Where Traditional Physics Stops

We're about to move into the modern age of physics. In the early 1800's, scientists began examining the basis of matter, space, and time. Sometimes it gets very confusing, but the big idea is that Newton's physics describe about 90% of the way things work in the universe (mechanics). His ideas start to break down when you talk about ideas such as objects moving at the speed of light, the inside of atoms, extreme temperatures, and when the objects are huge (like galaxies interacting with each other).

Into the Atom

The original idea of atoms developed by Niels Bohr showed a structure based on various shells and a center area called the nucleus. The electrons were found in those shells while the protons and neutrons were found in the nucleus. There are other ways to look at the structure of atoms (you may have heard of "spdf"), but we're going to stick with the classic view for many of our discussions. This view of the structure of an atom was one of the foundations for modern physics.

Into the Universe

Albert Einstein also played a large part in modern physics. He developed formulas that described the way matter and energy were related. Just about everyone has heard of the formula E=mc^2. That formula explains how energy is related to mass. The idea found its way into the study of fission reactions, and it was proved that enormous amounts of energy were stored in even one atom of a substance.

Current Studies

Even now, scientists are still testing the boundaries of physics and the laws of physics. Only a few years ago a new state of matter was created. The Bose-Einstein condensate was theorized decades ago, but scientists have only recently been able to create it in a lab. Every day astronomers are studying space and learning how black holes and galaxies interact. Stephen Hawking is one of the more famous scientists working in that field. Our point is, there is still much to discover.

Looking at the Nucleus

While atomic physics deals with atoms as a whole, nuclear physics deals specifically with the nucleus of the atom. Physicists still need to understand the area around the nucleus, but they are more concerned with the forces at work keeping that nucleus together. Once they understand those forces, they often try to create new types of fusion and fission reactions.

It's Splitsville

Nuclear energy is the energy released when the nuclei of atoms split or are fused. The nucleus is made up of protons and neutrons. Nuclear forces hold all of the pieces together. Fusion is when two nuclei come together. Fission is when one nucleus is split into two or more parts. Huge amounts of energy are released when either of these reactions occurs. Fusion reactions create much of the energy given off by the Sun. There are even smaller particles that make up the protons and neutrons that physicists are studying every day.

Antimatter

Since we are talking a little about atomic and nuclear physics, we wanted to tell you about antimatter. It is not just found in television shows. Scientists have discovered evidence that it is real. While a regular atom has positive and neutral pieces (protons/neutrons) in the nucleus and negative pieces in orbiting clouds (electrons), antimatter is just the opposite. Antimatter has a nucleus with a negative charge and little positive pieces in the orbits. Those positively charged pieces are called positrons.

Looking into Atoms

Quantum physics is a branch of physics that works with the activities going on inside of atoms. They talk about subatomic particles interacting with each other. We're starting to talk about Albert Einstein and Max Planck's ideas here. In the early 1900's, scientists were beginning to examine the inside of atoms. They were wondering what was going on inside those things that were once thought to be solid. One big idea they came up with was that the energy of an electron depends on the frequency, or wavelength, of the EM Radiation. Another interesting idea they discovered was that energy didn't depend on the intensity, or amount, of radiation.

If you apply this idea to the structure of an atom, in the older, Bohr model, there is a nucleus and there are rings (levels) of energy around the nucleus. The length of each orbit was related to a wavelength. No two electrons can have all the same wave characteristics. Scientists now say that electrons behave like waves, and fill areas of the atom like sound waves might fill a room. The electrons, then, exist in something scientists call "electron clouds". The size of the shells now relates to the size of the cloud. This is where the spdf stuff comes in, as these describe the shape of the clouds.

Packets of Energy

During the early 1900's scientists also discovered that EM radiation not only moves like a wave, but has packs of energy (quanta) as well. It's like a stream of individual packets.

The Uncertainty Principle

A German scientist named Werner Heisenberg came up with this idea called the uncertainty principle. He figured that the position and momentum of an atomic particle cannot both be observed accurately at the same moment in time. The idea shows that because these pieces are so small, whatever device you use to measure the particles will affect them. Think about it. If you use light to examine a piece of light, won't you knock it around? Well now you just lost the idea of position. What if you freeze it in place? That's all very well, but now you don't know where it was going, or how much momentum it had. When you increase the precision of one measurement, the other measurement will suffer.

Look at the Heisenberg uncertainty principle in a more general way using the observer effect. While Heisenberg looks at measurements, you can see parallels in larger observations. You can not observe something naturally without affecting it in some way. The light and photons used to watch an electron would move the electron. When you go out in a field in Africa and the animals see you, they will act differently. If you are a psychiatrist asking a patient some questions, you are affecting him, so the answers may be changed by the way the questions are worded. Field scientists work very hard to try and observe while interfering as little as possible.

Releasing Particles

Radioactivity occurs when an atomic nucleus breaks down into smaller particles. There are three types of nuclear radiation: alpha, beta, and gamma. Alpha particles are positively charged, beta particles are negatively charged, and gamma particles have no charge. The radiations also have increasing levels of energy, first Alpha, then Beta, and finally Gamma, which is the most energetic of all these. Alpha and Beta are particles, but Gamma is a wave.

Half of a Life

When a radioactive nucleus changes, the remaining nucleus (and atom) is not the same as it was. It changes its identity. The term half-life describes the time it takes for half of the atoms in a sample to change, and half to remain the same. Let's say you have 100g of uranium (don't try this at home, it’s radioactive). When 50g remain (and 50g have become something different), the amount of time that has passed is the half-life. Every element has its own unique half-life. The half-life of uranium-235 is 713,000,000 years. The half-life of uranium-238 is 4,500,000,000 years. That is a long time to wait for radioactive atoms to change, and many of the things that the original atoms change into are ALSO radioactive and dangerous!

There is even a radioactive isotope of carbon, carbon-14. Normal carbon is carbon-12. C-14 has two extra neutrons and a half-life of 5730 years. Scientists use C-14 in a process called carbon dating. This process is not when two carbon atoms go out to the mall one night. Carbon dating is when scientists try to measure the age of very old substances. There are very small amounts of C-14 in the atmosphere. Every living thing has some C-14 in it. Scientists measure the amount of C-14 in the things they dig up to estimate how old they are. They rely on the half-life of 5730 years to date the object.

A Danger to DNA

Radioactivity is generally not good for living organisms. There are times that radiation passes right through organisms with no effect, but there are other times that it hits DNA or affects replicating cells. Bad things can happen when DNA is exposed to radiation. One result of moderate levels of radioactive particles can be cancer. Cells reproduce in ways that are not normal. High doses of radioactivity can kill a human within 24 hours. Medicine, however, has learned how to use radioactivity to stop cancers. Since they know that excess levels of radioactivity can kills cells, doctors target areas of cancer with radioactivity to stop the cancer cells from dividing.

Splitting Up

Fission is the splitting of an atom. Not all atoms will go through fission; as a matter of fact, very few do under normal circumstances. A small percentage of Uranium atoms have an atomic mass of 235 amu (atomic mass units). Only U-235 undergoes fission, so these atoms must be separated from the far more numerous U-238 atoms. The difficulty and cost of completing this separation is what has prevented most countries from having nuclear weapons (thank goodness).

In a nuclear reaction, scientists shoot a whole bunch of neutrons at uranium-235 atoms. When one neutron hits the nucleus, the uranium becomes U-236. When it becomes 236, the uranium atom wants to split apart. After it splits, it gives off three neutrons and a lot of energy. Those neutrons hit three other U atoms in the area and cause them to become U-236. Each cycle, the reaction gets three times bigger. A reaction that, once started, continues by itself, is called a chain reaction. A chain reaction that keeps getting bigger is called an uncontrolled chain reaction. Left alone, and with sufficient U-235 (which you do not have in a reactor), the energy would grow large enough to cause an explosion – A BIG one! The worst that can happen with a nuclear reactor that gets out of control would be a melt down; which is plenty bad, but not as bad as an explosion.

Fizz vs. Fuse

When we were kids we always got fusion and fission confused. The confusion wasn't because the processes were similar; the words were just similar. You need to remember that one process is a breaking down process and the other is a process of building up. When things fuse (fusion), you start with smaller objects (tritium, deuterium) and build larger objects (helium). When things "fiss" or break down, you start with a larger object (uranium) and finish with smaller objects (strontium, calcium, barium, etc).

Isotope Action

Why do we say that atoms are radioactive? There is another isotope of uranium with the number 238. When one of those free neutrons hits a 238, it will bump it up to 239 (that just makes sense). But that 239 is radioactive and releases a beta particle when it decays. It's not over. That U-239 breaks down into neptunium-239. The neptunium is also radioactive. It will release another beta particle when it breaks down into plutonium-239. The plutonium will eventually give off an alpha particle (not as strong as beta and less dangerous). That's a lot of particles being given off.

Einstein's Legacy

The fission process, however radioactive it is, is the main reaction that happens in many nuclear devices. It all started with Einstein's equation E=mc^2. As soon as scientists thought there were huge amounts of energy available in each atom of the universe, the military began to develop weapons that had enormous destructive abilities. Usually uranium or plutonium is in the bomb and a smaller explosion of material that surrounds the uranium and plutonium sets off the fission reaction. They have even developed fusion bombs that are set off by a fission reaction.

Bringing Together

Fusion is the process of two small atomic nuclei coming together to make a larger nucleus which is stable. The simplest nuclei to use are deuterium and tritium (isotopes of hydrogen). Scientists find deuterium in the oceans, so it's pretty easy to find if you know where to look.

Look in the Sky

The fusion reactions in many stars are different from the reactions we are trying to develop on Earth. Scientists call the fusion process on a star the proton-proton chain reaction. Two protons collide with each other and form something called a deuteron. A third proton then collides with the deuteron to create a helium isotope. Helium isotopes then fuse to make beryllium, which then breaks down. When the beryllium breaks down, two protons are released and the reaction can start again.

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Making Fusion a Reality

Fusion reactions need very hot environments to occur. Temperatures hit millions of degrees, like the temperature of the Sun. When you heat a gas, you create plasma. The problem is that we can't create a container that can make plasma hot enough to let a fusion reaction occur. To make sure that the plasma doesn't really touch the container, scientists use magnetic fields to hold the plasma in place. It's like the plasma is just floating, not touching anything. Right now the best container is in the shape of a torus. That's like the shape of a doughnut. Compared to a fission reaction, there is very little radioactivity released when a fusion reaction is complete.

Creating Usable Energy

Researchers use uranium 235, an isotope of uranium, in many nuclear reactors (In some cases, they use plutonium instead). The uranium comes to the reactor in small pellets. Those pellets then go into fuel rods. The fission reaction produces heat, and the entire reactor has to be cooled by water, so nuclear plants are built near rivers, lakes, etc. Since the reaction keeps growing, and since no one wants a reactor to melt, they have to do more than just cool things off. Since the number of neutrons controls the size of the reaction, you can control the reaction by controlling the neutrons. Reactors use control rods, which absorb neutrons, and insert them into the reactor to keep it under control. The further they insert the rods, the slower/smaller the reaction. When most of the fuel pellets have changed from U-235 to other atoms, the rods are removed and kept in a big pool of water for a year. Then new fuel rods are inserted in their place.

After enough time has gone by, and the radioactive materials have cooled down, officials have to bury the nuclear waste deep underground. They bury them so that the radioactivity will not contaminate the surrounding water or land.

When biological substances become irradiated by very powerful radiation, they can no longer survive. The result is something called radiation poisoning and nuclear plant workers have to be very careful.