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The New Particles in High-Energy Physics: What Do They Mean?[1]

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Since the earliest of times man has searched for an underlying unity to the rich diversity observed in nature. That search has taken him from the world of atoms and molecules to the domain of sub-nuclear particles and quarks as powerful accelerators have enabled physicists to probe smaller and smaller distances with higher and higher energies. The last six years have been especially significant in high-energy physics. During this brief period there have been unexpected discoveries of matter described by such whimsical names as "charm" and "beauty." These recent developments are reviewed for the purpose of explaining the role which these new particles may play in attempts to identify the fundamental building blocks of matter.
INDEX DESCRIPTORS: Elementary particles, high-energy processes, quarks

THE AGELESS SEARCH

"...all we observe about us, and ourselves also, may be so many passing forms of a permanent substance..."[2] George Santayana

The search for an understanding of matter at the fundamental level of basic constituents is as old as recorded history. More than 2,000 years ago the Greek metaphysicists were led in various directions in their quest for an underlying unity to the rich diversity observed in nature. Democritus proposed that matter is composed of indivisible constituents, which he named "atoms." Anaxagoras believed in a model of infinitely divisible seeds within seeds, each as complex as the whole. Since the 19th century, this search for nature's basic building blocks has taken scientists from the world of atoms and molecules to the domain of subnuclear particles and quarks.

During the unfolding of this remarkable scientific adventure, one fact has clearly emerged: nature's uncanny knack for creating surprises just when it appears that the end of the search is in sight. This is particularly true now after six rather explosive years of momentous discoveries of new particles, some of which carry properties of matter described by such whimsical names as "charm" and "beauty." In the wake of these unexpected discoveries it is perhaps timely to review these recent developments and explain the role which these new particles may play in attempts to identify the fundamental building blocks of matter.

THE SIMPLE WORLD OF 1932

By 1932 a fairly simple picture of the structure of the world had emerged. All matter was comprised of just four elementary particles (Table 1). The proton and neutron serve as the constituents of nuclei. The electron is vital for the electrical neutrality of atoms and to explain a host of electrical and chemical phenomena. The neutrino was postulated to explain the phenomenon of nuclear beta-decay. At the same time it was recognized that there were four fundamental forces of nature: the strong force identified with the nuclear interaction; the electromagnetic force which is responsible for the interaction between charged particles; the weak force which accounts for such processes as nuclear beta-decay; the familiar gravitational force which acts between any two massive bodies. A summary of the properties of those forces is given in Table 2.

Table 1. **The simple world of 1932**

Leptons	Hadrons
electron (e^-)	proton (p)
neutrino (ν)	neutron (n)

Table 2. **The four fundamental interactions of nature**

Force	Relative Strength	Range	Particles Acted On
Strong	1	10^{-13}cm	hadrons
Electromagnetic	10^{-2}	infinite	charged particles
Weak	10^{-13}	$<< 10^{-13}$cm	leptons, hadrons
Gravitational	10^{-40}	infinite	all particles

Although the four elementary particles have some properties in common (e.g., they all have an intrinsic spin of 1/2), there is a natural division based on whether or not a particle can participate in the strong interaction. The proton and neutron which interact strongly are called *hadrons*(from the Greek word hadros meaning "strong"). The electron and neutrino, which do not interact strongly are called *leptons* (from the Greek word leptos meaning "small"). This picture of matter was very appealing since the role of each elementary particle in the structure of the Universe was essential and clear. It seemed that no other particles were necessary to explain the contents of the Universe. In addition, the four particles displayed what is called "lepton-hadron symmetry" which simply means there are equal numbers of leptons and hadrons. Indeed, the world was very simple in 1932!

THE DISORDERED WORLD OF 1962

During the next thirty years the simple world view was shaken when physicists went on to find a bewildering number of elementary particles. Some came to light from cosmic rays but it was the development of more and more powerful particle accelerators that ignited numerous discoveries of new particles. By 1962 physicists were confronted with a veritable "particle zoo" containing dozens of fundamental particles distinguishable by their masses and other assigned properties (quantum numbers) such as electric charge, spin angular momentum, and baryon number. Most of these particles

Table 3. A partial listing of elementary particles in 1962

Name	Symbol	Mass (MeV/c²)	Charge	Spin	Baryon Number	Strangeness	Lifetime (sec)
				LEPTONS			
electron	e^-	0.511	-1	1/2	0	0	stable
muon	$\mu-$	105.6	-1	1/2	0	0	10^{-6}
electron neutrino	ν_e	0	0	1/2	0	0	stable
muon neutrino	ν_μ	0	0	1/2	0	0	stable
				BARYONS			
proton	p	938	1	1/2	1	0	stable
neutron	n	939	0	1/2	1	0	10^3
lamda	Λ^0	1116	0	1/2	1	-1	10^{-10}
sigma	Σ^+	1189	1	1/2	1	-1	10^{-10}
delta	Δ^{++}	1232	2	3/2	1	0	10^{-24}
chi	Ξ^-	1321	-1	1/2	1	-2	10^{-10}
omega	Ω^-	1672	-1	3/2	1	-3	10^{-10}
				MESONS			
pion	π^+	140	1	0	0	0	10^{-8}
kaon	K^0	498	0	0	0	1	10^{-10}
eta	η	548	0	0	0	0	10^{-18}
rho	ϱ^-	776	-1	1	0	0	10^{-24}
omega	ω	783	0	1	0	0	10^{-22}
phi	ϕ	1020	0	1	0	0	10^{-22}

were unstable with lifetimes ranging from about 10^{-24} seconds (strong decay) to about 10^{-6} seconds (weak decay). A partial listing of the particles known in 1962 is given in Table 3. It seemed as though the structure of matter was growing more complex than simpler.

By then there were four leptons: the electron, the newly-discovered muon, and two types of neutrinos, one associated with the electron and the other with the muon. Most of the new particles were hadrons but with different values of spin and it became necessary to classify hadrons into two categories. Those hadrons carrying integral spin (0, 1, 2, . . .) were called *mesons* and those carrying half-integral spin (1/2, 3/2, 5/2, . . .) were called *baryons.* To further complicate matters, it was discovered that for each particle there is a corresponding antiparticle which is identical to the particle in certain respects, such as mass, but has other properties that are exactly opposite those of the particle.

Among the hadrons discovered there is a class with "strange" properties. Although they are easily produced in pairs from hadron-hadron collisions, thus suggesting they are themselves hadrons, these particles exhibit unusually long lifetimes before decaying to other hadrons. This puzzle was solved by introducing a new attribute of matter called "strangeness" which only these particles possess. If strangeness were conserved by the strong and electromagnetic interactions but violated by the weak force, strange particles could undergo associated production by strong interactions, but could only decay to ordinary hadrons through weak interaction, thus accounting for their long lifetimes. But why do strange particles exist? The role of these particles in the structure of the world was, and still is, a mystery.

THE EIGHTFOLD WAY AND THE QUARK HYPOTHESIS

An important step was made in 1961 to restore order to a rather chaotic situation. In an effort to systematize the growing proliferation of elementary particles, Murray Gell-Mann and Yuvel Ne'eman independently developed a classification scheme known as the "eightfold way".[3] In this scheme, hadrons of the same intrinsic angular momentum and parity are considered to be a "super-multiplet" of particles. The eightfold way is based on the application of symmetry principles and depends on a mathematical techique known as *group theory,* developed at the turn of the 20th century by the Norwegian mathematician S. Lie. It was proposed that the appropriate symmetry group for hadrons is the "special unitary" group of 3x3 matrices known as SU(3).[4] The SU(3) group leads to multiplets of 1, 3, 8, 10, . . . elements. When the SU(3) scheme was applied to the hadrons it was discovered that the spin 1/2 baryons and spin 0 mesons each form an octet pattern. In addition, spin 3/2 barons were shown to fall into a decuplet containing 10 particles. The significance of the SU(3) theory was first demonstrated by the fact that Gell-Mann predicted the mass and quantum numbers of a particle belonging to the decuplet before it had been observed experimentally. The discovery of this "missing" particle, called the Ω^-, in 1964 at Brookhaven National Laboratory with the properties predicted by SU(3), was a great triumph for the theory.

The next major development occurred in 1964 when Murray Gell-Mann and George Zweig pointed out[5,6] that a special grouping of three particles came out of SU(3) theory and all of the properties of hadrons could be expressed in terms of the properties of these particles. They further proposed that all hadrons are actually composed of three different kinds of particles which have spin 1/2 and are fractionally charged. These particles were given the name *quarks* (from a quotation from *Finnegan's Wake* by James Joyce) and were labeled u ("up"), d ("down") and s ("strange"). Each quark would have its own set of quantum numbers (see Table 4) and there would also be a set of three antiquarks, with quantum numbers exactly the negative of those of the original three quarks.

Table 4. **The quark quantum numbers**

Type	Q[a]	B[b]	S[c]
u	2/3	1/3	0
d	-1/3	1/3	0
s	-1/3	1/3	-1

[a]electric charge; [b]baryon number; [c]strangeness

It is remarkable that from this hypothesis one can construct the entire spectrum of hadrons (with their different sets of quantum numbers) out of quarks by following two simple rules. Mesons are made by combining a quark and an antiquark. Baryons are made by combining three quarks. Table 5 gives some examples of the quark composition of various hadrons. Non-strange hadrons contain only u and d quarks while an s quark carries the strangeness quantum number. In the physicist's jargon the different quark types (u, d, s) are often called "flavors".

Table 5. **Classification of particle states in terms of quarks**

Name	Symbol	Quark Composition
proton	p	u u d
neutron	n	u d d
antiproton	$\bar{p}$	$\bar{u}$ $\bar{u}$ $\bar{d}$
lamda	Λ^0	u d s
Sigma plus	Σ^+	u u s
Sigma minus	Σ^-	d d s
pi plus meson	π^+	u $\bar{d}$
pi minus meson	π^-	$\bar{u}$ d
K-plus meson	K^+	u $\bar{s}$
K-minus meson	K^-	$\bar{u}$ s
phi	ϕ	s $\bar{s}$

By observing the rules for combining the quarks, physicists were able to account for all the properties of hadrons. Every known hadron could be explained as some combination of a quark and an antiquark or of three quarks. Moreover, every allowed combination of quarks corresponded to a known hadron. There were *no* vacancies to accommodate any fundamentally new particles in the existing quark scheme.

THE NOVEMBER REVOLUTION OF 1974

This reasonably clear picture of the basic constituents of matter was shattered in November of 1974 with the widely heralded discovery of a new particle which simply could not be accounted for within the context of the conventional quark model. The discovery was announced [7,8] simultaneously and independently by two experimental groups employing vastly different techniques. One group, led by Samuel Ting of MIT and working at Brookhaven National Laboratory, named the new particle J. The other group, led by Burton Richter of the Stanford Linear Accelerator Center (SLAC), named the particle ψ. The new particle became known as J/ψ (although "gipsy" might be more appropriate).

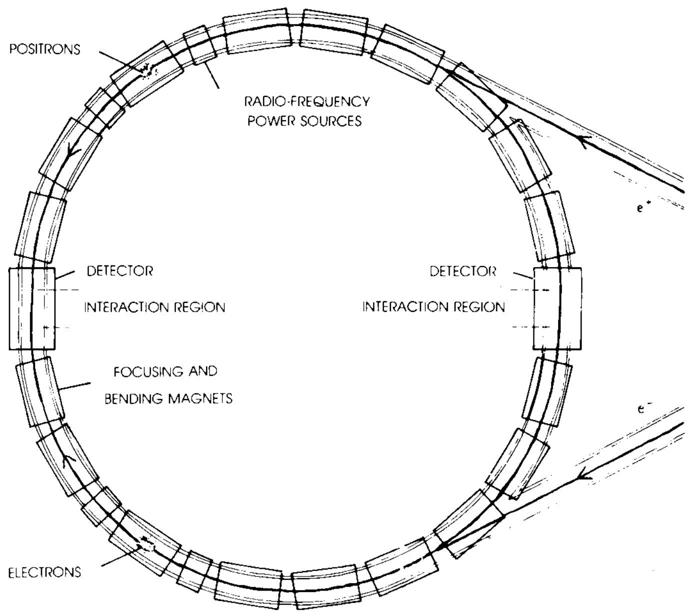

Figure 1. **Counterrotating beams of electrons and positrons in the SPEAR storage ring.**

Down through the years SLAC has played an important role in the study of the structure of matter. In the late 1960's pioneering experiments were performed there in which high energy electrons were scattered by protons and neutrons. These experiments, reminiscent of the earlier Rutherford scattering experiments which unveiled the structure of the atom, revealed that hadrons are composed of point-like constituents which are presumably the quarks originally proposed by Gell-Mann and Zweig.

By 1973 the facilities at SLAC were capable of creating separate beams of very high energy electrons and positrons (antielectrons). Moving at nearly the speed of light, these beams were injected into a large ring called SPEAR and stored there for relatively long periods of time (hours) by means of a magnetic field (see Fig. 1). These counterrotating beams could pass through each other several hundred thousand times per second with each beam having an energy of up to 4 billion electron volts (GeV). When electrons and positrons collide they annihilate each other, producing pure energy in the form of a photon from which new particles might form. An important constraint in the annihilation process is that energy must be conserved and, consequently, the kinds of particles created in the process are limited to those whose masses are no greater than the collision energy, i.e., the combined energies of the colliding electron and positron. Using an elaborate detection system, the experimenters at SLAC were able to discover the presence of any new particles created in the collision process.

The detection of a new particle shows up as a "resonance" in the annihilation process (see Figure 2). The resonance appears as a dramatic increase in the reaction rate $e^+e^- \rightarrow$ hadrons. This indicates that the energy of the incoming beam is exactly right for the creation of a new particle.This phenomenon is similar to the situation in atomic physics. When light is shot at atoms, most of the light passes through. However, if the incoming light has an energy corresponding to one of the energy level differences of the atoms, then the photon absorption rate increases sharply. Some of the properties of the resonance particle can be deduced from analyzing the "bump"

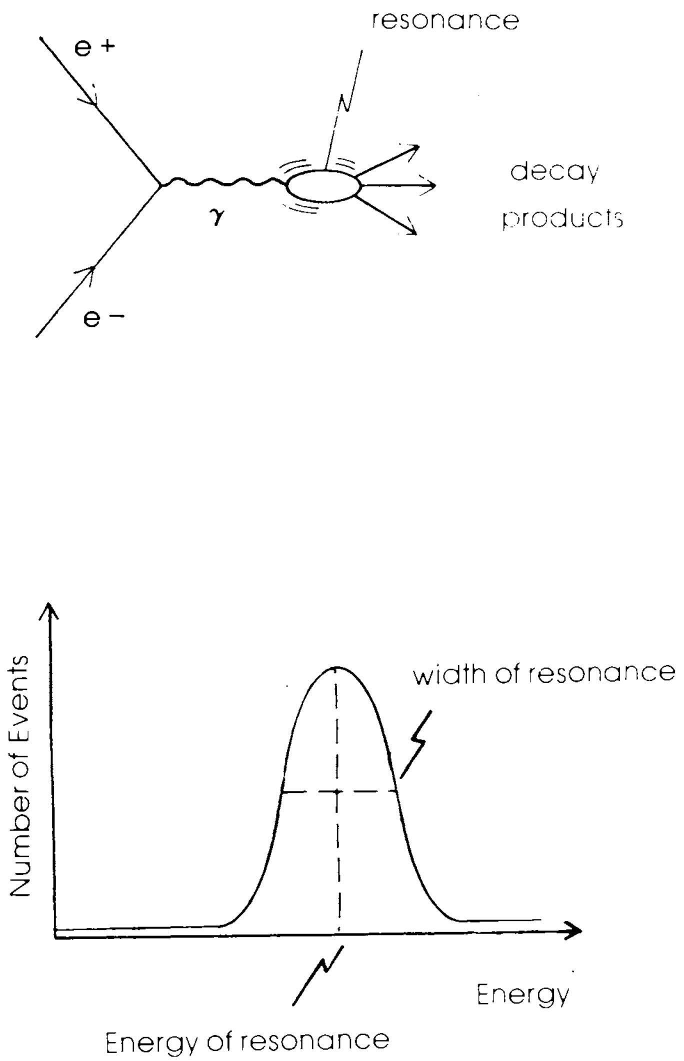

Figure 2. Formation of a "resonance" in a e + e − annihilation experiment.

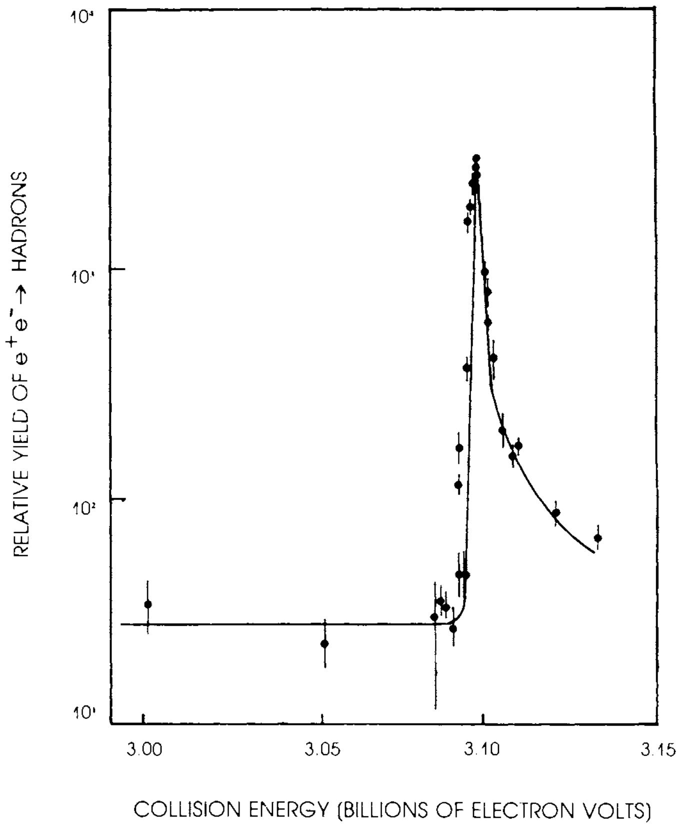

Figure 3. The J/ψ resonance detected in electron position annihilations at SPEAR.

in the reaction rate. The location of the peak reveals the mass of the new particle. The lifetime of the resonance can be determined from the Heisenberg uncertainty principle which states that the resonant width is inversely proportional to the life-time of the state.

On November 9, 1974 a new unstable particle was discovered at SLAC by Richter's group, the very day that the same discovery was being announced by Ting at Brookhaven. The existence of the J/ψ can be seen from a plot of the relative yield of hadrons from electron-positron annihilation versus the collision energy (see Figure 3). A sudden rise in the curve indicates the formation of a new particle at an energy of 3.095 GeV corresponding to the mass of the J/ψ. One puzzling feature of the resonance is its unusually narrow width (~ 60 KeV) implying a longer lifetime than expected for such a massive particle. Something seemed to be inhibiting its decay. Aside from its large mass and narrow width it might have seemed as if the J/ψ was just another ordinary hadron. However, the problem confronting physicists was that in a world made up of three quark flavors, there was no room to accommodate this new particle. To add to the excitement, only eleven days after the J/ψ discovery, the same group at SLAC found[9] a second new particle, the ψ', with a slightly higher mass of 3.684 GeV and believed to be an excited state of J/ψ.

THE CHARM HYPOTHESIS

Among the ideas proposed to explain the properties of the J/ψ, the most intriguing one was that the J/ψ consists of a new flavor of quark and its own antiquark. In fact, the existence of a fourth kind of quark had been predicted[10] in 1970 by Sheldon Glashow of Harvard University in order to overcome certain difficulties in developing a unified theory of the weak and electromagnetic interactions. He gave the new quark the property *charm*. The charmed quark is designated c, the charmed antiquark $\bar{c}$. In this picture the J/ψ consists of a c quark and a $\bar{c}$ antiquark.

The notion that J/ψ is a $c\bar{c}$ bound state also provided an explanation for its narrow width. Such a state would be inhibited from decaying due to an absence of any energetically available decay channels that could be reached without quarks having to change flavor.

Within a year of the discovery of the J/ψ particle, no less than seven distinct $c\bar{c}$ states had been detected. It was clear that a rich spectrum of closely related states was emerging. The bound system of a charmed quark and a charmed antiquark in many ways resembles a simple hydrogen atom, and the name *charmonium* was applied to all the states of this system. Charmonium is analogous to another exotic atom-like species, positronium, which is a bound state of an electron and a positron. As shown in Figure 4 the various states

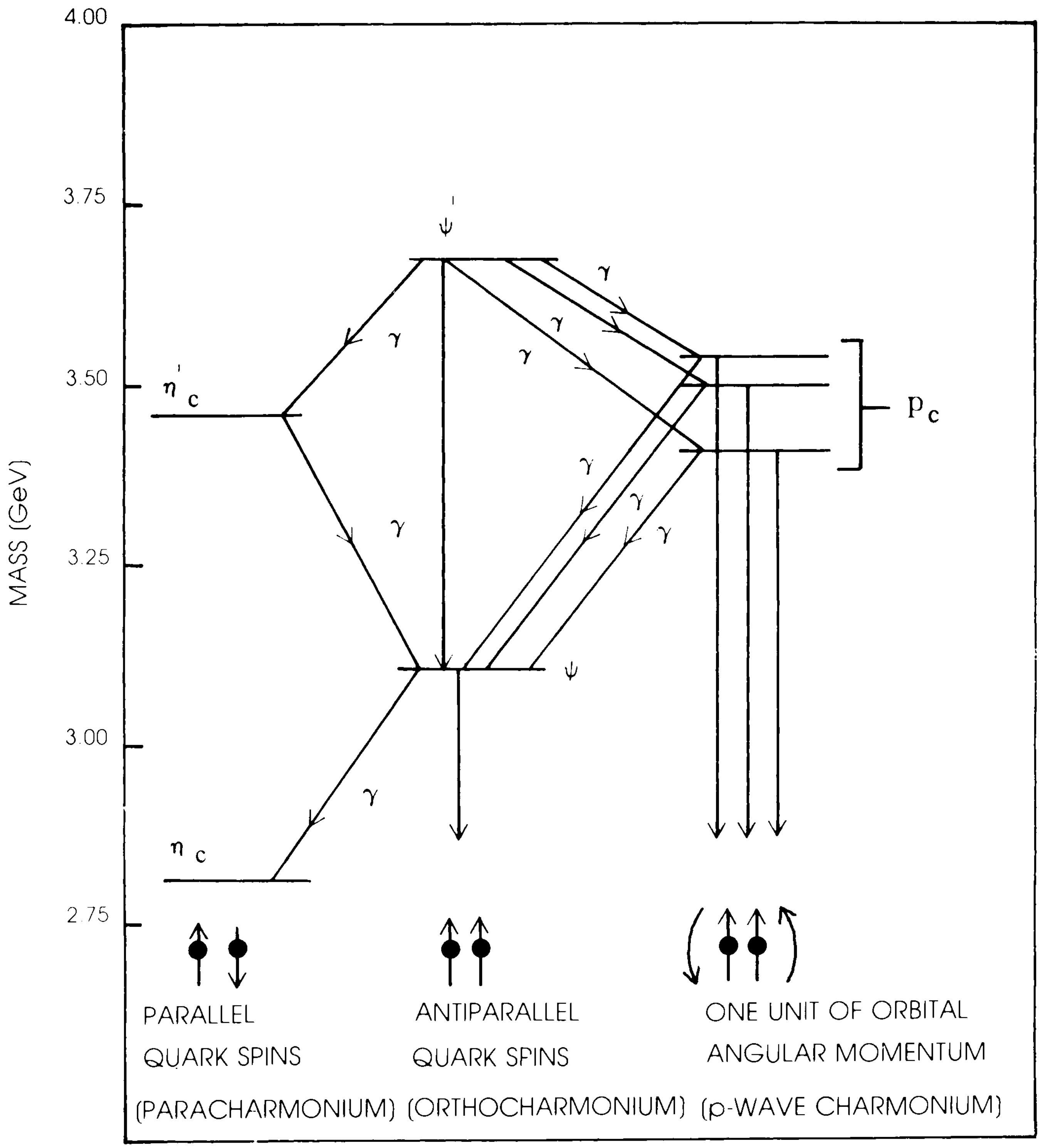

Figure 4. Spectrum for Charmonium.

of charmonium are distinguished by various combinations of spin and orbital angular momentum. As in the spectrum of energy levels in an atom, one state can be transformed into another of lower energy through the emission of a photon.

Although the J/ψ contains charmed quarks, it has no net charm since it contains a quark and its own antiquark whose charm quantum numbers cancel. On the other hand, if the charm hypothesis were valid, there had to exist new particles which carried net charm

Table 6. Charmed particles

Name	Quark Content	Strangeness	Charm
	MESONS		
D^0	$c\bar{u}$	0	1
D^+	$c\bar{d}$	0	1
F^+	$c\bar{s}$	1	1
$\bar{D}^0$	$\bar{c}u$	0	-1
D^-	$\bar{c}d$	0	-1
F^-	$\bar{c}s$	-1	-1
	BARYONS		
Λ_c^+	c u d	0	1
A^+	c u s	-1	1
A^0	c d s	-1	1
Σ_c^{++}	c u u	0	1
Σ_c^0	c d d	0	1
T^0	c s s	-2	1
X_u^{++}	c c u	0	2
X_d^+	c c d	0	2
X_s^+	c c s	-1	2

("naked charm"). Charmed mesons and baryons would be formed by combining the charmed quark with the original three quarks according to the usual rules (see Table 6). The search for particles with bare charm suddenly became a preoccupation of high-energy physicists.

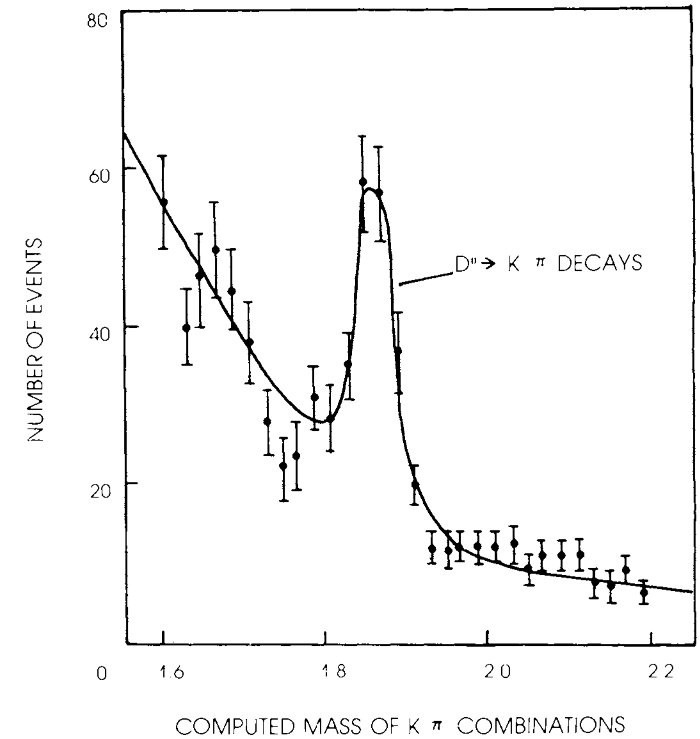

Figure 5. Experimental evidence for the first charmed particle, the D°.

THE DISCOVERY OF CHARMED PARTICLES

The search for particles with charm proved to be difficult. The lightest of the charmed particles was expected to be unstable and to decay by means of the weak interaction (which does not conserve the charm quantum number) into particles without charm. But because these charmed particles had to be rather massive there were many possible sets of decay products and it was difficult to design an experiment without knowing the most likely decay modes of charmed particles to look for. A way out of this difficulty was found when it was realized that the weak interaction theory proposed earlier by Glashow required a special relation to exist between the charmed quark and the strange quark. Because of this relation weakly decaying charmed particles should usually include strange particles among their decay products. The K-meson, the strange particle of lowest mass, should therefore serve as a distinctive signature of events involving the decay of charmed particles.

In the spring of 1976, a group at SLAC from the Lawrence-Berkeley laboratory were examining[11] electron-positron collisions at energies above the mass of the ψ' resonance. They were particularly interested in multi-particle events in which there are long-lived particles that included K-mesons among the decay products. From measurements of the momentum of the decay products in each event, the mass of the parent particle was calculated. They found for the classes of events involving a single K-meson and a single π-meson in the final state that the majority of the computed masses were clustered at a single value (see Figure 5) corresponding to a mass of 1.863 GeV. Thus, the first charmed particle was discovered and named D^0. The D^0 is a meson composed of a c quark and a $\bar{u}$ antiquark. Soon after this discovery the charged counterparts D^+ and D^- were discovered as well as the first charmed baryon Λ_c.[12] Several searches for other charmed mesons and baryons predicted by the quark model are currently underway. With the discovery of charmed particles there was no longer any serious doubt about the existence of charmed quarks.

For the discovery of the J/ψ particle, Ting and Richter shared the 1976 Nobel Prize for physics. In 1979 Sheldon Glashow, the father of charm, was awarded the Nobel Prize for physics along with Steven Weinberg and Abdus Salam for their work on the unification of the electromagnetic and weak forces.

THE NEED FOR COLOR

Despite the enormous success of the quark model in describing the structure of hadrons, there were a few nagging problems that remained to be solved. One problem was that no free quarks had ever been observed despite attempts to detect them.[13] Why does nature prevent quarks from existing outside of hadrons? Another problem was related to a fundamental law of nature, the Pauli exclusion principle. This principle states that when two or more spin 1/2 constituents form a particle, they cannot have exactly identical properties. Indeed, the periodic structure of the atomic elements is a direct consequence of the exclusion principle. However, the observed particle Δ^{++} is composed of the quark combination uuu where all quarks are identical. Thus, there would appear to be a violation of the exclusion principle.

A way out of these difficulties is to propose[14] that the quarks, in addition to their distinctive flavors (u, d, s, c) also come in three different "*colors*". The colors are arbitrarily named red (R), blue (B) and green (G). Each antiquark comes in each of three anti-colors ($\bar{R}$, $\bar{B}$, $\bar{G}$). Furthermore, it is proposed that physically observable particles must always be *color neutral* (nature is "color blind"!); that is,

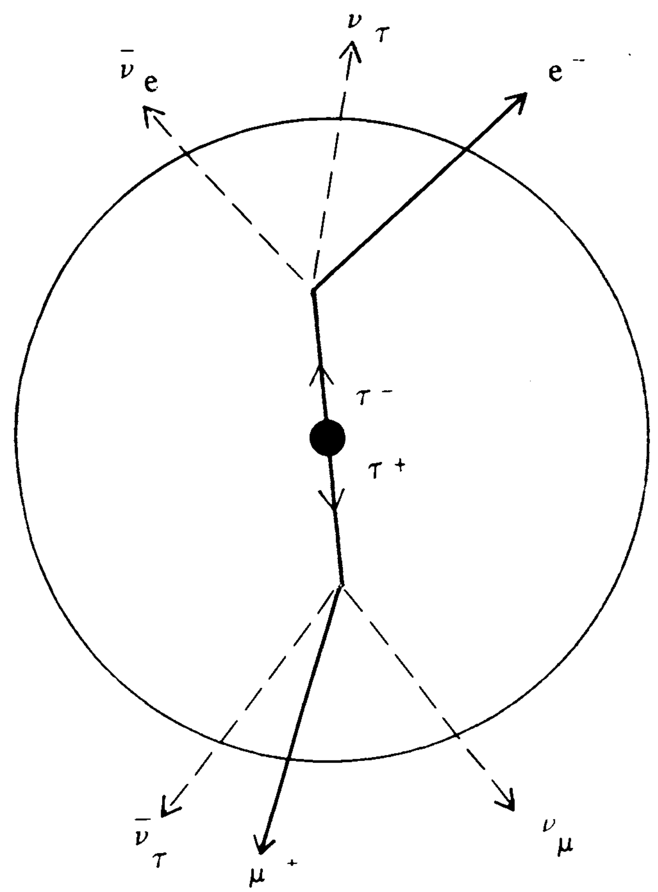

Figure 6. Discovery of the tau lepton from a typical electron-muon event observed at SPEAR.

they must consist of three quarks with different colors (which neutralize each other) or of a pair of a quark and antiquark of the same color (which cancel each other). Here color is merely a descriptive word used to indicate a new property of the quarks which can be used to distinguish quarks of the same flavor.

The introduction of three colors reconciles the existence of a uuu particle and the exclusion principle because each of the three u quarks must be of a different color in order to make the particle color-neutral. Thus the three quarks are not truly identical. On the other hand, no free quarks are observed because they would be color objects violating the color neutrality postulate.

The color quark model makes several predictions in essential agreement with the experimental data. Furthermore, it provides a theoretical framework for the explanation of the forces that exist between quarks and leads to a dynamical theory of quarks known as *Quantum Chromodynamics* (QCD). Whether QCD is correct or only an approximation is very much an open question. More decisive tests are needed and one is hopeful that they will be forthcoming in the near future.

DISCOVERY OF HEAVY LEPTONS

While the notion of charm was being pursued, an unexpected development occured in the lepton family—the discovery of a new generation of leptons which are heavier than the previously known electron and muon. The idea of the possible existence of heavy leptons was in the air for some years but the decisive experiment[15] was done at SLAC in 1975. From e^+e^- colliding beam studies it was found that a pair of oppositely charged heavy leptons were produced from the e^+e^- annihilation process. Each of these leptons would then rapidly decay into an electron or a muon and a pair of neutrinos (see Figure 6). The new lepton was given the name tau [τ] and its mass has been measured to be around 1.78 GeV, about twice the mass of the hydrogen atom.

Less information is available about the neutrino associated with the tau lepton. It seems to be very light, if not massless, and different from the two other neutrinos. The direct detection of tau neutrinos is difficult because the $\tau^\pm$ is more difficult to produce than light leptons.

Another recent development in the world of leptons involves the mass of the neutrinos. Although it had been generally believed that all kinds of neutrinos are massless, a recent experiment[16] carried out in the Soviet Union has yielded some tantalizing evidence that neutrinos have a small but non-zero mass (~34 eV). One consequence of massive neutrinos is that they can switch from one form of neutrino to another ("neutrino oscillations") and thus destroy a long held conservation law known as "conservation of lepton number". Confirmation of the phenomenon of neutrino oscillations must await future experiments.

BEYOND CHARM

The discovery of new leptons led to increased speculation that there are additional flavors of quarks which are heavier than the u, d, s, and c quarks. One motivation for new quarks was based on the notion of quark-lepton symmetry that matches the number of quarks with the number of leptons. With the discovery of the tau lepton and its associated neutrino, there were then six leptons. Thus, for quark-lepton symmetry to be restored, two new quarks labeled t and b (for "top" and "bottom" or "truth" and "beauty") had to exist.

Table 7. Quarks and leptons

Name	Symbol	Charge	Mass (GeV/c^2)
Quarks Spin = 1/2, Baryon Number = 1/3			
up	u	2/3	small
down	d	-1/3	small
strange	s	-1/3	0.15
charm	c	2/3	1.5
bottom	b	-1/3	4.5
top	t	?	?
The corresponding *Antiquarks* have the same mass and spin but opposite baryon number and electric charge.			
Leptons Spin = 1/2, Baryon Number = 0			
electron	e^-	-1	0.0005
electron neutrino	ν_e	0	0
muon	μ^-	-1	0.105
muon neutrino	ν_μ	0	0
tau	τ^-	-1	1.78
tau neutrino	ν_τ	0	?
The corresponding *Antileptons* have the same mass and spin but opposite electric charge.			

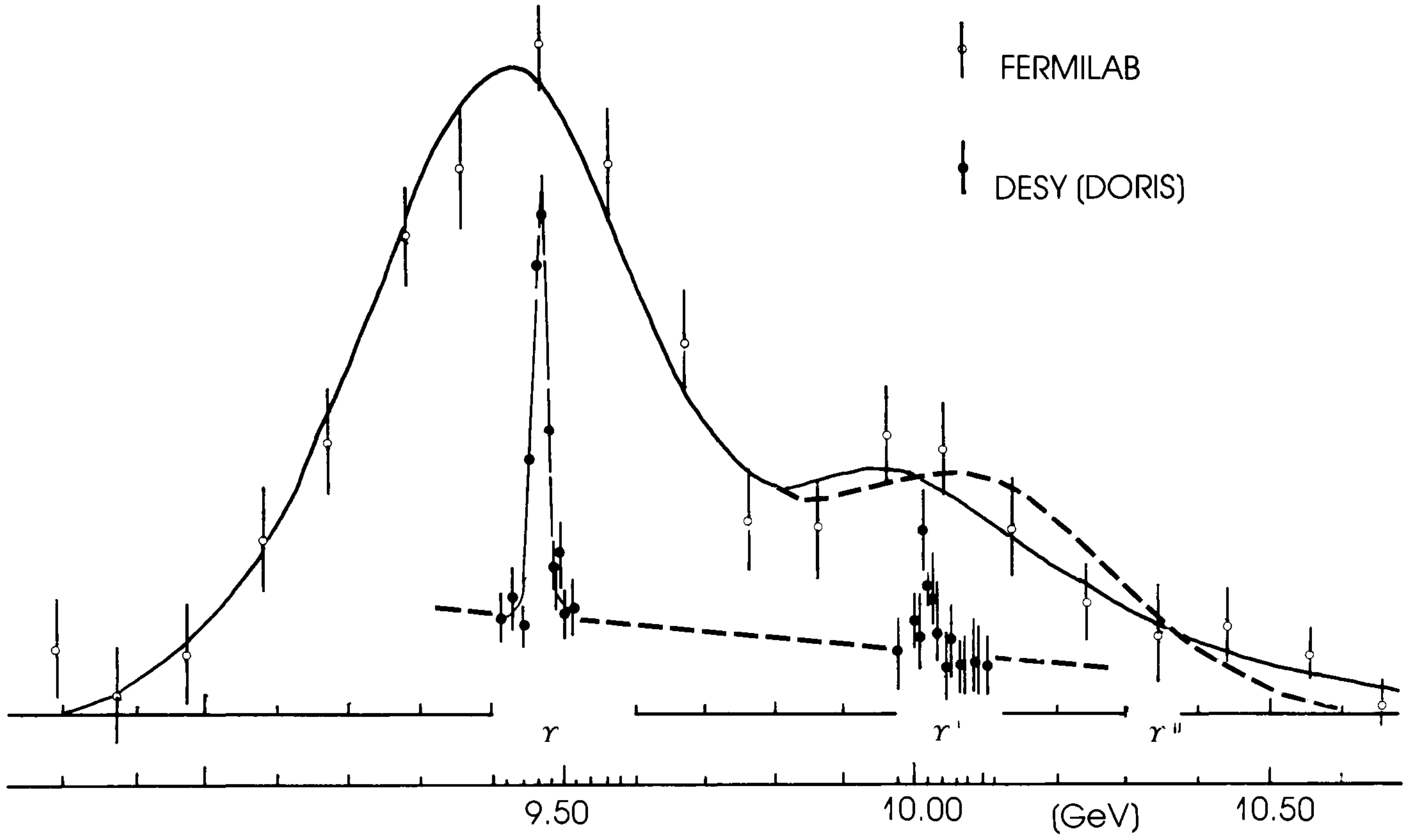

Figure 7. The production of the Υ particles as observed in proton-proton collisions at Fermilab (open circles) and in e^+e collisions at DESY points.

In 1977 an experiment was carried out by Leon Lederman and coworkers[17] at the Fermi National Laboratory which led to the discovery of two new particles with masses of 9.46 GeV and 10.02 GeV. These states were interpreted as belonging to a new family of $b\bar{b}$ states ("bottomonium") and were named the upsilon resonances Υ and Υ'. Since then two more upsilon states (Υ'', Υ''') have been detected[18] (see Figure 7). However, being $b\bar{b}$ bound states, the upsilon mesons would exhibit no net bottom flavor (just as charmonium has no net charm). It was generally believed that the case for the new quark flavor could not be made until one had actually seen "bare bottom" states-particles containing an unpaired b or $\bar{b}$ quark. (The reader who finds this vivid nomenclature objectionable may wish to consider the only alternative usage in general circulation—"naked beauty"). There is strong evidence recently reported[19] by CESR, the electron-positron storage ring at Cornell University, for the existence of bare-bottomed B mesons. Also, the properties of B mesons thus far measured appear to be in good agreement with the expectations of the quark model.

To date the top quark has not been found. However, it is generally believed that it will be discovered when higher energies are reached with the next generation of accelerators. When the top quark is seen the world of fundamental particles will be represented by six quarks and six leptons as shown in Table 7.

IS THE END IN SIGHT?

It would now appear that things are beginning to get out of hand again. We seem to be witnessing another alarming proliferation of fundamental particles: six leptons and six quarks (actually eighteen quarks if one includes color). Might not additional quarks and leptons be discovered as higher and higher energies are achieved by future generations of accelerators? A clue to the answer to this question may be found from observational cosmology. Some claims have been made[20] that, from the big bang theory and the observed abundance of ^{4}He in the Universe, the number of different kinds of massless neutrinos should be less than seven. This would suggest that there may be only a few more generations of quarks and leptons left to be discovered. On the other hand, what about the quarks themselves? Are they truly fundamental or are they in turn comprised of more fundamental entities ("preons", "tetons", "quaits" and "quixes", etc.)?

In 1947, George Gamow wrote down his version of the future of particle physics in the following terms (underlined by us):

"...we have now sounder reasons for believing that our elementary particles are actually the basic units and cannot be ***subdivided further***... The properties of elementary particles of modern physics are ***extremely simple***... We are now left with ***only three*** essentially different entities: nucleons, electrons and neutrinos. And in spite of our greatest desire and effort to reduce everything to its simplest form, one cannot possibly reduce something to nothing. Thus it seems that we have actually ***hit the bottom*** in our search for the basic elements from which matter is formed!"[21]

With all due respect to George Gamow, we cannot conclude on such a statement. Perhaps a more clear-sighted view of today's situation in particle physics is expressed in the following quotation:

"...There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy..."[22]

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3. From a saying attributed to the Buddha: "Now this, O monks, is the noble truth of the way that leads to the cessation of pain; this is the noble *Eightfold Way:* namely, right views, right intention, right speech, right action, right living, right effort, right mindfulness, right concentration."
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In Memoriam

Delma E. Harding, emeritus professor of Zoology and Secondary Education at Iowa State University, died February 1, 1982 at age 76. Born March 17, 1905 in Iowa City, she earned her B.A. (1929) and M.S. (1938) from the State University of Iowa, then taught in Iowa high schools at Bayard, Sharon Center, Lisbon, and Newton, where she headed the Science Department in 1939. Her teaching, characterized by its innovative "hands on" approach, gained her a reputation for excellence.

She also worked with the Public Health Service on the anopheles mosquito, and taught at the University of Tennessee and Illinois Normal College. She received her Ph.D from Iowa State University in Zoology in 1953, and taught there until retiring in 1975.

Dr. Harding conducted parasitology research, taught introductory human anatomy and physiology, and co-authored a popular lab manual for basic physiology. She is perhaps best known for the Science Teacher Training Program, in which she taught and supervised student teachers. She co-authored the useful resource book "Creative Biology Teaching" and contributed to the *Iowa Science Teachers' Journal* and other journals of science education. Delma organized the biology portion of the annual ISU Science Teachers' Short Course, directed N.S.F. Summer Institutues, and served as visiting professor in high schools.

Dr. Harding was active in the Iowa Academy of Science and received its 1978 Iowa Science Teacher Award. She received ISU's Outstanding Teacher Award (1957) and was honored by Mortar Board (1957), Alpha Lambda Delta (1957), Tomahawk (1962), and Lampos (1962).

Delma added immeasurably to the quality of student life and education. Her positive, sincere outlook encouraged students to grow, and her open door policy at work and at home provided them with a place to drop in for friendly conversation. She sponsored a number of foreign students' educational experiences in this country and provided a home for students from many lands. Her contagious optimism cheered and inspired students and faculty alike.

Dr. Harding's dedication to secondary science teaching is memorialized by and ISU alumni achievement fund. Contributions may be sent to: Delma Harding Educational Fund, Alumni Achievment Foundation, Memorial Union, Iowa State University, Ames, Iowa 50011.

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