaxy, stars are much smaller than the average distance between them, so two galaxies can pass through each other without any of the stars "colliding." The stars are similar to atomic nuclei, which are also much smaller than the distance between them. However, stars do not have a large electron cloud that would repel the electron cloud surrounding other stars.

— Sam DeMarco

9. **Why does the rate of fission for Uranium increase when the neutrons move slower?**

   In addition to spontaneously breaking apart (which is rare) a uranium nucleus undergoes fission when free neutrons are fired at it. This in turn breaks apart the nucleus into several pieces (the total mass of the products is less than the mass of the initial particles) and the energy produced from this reaction can be used for many things like propulsion of a submarine. When the free neutrons are shot at the a U-235 nucleus, they are more likely to interact with the nucleus if they are moving slowly. The nucleus needs enough time to interact with the neutron, which means that fast neutrons will pass through the nucleus without breaking it apart. A slow neutron, on the other hand, will interact with the nucleus longer, and the nucleus essentially absorbs the neutron, which sets the nucleus oscillating like a drop of liquid. As the oscillations become more violent, the nucleus is split apart, usually resulting in two approximately equal parts, which of course are the nuclei of atoms.

   — Austin Kim

10. **Who won the 2010 Nobel Prize in Physics, and for what?**

    The Nobel Prize in Physics 2010 was awarded jointly to Andre Geim and Konstantin Novoselov "for groundbreaking experiments regarding the two-dimensional material graphene." See `http://nobelprize.org/nobel_prizes/physics/laureates/2010/`

    Graphene is a thin layer of carbon one atom thick. It's a great conductor, it's flexible, transparent, strong (for its size) and light. It is produced by peeling thin sheets off of graphite, the material in pencils. In fact, the reason why pencils write so well, is that it is fairly easy to rub off thin sections. In your pencil scratchings, therefore, there are probably pieces of graphene. Graphite itself is constructed of layers of carbon atoms in hexagonal (honeycomb) pattern, where the layers are only weakly bonded to each other.

    Possible future uses for graphene include touch screens, electronic sensors, and electronic components. However, it has not been produced in quantities large enough for commercial applications.

    — James Kendall

11. **How hard is it to contain plasma?**

It is essentially impossible to contain a plasma. A plasma is a collection of charged particles, i.e, and ionized gas. Fusion reactors contain plasma and utilize them to create exothermic fusion reactions. The idea behind fusion reactors is if you take two nuclei with relatively light masses and cause them to collide, if they "fuse" into a heavier nucleus there will be a substantial amount of energy released. However, these are charged particles. Before the nuclei can get close enough to become bound and release energy, they must overcome the repulsive Coulomb force. This repulsive Coulomb force makes it extremely hard to get these two particles close enough so that the strong nuclear force will allow them to form a single, heavier, nucleus. To increase the likelihood that the particles will fuse with each other, fusion reactors operate with extremely high densities, pressures, and temperatures. Unfortunately, the high temperature plasma wants to expand, and will ultimately be absorbed by the walls of any container built to confine it. (Even though it is high density for a plasma, it is still close to a vacuum, so usually no damage is inflicted on the walls of the container.)

In order to confine this extremely volatile substance, physicists have used what is called a "magnetic bottle." Quite literally, a bottle shape is constructed using magnetic field lines. The field lines are the furthest apart at the middle portion of the bottle, and at either end they converge, making the magnetic field much stronger at the ends of this "bottle." The plasma particles (charged particles, of course) spiral around the magnetic field lines, and when they reach the ends of the bottle, the get reflected to the other side and oscillate between the bottle ends. However, these lines do not completely seal off the end. That is to say, the value of B at the ends of the bottle is finite, and as a result, magnetic bottles always leak.

Another confinement method is to bend the magnetic field lines into a torus shape; such a machine is called a "tokamak." However, even though the plasma cannot escape from the ends (there are no ends), other problems are introduced by the torus shape, and ultimately confinement is one of the main obstacles to true plasma confinement (and hence fusion energy).

If you are interested in learning about these methods, consider taking EP 495C — Plasma Physics and Engineering — during the Spring 2011 semester.

— Anthony Bonds

12. **Since hydrogen is a stable atom, why does positronium decay?**

Positronium is a system of an electron orbiting its antiparticle, a positron, which exists for approximately 10^{-10} s before annihilating into 2 photons. This reaction is likely because when matter and antimatter interact the result is annihilation. Hydrogen atoms consist of protons and electrons which are not antiparticles of each other, so they are "stable" against annihilation. Protons and electrons can annihilate each other in the reaction

$$p + e^- \to n + \nu_e,$$

which is endothermic and requires more than 13.7 eV, the ground state energy of the electron, to occur. Hydrogen requires external energy to "decay" so it a stable atom.

The above reaction is similar to the neutron decay reaction $n \rightarrow p + e^- + \bar{\nu}_e$, which is exothermic and occurs naturally, with a half-life of 10 minutes.

NOTE: These two reactions can be obtained from each other by replacing each particle by its antiparticle when it is moved to the opposite side of the reaction.

— Rick Burges

13. **Where are the other dimensions that string theory predicts?** The extra dimensions that string theory predicts cannot be readily explained. The number of spacetime dimensions varies from 10 dimensions to 26 for the various string theories. Some scientists explain these dimensions as "rolled up" dimensions. This concept cannot be comprehended with the spatial recognition humans perceive. In truth, no answer can explain these extra dimensions in satisfactory terms, nor can the existence of these extra dimensions be verified experimentally. These extra dimensions seem to be a convenient way to make the mathematics work out.

    Therefore, why is string theory so popular if it has not yet predicted any experimental result? Currently, gravity is the only fundamental force that has not been described quantum mechanically. One possible reason is that it is the weakest of all the forces (strong, weak, and electromagnetic), and these other forces have been "quantized." String theory is one attempt to unify gravity (that is, general relativity) and quantum mechanics, and this accounts for its popularity. If string theory is successful, a byproduct may be a unification of all the fundamental forces, a"theory of everything."

    — Dean White

14. **What is the next step for space exploration?** The biggest concern is that we need to be able to survive. Radiation is a huge issue. Galactic cosmic rays can cause long term effects such as cancer, and the high energy emissions from solar flares can be immediately lethal. These are not a problem on Earth, or in low earth orbit (LEO) as we are protected by the Earths magnetic field and atmosphere.

    The most feasible next step to develop life support technologies would be to return to the moon. Unfortunately, sending manned spacecraft to the moon is a very expensive endeavor, so the cheaper, unmanned alternative is often preferred with space missions. The root concern for this debate is about how much society is willing to spend, i.e., how much we desire the ability to exist in space. Proponents for space travel may argue that it is a necessity for long term sustainability of human life, as the Earth is not infinitely renewable or a guaranteed safe environment (e.g., the sun will evolve over the long term) and subject to nuclear wars, which could cause widespread radiation (from sources such as Strontium-90). Regardless of how likely (or unlikely) these scenarios are, they don't obviate the need for further research and exploration.

    — Marcus Jackson