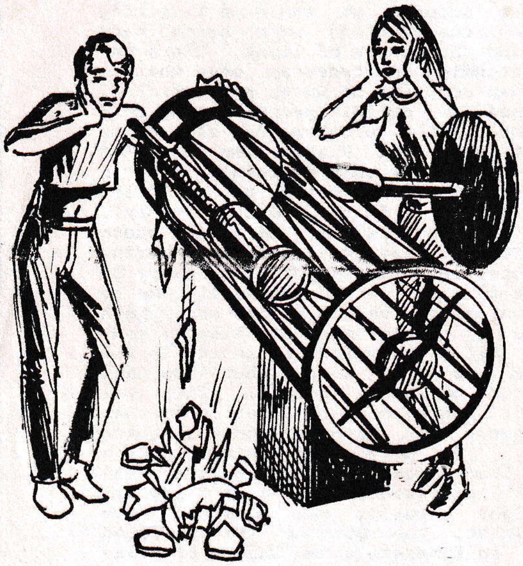
REFLECTIONS

of the

UNIVERSITY

LOWBROW

ASTRONOMERS



EDITOR JEFFERY BASS

vol. V no. III

PREVIEW

This Friday's meeting of the University Lowbrow Astronomers will feature a talk by John Salazar who is a Graduate student in the Astronomy Department at the U of M. He will be talking about Emission-Line Galaxies. Your typical galaxy usually exhibits an absorption-type spectra. Galaxies with emission lines in their spectra are often associated with violent, high energy events. Seyfert galaxies and the so-called N type galaxies, I assume, both fit into this high-energy category. I'm not quite sure, though. If you're not sure either, and you want to be brought up-to-date on what is known about these violent beasts, then I guess we'll see you at the meeting this Friday.

OPEN HOUSE

The club owes a debt of thanks to Jim and Irene Newhouse, who at the last minute salvaged last month's open house at Peach Mountain by procuring a timing belt for the 24 inch telescope. This chronic problem of timing belt breakage is being rectified (even as I write this) by Doug Nelle and Tom Ryan who are working on installing a set of GEARS to permanently replace the belt. It should be in operation by this month's open house which will take place on Saturday, July 28.

WARNING

I guess I got a little carried away this month. I mean, the article I wrote got to be a little LONG, so read it when you have about 45 minutes of uninterrupted time to spare.

Except for those who majored in a science, most of us recieved our science education at the hands of high-school and college teachers in the broad context of introductory courses. Whatever gaps occured, we filled in ourselves. My article on Quarks is supposed to update those of us with a skimpy or antiquated knowledge of atomic physics. Why?

There are some of us walking around who still think that an atom is some kind of a miniature solar system with electrons orbiting around protons! Most of us were taught that in high school, anyway. Of course it's a nice way to explain the atom, but it's wrong.

Anyone even remotely interested in astronomy usually discovers that without at least a basic understanding of atomic physics, virtually nothing in astronomy can be understood either. And with the advent of the idea of quarks and unified field theories, astronomers are busying themselves with experiments and projects that to the uninitiated seem exotic and bizarre (like the search for "gravity waves", "quantum black-holes" etc.) Even in Sky and Telescope, hardly an article is written that doesn't mention the word "quark" or "graviton" in some context or another. If you'd like to keep even a little abreast of these developments, you need to understand TODAY'S modern physics, not just the physics of 1910. This month's article might help to provide an overview, at least, of how today's scientist understands the sub-atomic world.

-- Jeffery Bass

ATOMS and QUARKS

by Jeffery Bass

This is an ambitious article. In only a few thousand words I am going to present an overview of the results of the last 50 years or so of sub-atomic research. And smile while I'm doing it.

One big achievement of the last 20 years in physics has been the development of the quark theory of matter. Just what is all of this "quark" business anyway? We all know the pat description of the quark theory that says that sub-atomic particles such as protons and neutrons are actually made of more fundamental particles: the quarks, but that isn't saying very much. Are quarks built from even smaller particles? Does the division of atomic particles just get finer and finer and smaller and smaller ad infinitum (or ad nauseum)? It seems as though the "quark" is just another tiny particle. But in fact, quarks are a little more complicated than that. Though the quark theory is far from complete, it seems to show that in terms of size, the universe indeed has a bottom-scale limit. At this lower size limit nature can create diversity only by clever and subtle interactions of quark properties. That is why it is possible to begin unifying forces using the quark theory.

But I'm getting ahead of myself. How did the idea of quarks ever come about in the first place? The answer is found in the events surrounding the great discoveries physicists and theorists made at the beginning of this century. This article will describe those discoveries that culminated in the formulation of the full-fledged Quantum Theory in the 1920's and ultimately lead up to the idea of of quarks in the 1960's. Then our "epic saga" will continue with a description of the quark theory itself as it stands today.

The idea that the chemical elements were made out of atoms began to be apparent late in the 19th century. As scientists classified the known elementes into groups of related properties (such as metalloids, inert gases etc.) interesting patterns appeared. Scientists realized that the patterns were manifestations of an inner symmetry present inside the elements themselves. What that symmetry actually was, and how it behaved in detail was not understood. Some scientists jumped the gun in trying to formulate a primitive sort of atomic theory in which the properties of the chemical elements could be derived. In the classical mechanical terms of the day atoms were considered "vortices in the ether". Well, this picture or model of the behavior of the elements was almost immediately found to be unsatisfactory. Most scientists correctly realized that what was needed first was to develop a descriptive theory based on classification schemes. Only after such a theory was constructed would it be possible to formulate a more fundamental, far-reaching theory.

To make an incredibly long story short, the prudent scientist's patience paid off. By the turn of the century, much was known of the behavior of the elements. And after Maxwell's mathematical formulation of a comprehensive theory of electromagnetism, scientists were able to make a few stabs at describing the structure of the atom itself. It became apparent quite soon that the atom was constructed according to electrical and magnetic principles. This discovery occured at the same time many important observations were being made concerning the nature of light. There was a long-standing controversy over whether light was composed of waves or particles. It seemed to exhibit properties of BOTH phenomena. This problem was cleared up somewhat by Max Planck who in 1900 presented a theory that explained light in terms of tiny corpuscles or particles called "quanta". In the "Quantum Theory", light behaves as a particle whose attributes can best be described as having WAVE properties. Simply put, the energy of a quanta of light, or photon as it came to be known, is equivalent to its wavelength factored by a constant 'h' (Plancks constant). All electromagnetic energy in the universe was seen as the shuffling back and forth of light quanta. This was extremely startling, because up to that time energy had been a highly abstract concept. To many scientists, Planck's Quantum Theory seemed to be merely a mathematical contrivance that didn't explain what light actually was made of. Five years later, the Quantum Theory found support in Einstein's new Theory of Relativity which showed that matter and energy could be considered as different conditions of the same "substance". With this revelation, Planck's energy quanta suddenly took on the look of being physically "real" objects.

In the meantime, scientists were poking into the insides of atoms. With Maxwell's equations in hand and a wealth of experimental evidence, it was discovered that the atom was made of two different electrically charged pieces. One piece was dense and positively charged; the other light and negatively charged. The dense heavy particle (the proton) was found to reside at the center or nucleus of the atom while the light particle (the electron) was noted to be swirling around the proton as though it were a tiny planet orbiting around a tiny sun. The idea of picturing the atom as a kind of miniature solar system enabled scientists to ascribe properties of motion and momentum to the particles of the atom, the proton and the electron. But there were problems. The electrons, it was realized, could not really be "in orbit" around the nucleus. The gravitational attraction between the proton and the electron is incredibly weak compared to the huge amount of electrical attraction between them. Mathematically there was no way of "spinning" an electron around an atom without the electron eventually spiraling in and crashing into the protons inside the nucleus. Such an event would release the orbiting electron's momentum energy in the form of electromagnetic energy. And indeed, when hydrogen atoms were studied, energy in the form of light was seen to emanate from them, but not in the manner that the spiraling electron scenario would indicate. Instead, the light was emitted in several discrete wavelengths, which in a spectrograph appeared as bright lines. The appearance and spacing of the lines could not be accounted for. In the 1920's, Niels Bohr solved this puzzle. The discrete line spectra of the hydrogen atom could only be explained if the electrons "spiraled" in towards the nucleus only in well ordered INCREMENTS which were termed "energy levels". As each electron descended to a lower energy level (closer to the proton) energy was emitted in the form of light quanta of an exact, specified wavelength.

This linked the behavior of the electron to Planck's energy quanta. These quanta (photons) were seen as the individual colored lines in the hydrogen spectrum.

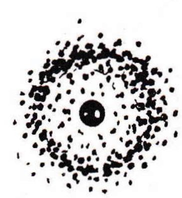
Not only did Bohr's theory explain the appearance of the hydrogen spectrum, but later mathematical work showed even more interesting results. Calculations showed that the spin angular momentum of the individual electrons in each energy level were such that no two electrons could be in the same energy state. Two electrons could be in the same energy state only if their SPINS were aligned in opposite directions, but other than this special case, the energy levels the electrons occupied were quite exclusive domains. The idea of these exclusive electron energy levels was the breakthrough that scientists had been working towards for the past century. With a few refinements in the energy level mathematics (in order to accomodate the larger numbers of electrons in big atoms), using the new Exclusion Principle it was shown how all of the chemical elements were related. The special vertical rows (or "families") in the periodic table of the elements were demonstrated to be atoms that had the same number of electrons in their outermost energy shells. The horizontal rows of the periodic table represented the 7 possible energy shells themselves. The chemical elements simply dropped, one by one, into their slots. The patient work of the scientists who began only to classify the elements, paid off with the advent of Quantum Electrodynamics which explained WHY the elements were arranged in each of their particular groups. Only one problem remained. Many scientists were bothered by the new theory when they tried to explain exactly WHAT happened during a quantum energy level jump. Did the electron just magically disappear from its original energy level, only to magically reappear at the new one? Was there a time lag? How did the electron actually get from one energy level to another? Being unable to solve this problem without violating time-honored conservation laws threatened to do considerable violence to the Quantum Theory which up until then had done so much in providing answers and order to the atomic puzzle.

Fortunately, an explanation of the electron's bizarre antics was forthcoming. With it, the last vestiges of classical physics, in which all phenomena could be intuitively visualized, were swept away. Werner Heisenberg and Erwin Schrödinger analyzed the quantum equations and came to a far-reaching conclusion. The problems of the mysterious electron behavior stemmed from the idea that an electron was a well defined entity, a particle, in which a precise position and velocity could be determined. But was this a true assumption? How could one "know" the precise position of something so small that it can't even be measured? How can one even "look" at an electron? Can it be seen?

To examine something as incredibly small as an electron, you need short wavelengths of light. The light waves must be several sizes smaller than the electron you are looking at in order to resolve it unambiguously. The shorter the wavelength of the light (or the higher the energy) the better your resolution is. But what happens when you shine high energy light such as ultraviolet light, on an electron? You knock the electron all over the place! So you can't even find it. If you reduce the wavelength and so reduce the destructive effect of the light, you also reduce the resolution that you need in order to precisely locate the electron.

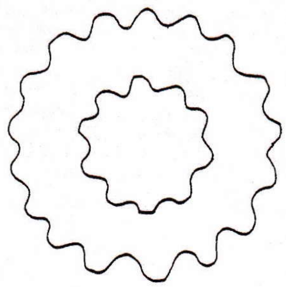
Thus, at high energies, or short wavelengths you can be relatively certain of the POSITION of the electron, because you're "pinning" it down for brief instances, but you don't know where it's going to zip off to in the next instant. Your short wavelength makes it hard to determine the direction-vector of the electron's velocity, hence you can't determine the electron's velocity very accurately at all. Conversely, at low energies and long wavelengths, you're not knocking the electron around too much and you can be more reasonably certain of the electon's velocity, but you can't locate the thing at all; your resolution is too low. All you know is that there is a likelihood, a PROBABILITY, that you will find an electron in a specific spot. This dilemma of not being able to know simultaneously an atomic particle's velocity AND position is called the Uncertainty Principle. It is intricately connected with the idea of wavelength. This situation is not just an acknowledgement that it is very hard for large scientists to examine small atomic particles. It is more fundamental than that. It is just as hard for the atomic particles THEMSELVES to determine another particle's velocity and position. The Uncertainty Principle is a REAL law of nature that operates everywhere, it just so happens that its effects do not become easily apparent except at the tiny scale of the atom.

Thus, it was revealed that an electron is not a hard, particle-like object like a planet which orbits around a sub-atomic sun (the proton). Rather, the electron is a THING that is better visualized as a QUALITY that has electron-type properties of electric charge and angular momentum; which has a PROBABILITY of being located in certain discrete areas (shells) around an atomic nucleus. What an electron

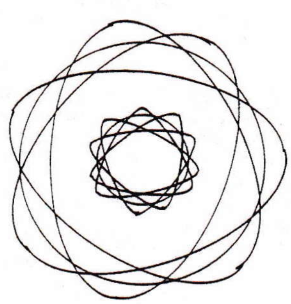


The probability of finding an electron in its lowest energy state takes on the appearance of a "smoke-ring" around the nucleus. The thickest part of the ring is where the electron is most likely to be found. For atoms with more than 2 electron shells, the probabilities of electron distribution are extremely complex, and correspond to no possible "real" geometrical representations.

"really" is, no one knows. Indeed, the whole concept of "real existence" has been virtually chased to death by philosophical hounds. Since 1905, with the publication of Einstein's Special Theory of Relativity, the idea that everything in the universe should be visualized mechanically has gradually become ridiculous. We now find that mechanical objects themselves are composed of "units of probability" held together by electric fields, and therefore it makes no sense to try to explain these "units of probability" (sub-atomic particles) in terms of mechanical models. If you MUST try to visualize it, an electron is more of a standing-wave sloshing around in a "fixed" energy compartment (energy level) with related harmonic waves sloshing simultaneously along with it (the other electron energy levels). Each such "standing wave" can have only very discrete wavelengths (energies) or else the standing wave effect will be disrupted or destroyed and the atom as a unit would disintegrate. Since protons have the same spin characteristics as electrons, so too must the protons obey the Exclusion Principle. When protons bunch together (in large atoms) no two can oppupy the same energy level and thus must "stack" up in other, higher proton-energy shells. Like electrons, protons can also be visualized as a standing wave phenomenon.



A simple hydrogen atom can be visualized as a system of two different standing waves: a proton wave and an electron wave.



A large atom with many protons and electrons can be imagined as a single system of superimposed standing waves.

In short, the state of physics at the beginning of the 1930's was nothing less than dream-like. All of the long standing puzzles of the centuries of alchemy and chemistry (and many from other branches of science) were "solved" by the Quantum Theory. Man had climbed out of the slime into the full light of day. The ENTIRE UNIVERSE was made of just two substances, the proton and the electron. And we knew how they were combined to produced every element that we could see in nature. The simplicity and beauty of the cosmos was marvelous to behold! Oh, and one more particle to add to the list; the neutron. It seemed to be almost like a proton, except that it was electrically neutral. The neutron explained why there were different versions or "isotopes" of the same elements. And it demonstrated why some of these isotopes decayed radioactively into other elements. In fact, the two most well known particles emitted in radioactive decay, the Alpha and Beta particles, were found to be our old friends. Scientists were relieved to discover that the beta particle was just a very energetic electron. The alpha particle was just 2 protons and 2 neutrons stuck together (a helium nucleus). But these phenomena started people thinking. What held the atomic nucleus of the alpha particle (or ANY particle) together in the first place? Why hadn't the like-charged protons repulsed and blown the nucleus apart a long time ago? Why wasn't EVERY atom in a similar state of radioactive decay? The electrically diluting effect of the neutron didn't adequately explain this. And what about that radioactivity jazz? What caused it? How did the process work? With more experiments in radioactivity, particles were observed ejected from decaying elements which did not behave as the Quantum Theory said they should. When neutrons, which were stable inside the atom, were removed from the nucleus they decayed into protons and electrons in only 18 minutes. The electron and proton together are about 1.5 electron masses lighter than the neutron, so this amount of mass appeared to be lost in the decay; it was equivalent to some 780,000 electron volts of energy. This should have shown up as the kinetic energy of the decay products, but in fact the proton and electron seemed rarely to have so much energy. To account for this discrepancy there was no choice but to assume that another particle, with zero rest mass (and almost undetectable) also was formed in the decay, and that it carried off the missing energy. Enrico Fermi, who pursued the idea, named the invisible particle the neutrino. (It turned out to be an antineutrino).

Quantum mechanics also revolutionized the idea of "force". A force was no longer considered as some mysterious condition of space, such as magnetism or gravity, that acted in violation of known facts "at a distance" and instantaneously. Rather, a force was seen to be merely the macroscopic effect seen when microscopic (indeed, ATOMIC) particles EXCHANGED other particles. Electricity and magnetism were the simple result of the exchange of photons. As people contemplated the workings of the electromagnetic force, it seemed just as likely that maybe there were similar particles that carried a "nuclear force" that could hold protons together against their mutual electrical repulsion inside the atomic nucleus. Such a force would have to be much stronger than the electrical force hence the nuclear force was dubbed the "strong force". The hypothetical particle that carried the strong force was called pi.

Similarly, gravity itself should arise when a quantum of gravity is exchanged: the graviton. Okay, maybe they were proliferating the so-called "elementary particles" a bit. And so what if things weren't quite so elegantly simple as it had originally been. It wasn't too bad; a small handful of particles that nevertheless accounted for EVERYTHING in the known universe. Then, they really put their foot in it.

They started picking at the nucleus of of the atom, again. This time by watching energetic cosmic rays smash headlong into target plates and seeing if anything happened. And lo and behold, bits and pieces of atoms were flying all over the place! Tiny sub-atomic particles that had never been seen or even guessed at, with different masses and electric charge were blasted from their comfortable places within the atomic nucleus. None of it made sense at all. Where did all the particles come from? By the middle of the 1950's physicists had a real mess on their hands. Over 50 sub-atomic particles were found and no one knew how they fit into the scheme of things. They couldn't all be "elementary". The experimenters were way ahead of the theorists who just when they could come up with a scheme that explained all of the known particles, a new batch of particles would be discovered which wrecked everything. It's interesting to read the journals and literature from these years. The physicists were surrounded by the detritus of their own curiosity, and were almost completely at a loss for any explanation. You can detect in these early articles a sense of frustration and despair. It's almost sad.

Physicists realized that they were in the same predicament that the 19th century chemists were in. Chemistry before 1900, as we have seen, was a DESCRIPTIVE theory. It described how the elements behaved; it did not try to explain why a particular set of elements, each with its particular properties, existed. To answer the question "why", completely new sciences were needed: atomic and nuclear quantum physics. Looking backward, it is now clear that the 19th-century chemists were right to concentrate on the "how" and to ignore the "why". They did not have the tools to begin to discuss intelligently the reasons for the individualities of the elements. They had to spend a hundred years building up a good quantitative descriptive theory before they could go further. And the result of their labors, the classical science of chemistry, was not destroyed or superseded by the later insight that the Quantum Theory gave. By analogy, modern particle physics is in the same situation. In the 1950's it was realized that what was needed was a working descriptive theory and a classification scheme that could help sort out the confusing jumble of new particles. Only with the establishment of such a theory could we be expected to reach a more complete understanding of the particles at a deeper level. The numerous attempts to bypass the historical process, and to understand the particles on the basis of general principles without waiting for a descriptive theory, were as unsuccessful as they were ambitious. In fact, the more ambitious they were, the more unsuccessful. These attempts seemed to be on a level with the famous 19th century attempts to explain atoms as "vortices in the ether."

During the 50's and early 60's much work went into trying to classify and arrange the known particles, which at that time numbered nearly a hundred, into groups of similar properties. The usual categories of quantum properties included such familiar ones as mass, charge and angular spin momentum. Unusual properties were noticed among the particles such as isotopic spin and a new quantity called "strangeness". Strangeness was an ad hoc quantity used to explain why certain particles that were normal in every way took abnormally long times to decay. Enough particles seemed to share this peculiarity that physicists began to suspect that perhaps their decay was impeded because of their need to conserve some new and different sub-atomic property. These "strange" particles were then fitted into the classification schemes by providing that they conserved a property called "strangeness". No one knows what "strangeness" really is. But physicists know what it DOES: it's conservation as an important quantum property impedes the otherwise normal decay of a certain class of particles ("strange" ones).

As more and more particles were discovered, the classification schemes grew more and more complex. Eventually patterns began to emerge. For instance, it was noticed that when particles were arranged according to their charges, all of the particles made nice neat rows except the "strange" ones; all of whose patterns could be made to fit merely by shifting them to the right or left one or two places. The displacement of these particles means that nature is trying hard to tell us something, but what it is we simply don't know yet.

Murray Gell-Mann and others in the early 60's began to notice that when particles were grouped by 2 different quantities (called isotopic spin and hypercharge) clumps or multiplets of particles formed in groups of 1, 3, 8, and 10. Someone dug around and found that there was a type of symmetry-mathematics which predicted the same group of numbers. A type of mathematics called Lie Algegra (after Sophus Lie) was invented in the 19th century that handled matricies and symmetries very well. A special group of matricies called the Special Unitary Group Three (SU(3)), which describes the properties of arrays 3 X 3, was found to predict nearly perfectly the same numbers observed as patterns in the atomic particle's properties. The lowest orders of SU(3) are the numbers 1,3,8 and 10. Managing a 3 X 3 array yields 9 possible orders but one is a redundant order, thus yielding a total of 8. The close relation of SU(3) to the classification of the sub-atomic particles was just too close to be coincidental. A theory of particle classification was devised by Gell-Mann using SU(3) called the "Eightfold Way" because it involved the operation of eight quantum numbers or properties and also because it recalled an aphorism attributed to Buddha: the 8 Noble Truths that lead to enlightenment. The unified symmetries of this new classification scheme predicted the existence of new, as yet undiscovered, particles that were required to fill in some of the "holes". When the particles were actually discovered, it proved that physicists were on the right track.

The numerical basis of SU(3) is the number 3. The mathematics of SU(3) led directly to the formulation in 1964 by Gell-Mann of the "quark hypothesis" in which all of the (then) known particles could be accounted for by positing that they were all made of different combinations of three basic particles called quarks (and their anti-quarks).

The word "quark" was whimsically taken from a line in James Joyce's Finnegan's Wake: "Three quarks for Muster Mark!" The quark idea, that atomic particles (like protons and neutrons) are made of smaller particles, however, does not seem like a particularly clever or innovative idea. It presents itself rather obviously even to someone who knows very little about Quantum theory. Knowing nothing about the properties of atoms it still would be possible to contrive all sorts of "quark-like" schmemes that would more or less explain atomic particles as composites of still smaller particles. Indeed, many such schemes have been devised. What makes Gell-Mann's Quark hypothesis have weight is that it is the END-RESULT of over 3 decades of painstaking observation, experiment and classification. The idea that there are 3 types of quarks could easily have been posited as early as 1940, but there would have been no way to prove or disprove it against any number of other competing theories. In 1964 enough was deduced of the symmetries presented by the nearly 100 sub-atomic particles then known to be able to formulate an underlying system of structure with a reasonable degree of confidence.

Before a description of the quark theory can be made in full, it is necessary to briefly summarize the new body of nomenclature that physicists over the last few decades have been using.

It is recognized that there exists four basic forces in nature. In order from the strongest to the weakest (at quantum distances anyway) they are: the strong force, the electromagnetic force, the weak force, and gravity. The strong force has a very short range (only about the size of a neutron) and is the force that holds the atomic nucleus together against electrical repulsion. The electromagnetic force has an unlimited range (that falls off as the distance is squared). The electromagnetic force is what binds electrons with protons in the atom. The weak force also has a short range, like the strong force. Its effects are most noted in certain types of radioactive decay such as beta decay. And finally, there exists the gravitational force which like the electromagnetic force has an unlimited range. At short range, at the scale of quantum effects, the force of gravity is absurdly weak and can be ignored in many instances.

Of course, as noted earlier, in quantum mechanics there are no such things as forces mysteriously acting at a distance in the classic sense. The effects that we ascribe as being those of a "force" are really the actions of particles. The strong nuclear force is actually an exchange of particles (with small mass) called pions. The emission or absorption of a pion by a nucleon such as a proton or neutron takes place in some 10^{-23} seconds, which is the characteristic time scale of the strong interactions.

As mentioned earlier, the strong force has a short range: its effects extend only about 10^{-13} cm, or approximately the diameter of a neutron. When two particles that feel the strong force approach to within this distance, the probability is very high that they will interact, that is, they will either be deflected or they will produce other particles. In contrast, particles that interact electromagnetically are 10,000 times less likely to interact under the same circumstances. If strongly interacting particles pass each other at nearly the speed of light (as they do in particle accelerators) then they must interact during the 10^{-23} second they are within range of each other. If they fail to interact within this time scale, there can be no strong interactions. As the passing particles separate, other forces less strong but longer ranged than the strong force may be felt, such as electromagnetism.

Electromagnetism is mediated by a massless entity, called the photon. The electromagnetic process is about 137 times slower than the strong nuclear process. If two charged particles separated by a large distance fail to interact even by the electromagnetic force, it is unlikely that they will interact at all via ANY force save gravity; the effects of which, of course, only become apparent at macroscopic distances and are vanishingly small at an atomic scale.

What about the weak force? The problem here is that the range of the weak force is even less than that of the strong force by a factor of about 100. Two particles must approach to within 10^{-15} centimeter in order to feel the weak force, and even at that short range the probability that they will interact is less than one in 10^{10}. Thus, in order to interact via the weak force, particles must (normally) be immune to the strong force, whose effects tend to swamp the weak force long before particles are able to approach close enough for the weak interactions to take place. (Some particles can interact weakly even though they feel the strong force. They will be discussed later). The weak interactions, when they do occur, are transmitted by particles with mass called W particles. The weak force is weaker than the strong force by a factor of about 10^{-14} ; it is a hundred thousand billion times weaker than the strong interaction.

At macroscopic distances, the effects of the already mentioned forces get drastically weaker leaving the gravitational force as the only noticable force operating at long range. That is why the large macroscopic events observed by astronomers are dominated by this force. Gravity is mediated by the massless graviton. The time scale for particle-interactions via the gravitational force is not known with certainty but is thought to be much slower than the weak force.

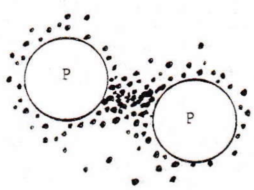
The unlimited range aspect of the electromagnetic and gravitational forces are attributable to the masslessness of their respective particle carriers; the photon and the graviton. Conversely, the limited ranges of the strong and weak forces stem from the measurable masses of their carriers; the pion and the W particle. At present all of these particles except the graviton have been discovered.

Sub-atomic particles are grouped into "families" according to the forces that they feel and do not feel. The two families are: the Hadrons and the Leptons. Hadrons (from the Greek word 'hadros' meaning "strong") are particles that are affected by several different forces, but all commonly feel the strong nuclear force. Hadrons include (among many other particles) the protons and the neutrons, both of which are commonly found inside the nuclei of atoms, where the strong force is prevalent. Leptons, on the other hand, are particles that do NOT feel the strong force, but CAN feel the weak force (or electromagnetism or both). Both hadrons and leptons have some particles that feel the electromagnetic force and some that do not. For instance, the neutron (a hadron) is electrically neutral unlike its counterpart the proton which is a hadron with positive charge. Nevertheless, they both feel the strong force, and that alone is what makes them hadrons. The electron (a lepton) has a negative charge whereas its lepton-colleague, the neutrino has no electric charge. Despite these electrical differences, electrons and neutrinos share the common property of being immune to the strong force. That alone is why they are NOT hadrons, but leptons. ALL particles, hadrons and leptons alike, feel the gravitational force. In essence, the difference between the Hadrons and Leptons stems from whether or not they feel the strong force.

There are at present almost 200 known hadrons but only 4 known leptons. This great discrepancy in the numbers of particles belonging to the two families has not been overlooked by physicists. It has always been THE task to explain the great numbers of hadrons. The quark theory is designed only to work for hadrons, which are composites of quarks. The leptons are not described in quark theory because it appears that all of the leptons are fundamental, elementary particles already. All experiments performed to date reveal that leptons behave as point-like entities, and unlike the hadrons, they exhibit no behavior that would indicate that they have any internal structure whatsoever. How leptons and quarks are related is not well understood. But when a good theory that links the two particle families is devised, it will be a major breakthrough.

There is another class of particles that contains only one member; the photon. The photon feels NO forces except gravitation and is thus in a class all by itself. The graviton theoretically feels no forces AT ALL, not even gravitation. That is why gravitons have been so hard to detect.

In quark theory, we are concerned primarily with the hadrons. As I'm sure you were suspecting, the hadrons are broken into sub-families (but only two). Hadrons consist of the Baryons, which are generally the most massive of the known sub-atomic particles, and the Mesons, which mostly have medium mass (hence the term "me"-sons) but are still much more massive than leptons. Protons and neutrons are examples of baryons, while the pions (the carriers of the strong force) are examples of mesons. (Sometimes, pions are called "pi-mesons"). As mentioned, there are hundreds of different baryons and mesons known at present, and there is every indication that many more will yet be discovered.



Two protons exchange pi-mesons; creating the strong nuclear force. The pi-mesons form a cloud around the protons.

The baryons and the mesons are different because of the way their constituent quarks are assembled. Baryons are composed of THREE quarks. (An anti-baryon such as an anti-proton is made of 3 anti-quarks). Mesons are composed of TWO quarks: a a quark and an anti-quark.

Since it has been brought up, it is probably a good idea to mention something about anti-matter. We all know what it is: its the stuff that makes the U.S.S. Enterprise's warp engines work! But where did the idea of "anti-matter" come from?

In 1930, P.A.M. Dirac devised a relativistic theory describing the behavior of those quantum particles that obey the Exclusion Principle. Remember that the exclusion rule prevents two electrons from having the exact same quantum numbers and the same energy. The baryons, but not the mesons, obey the exclusion rule. The particles that DO behave according to the exclusion rule have quantum spins in units of 1/2 (don't worry about what 1/2 means) and are analyzed according to what are known as Fermi-Dirac statistics and are called fermions (protons, electrons etc.). The particles that DO NOT follow the exclusion rule (they have spin in integer units of 1) are described by Bose-Einstein statistics and are therefore called Bosons (i.e. mesons, W particles). Unlike fermions, any number of bosons can occupy the same energy state.

In Dirac's theory for FERMIONS (particles with spins of 1/2), he was puzzled by solutions to the quantum equations that indicated negative energy states. The negatives arose from the space-time symmetry of Special Relativity and could not be ignored. The negative energy levels extended downward, without limit, mimicing in mirror images the positive energy levels of the atom's electron shells. Dirac reasoned that this meant that the usual ground state of, say a hydrogen atom, (an electron in the lowest energy shell) was not really a "ground" state at all, but was poised over a bottomless well of negative states. There seemed no reason why electrons should not continue to drop into these lower states. Dirac assumed, therefore, that these negative energy levels must be filled ALREADY. Hence, the exclusion rule would prevent electrons from falling into them. The negative energy states were like an invisible, infinite sea.

Though downward transistions are forbidden in this circumstance (by exclusion), nothing should prevent UPWARDS transitions of particles from this negative "sea" into the normal positive states (prompted, of course, by just the right amount of energy-quanta). Such a sudden upward transition should be seen, Dirac reasoned, as the sudden appearance of an electron where none had been before. If an electron in the negative sea were invisible, the "hole" it left behind when it jumped upwards must then be VISIBLE; the absence of an invisible negative energy particle would be the equivalent of a visible positive energy particle. Thus, the appearance of a newly created electron MUST be accompanied by a "hole"; a positively charged particle with the same mass as the electron: a positron. Though Dirac's reasoning process was hard to reconcile with an actual mechanism, it nevertheless had predictive power. Positrons were eventually discovered. Later mathematical treatment of this concept removed the limitation of exclusion and showed that indeed ALL particles must have their counterparts in the form of anti-particles. More concisely stated, an anti-particle is a particle that has all of its quantum numbers or properties reversed. In this way a particle with charge +1 has an antiparticle of charge -1. An electron has a property called Lepton Number which is +1. An anti-electron (positron) has a lepton number of -1. For comparison, a proton (which is a hadron) has a lepton number of 0. When particles and their antiparticles meet, all of their quantum numbers cancel to produce zeroes. In other words, the particles are entirely annihilated producing in their stead a flood of energy (which in the case of electron-positron annihilation are very energetic photons, gamma rays). By symmetrical reasoning, the annihilation process should also run backwards. A bunch of gamma rays should be able to CREATE pairs of particles and antiparticles. This interesting event has, in fact, been observed.

This business of quantum numbers needs some clarification also. Quantum numbers represent the very PROPERTIES of atomic particles. A particle with a set of quantum numbers cannot lose or change its quantum numbers without violating conservation laws. A lepton, for instance, always conserves its Lepton Number no matter what else happens to it. (Unless, of course, it is totally annihilated which cancels its Lepton Number to zero). If Lepton Number could be spontaneously changed, it would be possible to convert a lepton directly into a baryon or vice versa. Such events are not observed because apparently these particles conserve their respective lepton-ness and baryon-ness. All of the other quantum numbers (up to 8 of them) work the same way. Quantum numbers must be conserved just like momentum and energy must be conserved whenever two particles interact. It's when particles interact and appear to VIOLATE a certain conservation law that physicists suspect perhaps an even more fundamental conservation factor to be at work. Instances of conservation "violation" do much to shed light on how quantum mechanics works.

Take, for instance, the case of the annihilation of an electron and an anti-electron (a positron). Scientists have alot of fun studying these objects. They are not content to just let two lazy, slow moving electrons and positrons sort-of annihilate eachother. Noooooo! The scientists first accelerate the particles up to incredibly fast speeds and then smash them into eachother. A device called a particle storage ring can accelerate an electron and a positron up to well within 99% the speed of light. Because of relativity effects, these objects become much more massive near the speed of light than when they are at rest. When the particles collide and annihilate eachother, the kinetic energy of their collision is additionally available in the interaction for the creation of new particles. How? According to $E=mc^2$ energy can be converted into mass. It takes alot of collision energy, millions of electron volts, just to make even one small mass particle like a meson. How does this reaction actually work at the atomic scale? The mechanism for it is provided for by what is called a "virtual" process, mediated by "virtual" particles.

What happens when we collide and annihilate an electron and a positron with a combined energy of a few billion electron volts? Because the particles are leptons they do not feel the strong force, and at the energies studied so far the weak interactions are feeble enough to be neglected. The particles are electrically charged, however, so that they do feel the electromagnetic force, and the energy produced by their mutual annihilation is (to a very good approximation) entirely electromagnetic. In other words, the electron and the positron annihilate each other, cancelling their electric charges and lepton numbers, to produce a very energetic photon (a gamma ray).

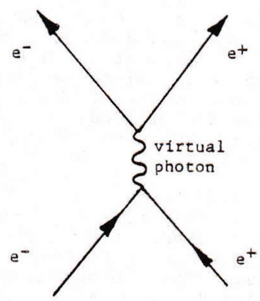
The photon emitted is not, however, a "real" photon such as those that are observed in nature as the quanta of electromagnetic energy. It cannot be real because it has the wrong proportions of energy and momentum, quantities that must be conserved in all interactions. For the photon, which has no mass and which travels at the speed of light, the relation of momentum to energy is constant: the momentum is a fixed fraction of the energy, equal to the energy divided by c. This energy momentum relation cannot be reconciled with the energy and momentum of the colliding particles. In a storage ring, the electron and positron move with equal energy but opposite momentum (they are colliding HEAD ON), and the state formed by their annihilation must therefore have large energy but zero momentum. A photon cannot have that combiniation of properties.

One possible resolution of this dilemma is for the annihilation to produce TWO photons that have equal but opposite momenta, thereby satisfying the conditions that the sum of the momenta of the products be zero. This reaction does in fact take place, and measurement of it is of major interest. Generally, however, the annihilation process generates as few photons as it possibly can. The probability that an electron or a positron will interact with or produce a single photon is measured by one of the great, mysterious constants found in nature; a dimensionless number called the fine-structure constant, equal to about 1/137. For each additional photon the probability is reduced by a higher power of the same factor.

The most likely outcome of the annihilation is therefore the creation of a single photon. As we have seen, however, it cannot be a real particle; it is called a "virtual" photon, and its most important characteristic is that it can never be observed; it can never emerge from the reaction as a normal radiation-type quanta. The virtual photon serves merely as a coupling between the initial electron-positron pair having zero total momentum and some subsequent ensemble of particles that must also have zero total momentum.

The virtual photon is not just a mathematical convenience. It is real. It can never be observed because its lifetime is briefer than the limit maintained by the Uncertainty Principle. Conservation laws apply only to the macroscopic events that can ACTUALLY BE OBSERVED in nature; observations which are made ABOVE the level of quantum uncertainty. Describing events BENEATH the level of uncertainty is like trying to describe what happens inside the event horizon of a black hole, or answering the question: "how high is the sky?" The conservation laws of momentum and inertia (and anything else for that matter) can be violated all over the place as long as it happens at a level below the threshold of uncertainty in quantum mechanics. Any event ABOVE the threshold of the uncertainty principle could actually be observed, in principle, and would therefore have to obey all of the known conservation laws (as all processes observed so far, in fact, do).

In the case of electron-positron annihilation, the virtual photon materializes in less than 10^{-25} second into particles with the correct combination of energy and momentum. This time scale is more fleeting than the uncertainty limit by a factor of around 100 and is the reason why the virtual photon can actually violate (temporarily) the law of conservation of momentum.



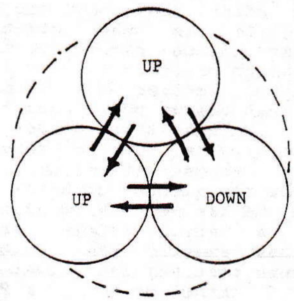
Electrons and positrons can annihilate each-other to form a virtual photon. The photon then decays into particles that conserve the same momentum as the original particles.

When the virtual photon decays, several kinds of particles can be created out of the available free energy. At the energies investigated so far, pairs of electrons and positrons, pairs of muons and anti-muons (leptons), and even hadrons have all been observed.

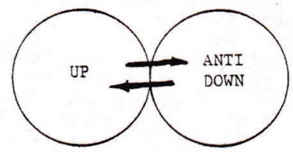
The idea of the virtual particle is very important, because in the quark theory several interactions and many quark "forces" occur below the uncertainty level. These forces and interactions are represented as an exchange of virtual particles.

And now for the quark theory itself. Originally, Gell-Mann proposed 3 different types of quarks which in arrangements with themselves and their 3 anti-quarks, made up all of the hadrons known at the time. The three quarks were arbitrarily named: u, d and s (for up, down and sideways). A baryon is made of 3 quarks. An anti-baryon is made of 3 anti-quarks. A meson is made of 2 quarks: a quark and an anti-quark. Quarks, like the particles they compose, are assigned quantum numbers. All of them have spin angular momentum of 1/2, for example, and baryon number of 1/3. Obviously, in a baryon the three constituent quarks add up their baryon numbers to produce a total baryon number of 1 for the baryon as a whole. Of the original triplet of quarks proposed by Gell-Mann the u quark has a charge of +2/3 while the d and s quarks each have a charge of -1/3. (Anti-quarks, of course, have the opposite quantum numbers.) According to these assignments, the baryons, being made up of three quarks, must have a half-integral spin, a baryon number of +1 and a charge of +2, +1, 0 or -1. The mesons, as aggregates of a quark and an anti-quark, must have an integral spin, a baryon number of 0 and a charge of +1, 0 or -1. A proton is therefore nothing other than the combination of two up quarks and a down quark. A neutron is composed of one up quark and two down quarks. A pi-meson is composed of an up quark and an anti-down quark. In each of these cases, all of the quark properties add up to produce the properties of each composite hadron.

A BARYON
(Proton)



A MESON
(Pion)



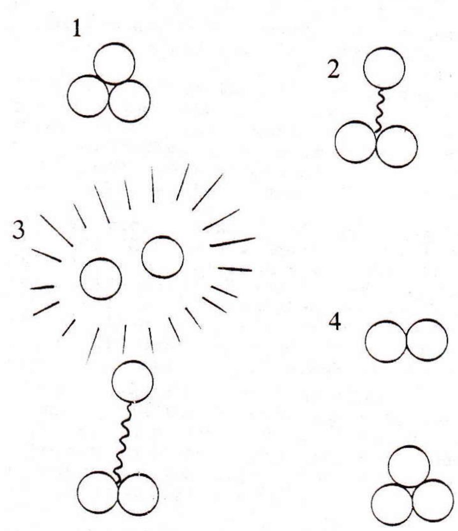
This ingenious scheme neatly accounted for all the particles that had been observed when it was proposed, and it soon proved its predictive power by postulating unknown particles that were promptly discovered. It contained a deeply disturbing peculiarity, however; the quarks were required to be particles with a half-integral spin but they did not behave as such particles were expected to.

As mentioned before, all observed particles with a spin of 1/2 obey the exclusion rule, which demands that no two be in an identical state. Particles with integral spin (Bose-Einstein statistics) such as the mesons and the photon, are not affected by the exclusion principle. The quarks individually, however, possess spin of 1/2 and therefore MUST obey the Fermi-Dirac statistics and abide by the Exclusion Principle. Quarks seem to violate these rules. If three quarks make up a baryon, they must ALL be in the same energy state, which is impossible if the quarks obey the exclusion rule. Two can be in the same state if their spins align in opposite directions (as electrons can do in their energy shells). But there is no way to fit three quarks into one state. This problem can be resolved, fortunately. All that is necessary to make them conform to the exclusion rule is to endow them with a new quantum number having three possible values, so that the three quarks bound together in a baryon, although identical in all other properties, can differ in this new one. The new property is called COLOR, although it has nothing to do with vision or the color of objects in the macroscopic world; in this context color is merely a label for a property that expands the original ensemble of three quarks to nine. Each quark of the original triplet can appear in any of three colors. The convention is to use the additive primary colors, thus, quarks come in colors of red, green or blue. A baryon is composed of three quarks all with different colors, so that the color-total is white or "colorless". A meson is composed of a quark and an anti-quark of the SAME color, but only one normally-colored while the other anti-colored so that their colors cancel out to produce white or no color. The fact that no "colorful" matter has been observed implies that quarks MUST group themselves in ways that make their colors cancel or add up to white. Such a process is un-observable because it occurs at a time scale below the quantum uncertainty level. Therefore we can never know exactly WHICH quark in a baryon triplet or a meson doublet has exactly WHAT color; we can only assume that any individual quark has a 1 in 3 chance of having a PARTICULAR color. Quarks are constantly EXCHANGING color in a "virtual" process that occurs below the level of uncertainty.

This idea of the quarks bound together, exchanging colors, immediately suggests an explanation for the strong nuclear force. The strong nuclear force is only a dim manifestation arising from the exchange of quark colors. The "color force" that glues the quarks together is transmitted by a "virtual" particle not-too-cleverly called a "gluon". The mathematics shows that any number of gluons can occupy the same state and are thus not fermions but bosons.

With quark colors, we now have a partial understanding of WHY it is difficult (and theoretically impossible) to ever observe a quark in isolation. Experiments have been undertaken which try to seperate quarks from hadrons by subjecting them to high energies in an effort to liberate the quarks. All that is observed is that a shower of normal mesons is produced, not an isolated quark. Why this happens is due to the nature of the color force itself. The color force cannot be described as easily as the elecromagnetic force. In electromagnetism the "force" is described by only one quantum number, electric charge, and is carried by only one particle, the photon. This yields a simple mathematical relation which produces the characteristic electric-field that diminishes with the square of the distance. However, quark colors are mathematically defined by TWO quantum numbers called color isotopic spin and color hypercharge, both of which are two varieties of "color charge." These two quantities are necessary to explain why you can have TWO colors (quark-color and quark-anticolor) bound together and have just as easily THREE colors bound together (quarkred, quarkblue, quarkgreen). The ultimate upshot of the two "color charges" is that you get not just one type of color "gluon" but nine (actually eight, because one gluon is redundant). In the mathematics of dealing with TWO quantum numbers, it turns out that the quanta CARRYING the "force field" can GENERATE a "force field" of its own. If you think about it, then, you will get a force field that actually gets STRONGER with distance, not weaker! This happens because each field-quanta gives rise to even more field-quanta. It appears that the gluons create just this type of a "force field".

A kind of field that INCREASES with distance seems to contradict an intuitive sense of how matter ought to behave. Quantum mechanics has contradicted intuition before, and made no apology for it. However, the idea of a force that gets stronger with distance is easily visualized. Just think of two balls connected with a rubber band. If the balls are close together, the rubber band is slack and has no energy. But if you pull the balls apart, suddenly the rubber band gets stretched and tries to pull the balls back together. You have here an analogy in which the rubber band represents a force between two objects that INCREASES with distance. The further you try to separate the two balls, the stronger their "attraction" becomes. The quarks are "glued" together in the same kind of way. As you try to separate the quarks, their mutual color attraction just gets stronger, not weaker. The color force may, indeed, become infinite with increasing distance or it may eventually drop off. No one's sure. Either way, it would take huge amounts of energy to separate the quarks, if not an infinite amount. If you apply energy in trying to separate a quark from other quarks, long before you achieve the energy needed to free the quark you reach a point where the energy applied is just enough to create a quark and an anti-quark pair. The newly created quark replaces the one extracted, and the anti-quark binds to the displaced quark, forming a meson. The result is that a



1. Energy is applied to a baryon.
2. The energy tries to separate a quark.
3. A quark/antiquark pair is created.
4. A new meson is the result, not a free quark.

quark is removed from the hadron but is not set free; all we can observe is the creation of a meson. In short, if you try to free a quark, all you get is a meson for your trouble. This is exactly what has been observed in accelerators.

With the addition of color, other quark properties began to make sense. It was also found that if the s (sideways) quark was assumed to instead carry the quantity called "strangeness" (recall that strange particles had abnormally long life spans), other symmetries from the SU(3) groups could be related. "Strangeness" is represented by the numbers -2, -1, 0 or +1 and is also equal to twice the average charge (the sum of the charges in an SU(3) group divided by the number of particle members in the group) minus the baryon number. By this contrivance strangeness was made to vanish for all of the hadrons except the strange ones.

An analysis of experiments performed in accelerators involving certain "strange" particles produced more violations (again) in conserving "strangeness". Another quantity was invented called "charm" (which needed to be conserved) and accounted for the observed anomaly. Further work on the "charm" hypothesis predicted several types of particle interactions that have since been observed, thus cementing the role of charm in quark interactions.

TABLE OF QUARK PROPERTIES

Quark types	Spin	Electric charge	Baryon number	Strangeness	Charm
u (up)	1/2	+2/3	+1/3	0	0
d (down)	1/2	-1/3	+1/3	0	0
s (strange)	1/2	-1/3	+1/3	-1	0
c (charmed)	1/2	+2/3	+1/3	0	+1
$\bar{u}$ (antiup)	1/2	-2/3	-1/3	0	0
$\bar{d}$ (antidown)	1/2	+1/3	-1/3	0	0
$\bar{s}$ (antistrange)	1/2	+1/3	-1/3	+1	0
$\bar{c}$ (anticharmed)	1/2	-2/3	-1/3	0	-1

So, at present we have a fairly good idea of how hadrons are constituted via the quark theory. Quarks come in four "flavors": up, down, strange, and charm and are "glued" together by an exchange of "colors": red, green and blue. It is understood that the strong force arises from an exchange of quark colors, while conserving the quark "flavors". In weak interactions, such as beta decay, we observe neutrons decaying into protons, electrons and anti-neutrinos; a nice mixture of hadrons and leptons. In quark theory, changing a neutron into a proton involves changing the arrangement of the neutron's quarks (up,down,down) into those of a proton's (up,up,down): in essence a change of quark "flavors". Thus, unlike the strong color force which CONSERVES flavors, the weak force seems to involve a CHANGE of quark flavors. Beta decay, for example, is interpreted as the emission of a W particle (the quanta of the weak force) by a down quark, which converts the quark into an up; the W then decays to yield the electron and anti-neutrino. From this process it follow that the W can also interact with leptons, thus providing a link between the two groups of elementary particles: the quarks and leptons.

The realization that the strong, weak and electromagnetic forces are all carried by the same kind of particle, bosons with a spin of 1, invites speculation that all three might have a common basis in some simple unified theory. Through the weak and electromagnetic interactions, quarks and leptons are related. These interactions "see" the four leptons and distinguish between the four quark flavors. The W particle can induce one kind of lepton, the neutrino, to become a muon (a different lepton). Similarly, the W can convert one kind of hadron, a u quark, into another kind, a d quark; it can also influence the u quark to become an s quark in rare "strange" and " charmed" interactions. The relations between the different forces are starting to become clear, but more work is still needed. At present, a mathematical theory based on what is called "guage symmetry" and "local symmetry breaking" has unified the strong, the weak and the electromagnetic force into one kind of super force. Gravity still is the hold-out and seems to resist most attempts to connect it with the other three forces, although many people are working on the problem.

It would be incorrect to give the impression that the quark model solves everything and that it represents a final unification of atomic physics. Like the 19th century's classification of the chemical elements, so too is the quark theory a descriptive theory. It shows HOW hadrons are built up from constituent particles, not WHY they are built so. Even though some details of the quark theory are a bit fuzzy, if not outright wrong, it is nevertheless an observed FACT that hadrons are constituted by some smaller class of sub-particles; be they quarks or objects very similar to quarks. If in the future the quark theory gets scrapped it will be in favor of a more fundamental, unified theory that includes a thorough description of quantum gravitation. In spite of any changes it undergoes, it is believed that the quark theory, at least in its main features, is correct.

What are some of the problems with the theory? At present, quark theory presents us with 4 flavors and 3 colors yielding a total of twelve quarks; hardly a simple group of elementary particles although it is better than the over 200 known hadrons. The relation of the four quark flavors to the four types of known leptons is not well understood yet, and what understanding we DO possess could be easily upset with the discovery of yet another quark flavor or lepton. There is nothing in the quark theory to prevent additional flavors and indeed nothing really explains why the four that ARE observed must exist at all. That leads us to perhaps the most perplexing part of this whole quark business. Two of the quark flavors, charm and strangeness, are rarely seen in actual natural occurences. The two leptons, the muon and the muon-neutrino are occasionally seen in cosmic rays, but mainly they are made in high-energy particle accelerators. From what we know about sub-atomic physics and the many processes that occur in nature, including nuclear fusion, it seems that by far most of the interactions use only u and d quarks and electrons and neutrinos. It would appear that nature could have made do with half as many fundamental things. Surely the other quarks and leptons were not created simply for the entertainment or edification of physicists, but what is the purpose of such a grand doubling? At this point there is no answer. The only time in the history of the universe that many of the more esoteric quark and lepton properties were active was in the first second of the Big Bang; where energies far exceeded that of even our largest planned particle accelerators. During this so-called "Quantum Era", all events in the cosmos were dominated by virtual quark-like processes. Studying these high-energy phenomena in accelerators gives us an idea of what the early universe was like. The way that matter interacted during the brief "Quantum Era" in the first second after the Big Bang almost certainly influenced the later evolution of the entire universe. Understanding these early conditions is of great interest to the astronomer and cosmologist who seeks to explain why the universe appears the way we see it today.

In summary, it can be seen that the universe around us is built according to the workings of a tiny sub-atomic world. A world in which strange laws of conservation compete against quantum randomness and chance to prevent undisciplined descent into chaos and annihilation. What exactly is "color hypercharge"? What is "isotopic spin"? These quantum numbers can't even be visualized. But that isn't necessary. Nature "visualizes" these conservable quantities for us. This visualization is achieved by their INTERACTIONS. We can "see" what isotopic spin and hypercharge IS simply by looking at a proton. Or a neutron. Or a pi-meson. These observable objects are nothing more than the visible combinations of the quantum numbers that make them up. How these numbers are combined reveals how diabolically clever nature turns out to be. Many of the discoveries described in this article are the result of intense and collective intellectual activity by some of the finest minds the world has ever known. Some of the theories presented have called upon subtle and obscure mathematical arguments that could easily have been overlooked even by highly competent mathematicians. Yet nature has been smart enough to spot them: to build up multiplets from SU(3) symmetry groups, to use the simplest and most beautiful guage symmetry to construct electro-magnetism and to spot loopholes in the mathematics that would otherwise prevent "charm" and "strangeness" from existing. Mathematics and beauty are the foundation stones of the universe. No one who has studied the forces of nature can doubt that the world about us is a manifestation of something very, very clever indeed. -- Jeffery Bass

ASTRONOMICAL EVENTS— JULY, 1984

MOON: The full moon of July is called the Thunder or Hay Moon. The moon is at perigee on the 2nd and 30th (57.6 and 65.8 Earth-radii away respectively), and at apogee on the 18th (63.5 Earth-radii away). The moon passes 0.1°S of Saturn (occultation visible in Africa and the Indian Ocean), and 4°N of Mars on the 7th; 0.4°S of Uranus on the 9th (occultation visible in S. America and southern Africa); 3°S of Neptune and 3°S of Jupiter on the 11th; and 7°N of Mercury on the 30th.

PHASE	DATE	MOONRISE	MOONSET	TIME OF PHASE
First Quarter	July 5	1:34pm EDT	1:38am EDT (6th)	5:04pm EDT
Full Moon	July 12	9:24pm EDT	6:20am EDT (13th)	10:20pm EDT
Last Quarter	July 21	1:01am EDT	2:35pm EDT	12:04am EDT
New Moon	July 28	6:11am EDT	9:41pm EDT	7:51am EDT

MERCURY: Mercury passes 5°S of the bright star *Pollux* (in Gemini) on the 3rd. They are about 12°E of the sun in the evening sky (so they set a little less than 3/4 of an hour after sunset). This elusive planet passes 0.8°S of the star *Regulus* (in Leo) on the 26th. The planet at that time is 27°E of the sun. Mercury is at greatest elongation east of the sun on the 31st (27.3°). This is, however, not a very good apparition for northern viewers.

VENUS: Venus is at perihelion (0.7184 astronomical units from the sun [Remember what an astronomical unit is?]) on the 14th. By the end of the month Venus is about 7° above the western horizon at sunset, at magnitude -3.9. It's still too close to the sun for observing. Wait until September.

MARS: Mars can easily be seen about 25° sbove the SSW horizon about an hour after sunset. The Red Planet is between the bright stars *Antares* and *Spica*, and just South of Saturn. An astronomical unit is the average distance between the Earth and the sun... about 93 million miles. On July 20, 1969 Neil Armstrong and Buzz Aldrin became the first humans to set foot upon the moon.

JUPITER: Jupiter trails Mars and Saturn by about 3 hours, but it is still easily visible in the SE sky after sunset. At magnitude -2.2, Jupiter is the brightest "starlike" object in the evening sky and thus, is very easy to pick out from the jumble of heavenly dots. Jupiter sets at 6:00am EDT on the 14th.

SATURN: Saturn is floating just north of Mars in the SSW evening sky. At magnitude 0.7, it is a bit fainter than the reddish Mars. Saturn is stationary in right ascension on the 13th, resuming eastward motion afterward.

OUTER PLANETS: Uranus is in Ophiuchus, Neptune is in Sagittarius, and Pluto is in Virgo. None of these planets are visible to the unaided eye.

METEORS: Two meteor showers this month and *good news*, the moon won't be in the way for either one. Look for the *Capricornids* on and around the 8th, 16th, and 26th. All these meteors will be slow (about 23-28km/sec.) Best around midnight. On the 29th, the *Delta Aquarids* peak. This shower is actually spread out from July 15 to August 29. Look slightly north of east. Best around 2am. About 10-35/hour.

Monthly Meeting

JULY 13 *7:30 p.m.*

Detroit Observatory Classroom

program: John Salazar on
Emission-Line Galaxies

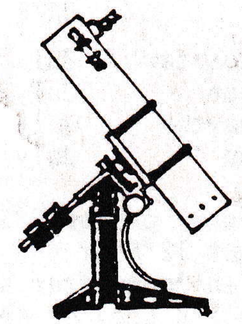
club address:

MSA Office Michigan Union

Ann Arbor, MI 48104

The next open house at Peach Mountain will be on Saturday, July 28. See ya!

Jeffery Bass Editor
1587-8 Beal Ave.
Ann Arbor, MI 48105



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