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STRANGE PARTICLES*

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Physics is the fundamental science of the natural world. It is fundamental because it is singularly successful in asking and answering questions about such basic features of the world as: time, space, motion, force, matter, electricity, light, and radiation, and some feature of every event that occurs in the natural world can be explained in these terms. Physics is an experimental science. Every concept and theory, every model is based ultimately upon experimental findings—what *does* happen in nature. Figure 1 shows the regions of activity of physics. Physics prior to the beginning of the twentieth century is now known as classical physics. Then came relativity physics to supplement the classical laws at higher speeds, and quantum physics was required to describe exceedingly small objects. This is not to imply that classical physics ceased abruptly in 1900, for many competent physicists are still working in classical problems. The rectangle in the upper left region is relativistic quantum physics, and the strip at the left is the great unknown which is presently challenging some of the best physicists in the world. (Note, the only line in the sketch which should be sharp and definite is the horizontal line at the top. It is the speed of light in a vacuum. All the boundaries between regions should be even more fuzzy than shown and the two axes are floating because both of them are logarithmic.) On this "map" I have spotted 14 well-known objects, all of which can be regarded as particles.

If we preserve the same size scale on the abscissa and calculate the kinetic energy for these particles, we obtain the results in figure 2. I have arbitrarily left out the electron microscope spheres, the snail, and the Mossbauer device, but I was *forced* to leave out the Mercury satellite, the jet airplane, and the earth. The energy of the satellite and jet on this scale are both 100 billion times higher. (Since cost is approximately proportional to energy, we can see why satellites are more expensive than protons). We are already encountering the scale problem.

SCALE

A preliminary evaluation of the scale of objects is very valuable at the outset of an investigation of a physical system. The relative importance of physical laws changes with change of scale. For large objects, like suns and planets, gravitation is the dominant force which is responsible for their spherical shape. We analyze the change in behavior of a system as we change its scale to uncover clues to new physical relations. Such a fact was recognized by Galileo (but ignored by Jonathan Swift) when he showed that human beings of 12 times our own height cannot exist merely by scaling up our own measurements by a factor of 12. As we go to the realm of small objects we can see why there are no warm-blooded animals much smaller than a mouse and why Lilliputians, as scale models

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*An edited transcript of the presidential address delivered at the banquet of the Annual Meeting of the Ohio Academy of Science, at Western Reserve University, Cleveland, Ohio, on April 24, 1964.

of us, are utterly impossible. Traditionally, the scale of man's own size has affected the way he sees the world. "It has been largely the task of physics to try to form a picture of the world which does not depend upon the way we happen to be built. But it is difficult to rid ourselves of these effects of our own scale. We build big roads and bridges, which are long and thin, but are essentially not three-dimensional, complex structures. The very biggest things we can make which have some roundness, which are fully three-dimensional, are buildings and great ships. These fall far short of being a thousand times longer than men in their linear dimensions. Nor can we build a watch scaled down to 1/1000 of our own length. Within this range of magnitudes lies all our engineering" (PSSC, 1960: 48).

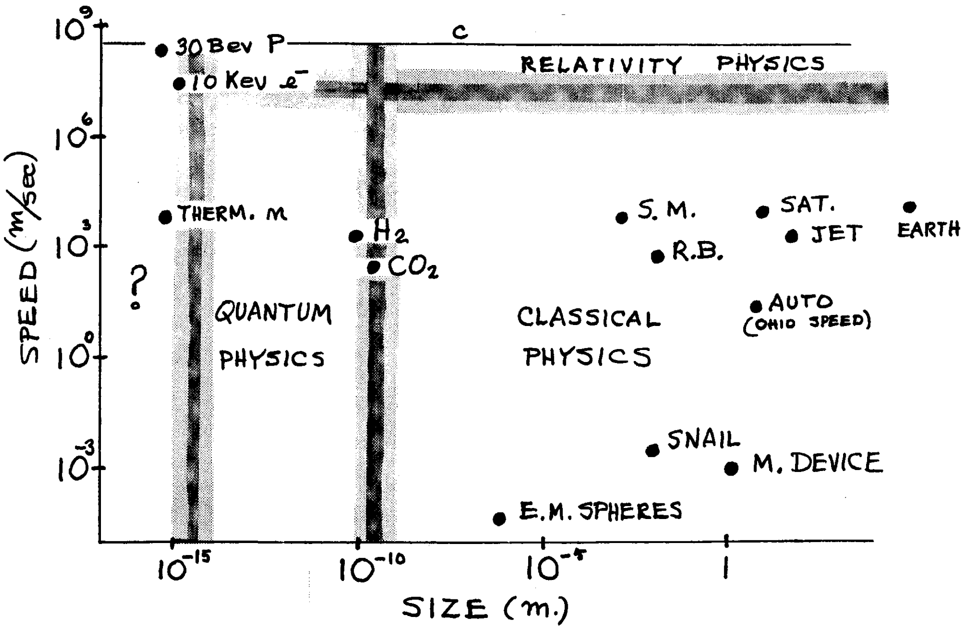


FIGURE 1. Regions of activities in which physicists engage. The speed and size of certain well-known particles are indicated as follows:

30 Bev proton
10 Kev electron
thermal neutron
hydrogen molecule (at 20C)
CO_2 molecule (20C)
electron microscope calibration spheres moving at 5×10^{-4}m/sec
small meteorites
rifle bullet
average snail
Mercury satellite
auto at 60 mph
707 jet airplane
Mossbauer device slow drive
Earth orbital motion

RANGE

Physics, on the other hand, goes outward to the galaxies and inward to the nucleus of the atom. Physics has no arbitrary bounds in time or space. Physicists have measured times from 10^{-20} sec, the lifetime of resonant particles, through 10^{17} sec, the lifetime of some isotopes, to 10^{18} sec the expected lifetime of the sun. Thus the time scale extends over a factor of 10^{37}. We have measured distances from 10^{-15} cm, the wavelength of 30 Bev protons produced by Brookhaven and CERN, to 10^{20} cm, the greatest distance ever measured by parallax. The distance scale extends over a factor of 10^{35}. Thus on the time scale we have stretched our muscles about 100 times better than we have in space.

Let us indulge in some mystical speculation for a moment. We ask: is it possible to choose a unit of length which lies exactly in the middle of this range of lengths? (*i.e.*, my math friends would say 10^0.) Yes, it is just under 2 m—

about the height of a man. Can we do the same for the time scale? Yes, it is about 1/10 of a second. My zoology friends tell me that this is just the period of a normal muscle tremor found in human beings! ! !

PARTICLES

A particle can have almost any size, from the very large to the very small. The first scientific concept of a particle emerged slowly from the work of Copernicus, Kepler, and Galileo, and culminated in Newton's law of gravitation. Before that time the speculations of Democritus and Dalton's law of constant chemical composition remained silent about the characteristics of the basic particles. My references to planets and atoms in the same breath are intended to emphasize that the *particle* concept may represent anything from planets to protons, from white dwarfs to photons. The important idea is that any object may be conceived of as a being without extension but retaining certain other properties of the object appropriate to the problem.

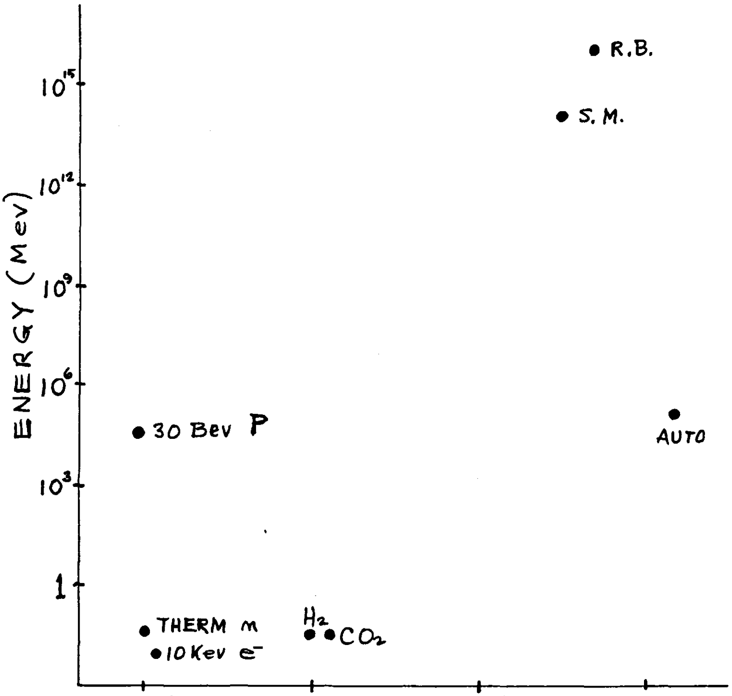


FIGURE 2. Kinetic energy for each of some of the particles shown in figure 1. Even on the log scale the energy of the satellite would be represented by a point above the x-axis about three times that of the rifle bullet.

A particle is a particle regardless of size;
The properties of some article exist in disguise.

The basic criterion in ascribing the attribute of *particle* to any object is the relative distance of the observer. A jet airplane so far away that you can see only its vapor trail is indeed a particle. If you are in a Cessna 180 near the Lockbourne air traffic pattern, you have serious misgivings about the particle-like nature of the same jet screaming toward you from 100 yards away. And if you are riding *in* the jet you are acutely aware of the bewildering non-particle-like array of dials, switches, levers, etc. Thus, for certain experiments in thermo-physics an atom may behave as a particle whereas the explanation of bright line spectra requires that the atom be represented as a complex structure of other particles.

The scientist postulates a model of the system to be studied. The model required by the problem must be appropriate to the problem; there must be a correspondence between the model and its prototype. A single correspondence may be extremely useful, as in the diagrams of football plays. Here the eleven circles and the real football team share just one property—mobility in two dimensions. But any one of these circles would serve very poorly as a tackling dummy because here the required property to be shared between model and player is the inertia of both. Conversely, tackling dummies would be quite unsatisfactory in "skull practice" on the blackboard. In short, a particle may be thought of as a geometric point, if by so doing, certain other fruitful correspondances are preserved. But don't ask me to define a geometric point. Thirty years ago my teacher confidently proclaimed that a point was "position without magnitude," which has sometimes been used by toastmasters to describe university deans. Today the mathematicians solemly swear that a point is an "undefined geometric element concerning which it is postulated that at least two exist and that two suffice to determine a line". Whether this new definition arises from insecurity of mathematicians or protest from deans I'll leave to the philosophers to explain.

I shall discuss several points all of which would be represented by geometric points under certain circumstances, all of which are particles in the broader sense, and all of which seem strange at first blush. As you live with them and get onto a first name basis with them their strangeness disappears and they become more fascinating, more of a challenge, and more successful in predictions of events in nature, which after all is the principal charge that a scientist has.

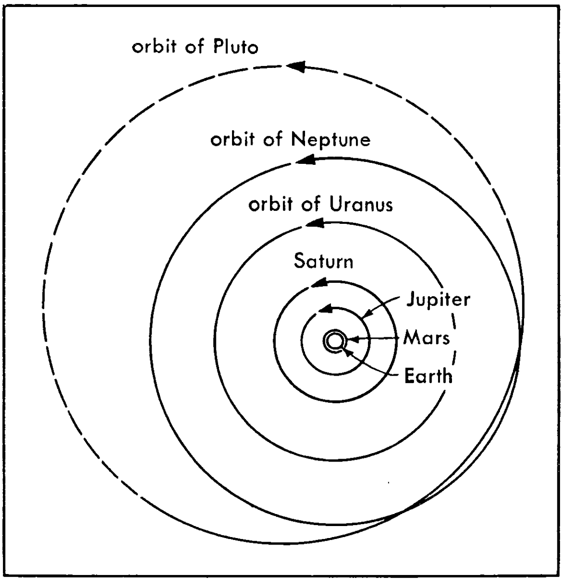
CLASSICAL PARTICLE CONCEPT

We shall now trace the development of the classical concept of a particle from Copernicus to Newton. You remember that the planets are very small compared with the sun. In fact the mass of the sun is 750 times the total mass of all the planets. Figure 3 shows their relative sizes. Our moon and the other natural satellites are so small they can't be seen here. Figure 4 shows the sun and parts of the orbits of the four inner planets. The figure has a scale of $1\ \text{mm} = 1.4 \times 10^6$ Km. At this scale the planets are too small to appear even as dots because, for example, Mars has a diameter of 1/200 that of the sun. The dot on earth's orbit is really the orbit of the moon. Enlarging this 10 times to get the next representation of only the sun and earth produces a figure too large to depict on this page, for the sun and the earth would be 5 ft apart, the moon's orbit a circle of 3 mm radius, and the earth a dot. Since it now appears impossible to show in a single figure both the relative sizes and the distances of the planets on the same scale I have enlisted the aid of a colleague for a demonstration of the next factor of 10. He's had no warning of this. I hold this grapefruit—which represents the sun. On this same scale the planets appear as follows:

Mercury—a mustard seed	25 ft away (Dr. John Major at Table 4)
Venus —a B-B shot	48 ft away (Grandfather clock)
Earth —a B-B shot	66 ft away (elevator)
Mars —a radish seed	100 ft away (garage entrance)
Jupiter —0.6 golfball	344 ft away (Rockfeller Church spire)
Saturn —0.6 ping pong ball	615 ft away (Chester Ave. new curb)
Uranus —a small marble	1250 ft away (Euclid Avenue)
Neptune—a small marble	1950 ft away (President Millis' Office)
Pluto —?	2500 ft away (Tudor Arms)
Nearest Star—Grapefruit	2800 miles away (Anchorage, Alaska)

You recall that the Polish Canon Nicolas Koppernigh, often known by his

Latin name Copernicus, at the age of 70 received into his hands on his deathbed the first copy of his only published work. It attempted to show that the sun is the center of the solar system and that the planets, including the earth, revolved about the sun, and that the earth revolved about its own axis. It represented a Herculean effort to break with the tradition of Plato, Eudoxus, Apollonius, Hipparchus, and Ptolemy, all of whom had the solid support of the church.



PSSC Physics
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FIGURE 3. Approximate orbits of the principal planets. (The orbits of Mercury and Venus are too small to show on this drawing.) They are very nearly circles, except for Pluto, and are in almost the same plane. Only careful measurements show them to be elipses. The orbits of Pluto and Mercury are the most elliptical, and the plane of Pluto's orbit makes an angle of about 17° with the planes of the other orbits. In the figure, the portion of Pluto's orbit below the plane of the paper is shown by a dashed line.

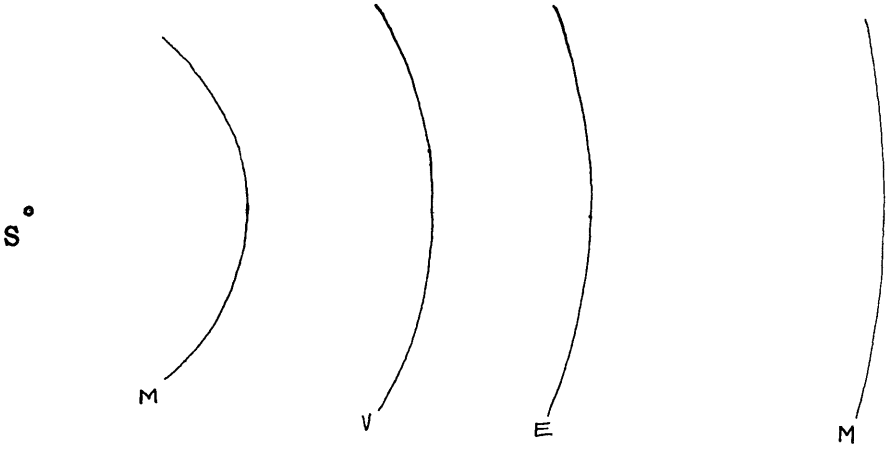


FIGURE 4. The sun and arcs of the orbits of Mercury, Venus, Earth, and Mars drawn to the same scale. The planets are too small to appear even as dots.

Tycho Brahe, a wealthy Dane, could not accept the Copernican system and he devised the largest and most accurate measuring instruments known at that time. Over a period of 38 years he catalogued the positions of thousands of stars so accurately that many of his observations are still used today. His planetary angular positions contain no error larger than 1 minute of arc—and all this without telescopes! His background of a tempermental family, addicted to gluttony, roisterous wine-bibbling, and dueling gave no hint of the patience and care with which he recorded these data. In fact there were two basic paradoxes in Tycho's life. First, his inheritance intruded upon his science. For example, as a youth his nose was cut off in a duel, to be replaced by a bridge of silver and gold alloy; and he died following a bout of excessive drinking. Second, his pupil Johannes Kepler, used his data to establish firmly the very heliocentric model of the solar system which Brahe had hoped to destroy.

The facts of Kepler's life form a fascinating digression. He kept a meticulous journal from which we learn that he was a sickly child, with thin limbs and a large, pasty face surrounded by dark curly hair. He was born with defective eyesight—myopia plus anocular polyopy. His stomach and gall bladder gave constant trouble and he suffered from boils, rashes, and hemorrhoids. His wife bore him five children, two of whom survived, and she died at the age of 37. At the age of 26 he compiled a kind of geneological horoscope embracing all members of his family. It is a remarkable document. One fascinating excerpt when he writes of himself is: "I have investigated the matter of my conception which took place in the year 1571, May 16, at 4:37 AM. My weakness at birth removes the suspicion that my mother was already pregnant at the marriage which was the fifteenth day of May. Thus I was born premature at 32 weeks after 224 days, 9 hours, and 53 minutes" (Koestler, 1959). With all his misery, grief, and pain, he was a tireless worker, completely absorbed in the problems of the solar system, except when he was forced into writing singularly successful horoscopes to eke out his precarious income as a college professor. Kepler suffered through some of the most bloody episodes of the Thirty Years War, and he exerted great effort to obtain a release for his mother who was imprisoned 18 months for witchcraft. It was against this background that he wrote his book announcing his three famous laws. He died just short of his 59th birthday.

What heritage did Kepler leave us? He carried astronomy through a momentous advance. After a decade of study he had translated the magnificent tables of data collected by Tycho Brahe into a simple and comprehensive system of curves and rules. Some of you may have seen the elaborate bronze structure that is preserved in his hometown in a little museum. The basic idea (you remember the law of gravitation was not discovered yet) was geometric. It's my suspicion there was somewhat of a coincidence in this. Kepler was absorbed with the idea—the well-known fact—that there are only five regular solid figures possible: the tetrahedron (4 sides), the cube (6 sides), the octrahedron (8 sides), the dodecahedron (12 sides), and the icosahedron (20 sides). So what he did was inscribe spheres in these objects and assume the orbits of the planets were great circles on these spheres. Only five planets were known then. It worked out beautifully; and from this he was able to deduce his three famous laws. I sometimes am impressed when correct conclusions can be drawn from wrong methods. I'm not saying this was a wrong method per se, but there is no obvious physical connection between the "perfect" solid figures and the planetary orbits.

I do not wish to get into the philosophic and religious controversy which raged then between the geocentric and the heliocentric descriptions of the universe, but it was Newton who cast the die in 1695. To explain planetary motion dynamically we need to choose an appropriate frame of reference. Can we choose that frame so that the earth is at rest in it? Newton answered, "No." But out of all of Newton's achievements, the most pertinent for our present purpose is his recognition that the planets and, indeed, the sun itself behave as particles. That is, gravitational forces are the same as if each member of the solar system had its own mass concentrated at its center. He was forced to invent integral calculus to verify the validity of this concept.

MODERN PARTICLE CONCEPT

Let us leave the large particles and look into the realm of small particles. I shall review some recent developments. I won't try to draw pictures of the scales involved here, but they are about as much below unity as some of the planetary dimensions are above unity.

I realize that the systematic, taxonomic approach demands that I discuss in detail all of the 80 elementary particles now known, but I shan't subject you to such a recital. It would take too long, and furthermore, as I shall show later, there are probably only 12 fundamental particles, the other 68 being exicited states or resonances of the basic dozen. This does not deny their importance, for resonant particles are a very exciting problem today. It has now been recognized that there are four basic kinds of interactions. I carefully choose the term interaction rather than the word force because force has a classical connotation that I don't want to carry over here. All particles interact according to one of these four basic interactions. The first is *gravitational;* the second is *weak* (it happens to be weak, so for want of a better word we call it weak); the third is the *electromagnetic* interaction; and the fourth is the *strong* interaction. Gravity and the electromagnetic interactions have been known for a long time, but the weak interactions and the strong interactions are relatively new. The weak interaction is, however, still 10^{25} times stronger than the gravitational interaction. Electromagnetic interaction is 10^{38} times as strong, and the strong interaction is only a hundred times stronger than that, which is 10^{40} times gravitation.

There are three remarkable characteristics of these interactions. The first is the tremendous disparity among them. I have trouble imagining 10^{25} and relating it to anything tangible. (It may be helpful to realize that it is about 1000 times the square of our national debt). There is an entirely different realm involved in 10^{25} compared with the number unity; the scale factor is enormous. The second remarkable fact that is now emerging is that the stronger the interactions the fewer of them exist. For example, out of 12 basic kinds of fundamental particles now known, all 12 engage in gravitational interactions. Only 11 of them engage in the weak interaction which is the next strongest, 9 in electromagnetic, and only 6 in strong interactions. The third interesting characteristic of these basic interactions is that there is a connection between interaction strength and conservation laws. When you and I went to school there were only two conservation laws—conservation of momentum and conservation of energy. But now there are 11. We now know 11 quantities that are conserved in physical interactions. At this point I shall merely name them (after all, they sound impressive) but I won't go into any great detail. In addition to conservation of energy and momentum there is conservation of angular momentum, charge, electron family number, muon family number, and baryon family number. These latter three conservation laws are bookkeeping schemes. All basic particles belong to one of these three families, and they just cannot change one to the other. If you are a Smith you will always be a Smith—if you are a Jones you will always be a Jones. There is some additional sublety, but essentially it is a bookkeeping item. The remaining laws are: conservation of parity about which Lee and Yang have so much to say and for which they won the Nobel Prize, charge conjugation, the conservation of isotopic spin, and finally conservation of strangeness, which brings me to my title, because I promised to talk about "strange particles"—something stranger than you have heard so far. Within the context of these conservation laws, the stronger the interaction the more restricted by conservation laws which limit the possible transformations, or, to put it conversely, the weaker the more lawless. (Maybe the sociologists should take a tip from this.) Let me give you some statistics. Those particles which engage in strong interactions obey all 11 of these conservation laws. Particles that enjoy electromagnetic interactions obey ten; those which participate in weak interactions, seven. We don't understand why this is so. I'm merely stating empirical facts. This is not a theory. In response to the question "Well, what good is it?", of course, the obvious answer is "What good is a newborn baby?" We don't know yet. But these facts are just emerging lately.

Let us discuss the electron. I have chosen the electron because it is a more familiar particle and we can do some tooth-cutting on it before looking at more esoteric particles. Nowadays we are rather blasé about the electron because we feel quite at home with it. This is particularly true when trillions of them deliver electrical energy to the many appliances in our homes. We feel even more at ease with electrons when they paint something like 600 pictures a second for us on our TV screens, but it was not always so. During the early days of history the electron was indeed a strange particle. Milikan found that the electron had an incredibly small charge, so small that six billion-billion of them must be delivered each second to an ordinary one hundred watt incandescent light bulb when it is in operation. (Of course, the gross application of conservation of charge means the same number must leave the light bulb each second.) Even more remarkable, no electric charge intermediate between zero and the size of the electron charge has ever been detected. More puzzling is the ratio of the charge to mass measured by J. J. Thompson. The knob on an ordinary gold leaf electroscope in which the leaf swings out when you rub the cat's fur on the rubber rod, typically receives charges of about 3×10^{-3} coulombs per kilogram, but the electrons that are responsible for charging it, have 1.7×10^{11} coulombs per kilogram, almost 10^{15} greater charge-to-mass ratio; in other words, about a hundred thousand billion larger. It was found that if an individual free electron moving at some respectable rate steps on its brake, hits the accelerator pedal, or negotiates a curve, it gives off a flash of radiation. However, if it is confined to a bound state in an atom, it does *not* radiate when travelling a curved path. As physicists pulled and hauled at the electron and subjected it to all sorts of delicate and subtle conditions other measured properties emerged. The electron spins on its own axis as does the earth. It behaves as a tiny bar magnet in a magnetic field. It shows internal structure. Its mass increases when it acquires high velocity. The fundamental foundation for the mass increase was laid by A. A. Michelson of Case and Edward W. Morley of Western Reserve in 1886 when they reported the first results of their series of monumental experiments which culminated in Einstein's theory of relativity nineteen years later. The electron emerges from metals even when its energy is too small to allow it to escape and it does this without violating conservation of energy. And it never can be found at rest. Finally, G. P. Thompson, in England, and Clinton Davidson and Lester Germer in this country discovered that electrons also behave like light waves. They obtained some beautiful diffraction and interference patterns almost identical to those exhibited by visible light a century before. In Germany, Kuker obtained interference patterns when electrons passed through an electrostatic prism. Can such a little monster really be called a particle? I shall return to this question a little later. But meanwhile back in the laboratory. . . .

Nature was reluctantly revealing other facts that seemed completely contrary to 19th century common sense. Protons and neutrons had similar properties. A positive twin brother of the electron joined the ranks and became known as a positron. Complete atoms and even molecules behaved as if they had wave properties. I am not going to proceed methodically through the whole list of eighty particles (this is a relief, isn't it?) and their hundreds of interactions because this would make not only a long but a rather dull catalog of facts from the great deal of data accumulated in the past few years. But among these facts, two kinds stand out as especially interesting, and probably especially important; but it is too early to know. In surveying the particles that we know about, we pick out only selected excerpts from the catalog of facts as illustrations of these two categories. Either they illustrate in a particularly simple and beautiful way some fundamental aspect of a law of nature or they underline clearly some important area of ignorance. Now, it has emerged just lately, that the electron not only exists in basic positive and negative types, but each type probably has a kind of an excited state. (This is not to be confused with the excited electron states in an atom.) We are now convinced that the muon is merely an electron to which nature has done something we don't yet understand. The evidence is becoming overwhelming. One of the many examples of evidence for the similarity of the electron and the muon is the fact that not only do they both behave like miniscule magnets but also they have the same magnetic strength. The strength of the magnet for the electron is 1.0011596 in certain units. That for the muon is 1.001162. I state these numbers not because they are particularly important *per se* but because the exceedingly small discrepancy between them is important. The experimental accuracy is tremendous, too. In the electron measurement there are eight significant figures. The error in the muon measurement is like a five cent out-of-balance in a ten thousand dollar bank account. Even more remarkable, the measurement was made in one millionth of a second. Of course to obtain the desired accuracy, many measurements were made in many millionths of a second. The electron accuracy is even better. It represents a lack of balance of about one cent in a bank account of a hundred thousand dollars. A rather good CPA is required to do that. The muon and the electron appear to be identical in every respect except mass and lifetime. This identity also appears in the interactions they have with other particles. For every interaction in which an electron is a participant there is a corresponding interaction for a muon (fig. 5). In this interaction a proton comes in from the upper left, a negative electron from the lower left. Some sort of interaction takes place, about which I slyly did not give any details, and out comes a neutron and a nutrino. The subscript e means it is the electron variety of neutrino. Compare this with figure 6, in which we have a proton and a negative muon interacting. What comes out? A neutron and a neutrino. This is just one of hundreds of examples in which electrons and muons behave similarly in similar social situations among the nucleii. Fermi had predicted that occasionally an anti-neutrino should react with a proton to produce a neutron and a positive electron. This is the reaction that was sought and found in 1956 by Frederick Reines and Clyde J. Cowan, Jr. Reines is now Chairman of the Department of Physics at Case, as many of you know.

To codify literally thousands of such reactions we've had to invent many new schemes and one of them which has proved to be very useful I shall depict briefly. I want you to imagine an airplane ride from Chicago to Cleveland. Now, what happens? You go out twenty minutes before take-off time, you get on the plane, you sit there. The stewardess hangs up your coat, you fasten your seatbelt, you wait a while. Finally you take off. Now let's assume that we have a perfectly straight flight from Chicago to Cleveland at a constant velocity. The airplane's course is undeviated by any storm centers. You land in Cleveland and then you have to wait a while before the door is opened. What are the two quantities featured here? Distance and time. These are the variables I wish to emphasize. See figure 7. There is no such thing as standing still in time, so as you wait to take off in Chicago time is passing vertically. Then you take off, make a perfectly straight flight indicated by the arrow, and a smooth landing in Cleveland. Here you wait at a fixed value of x until the door is opened. The flight is represented by a line often called "world-line." This same scheme is used to indicate some of the elementary reactions of fundamental particles. In figure 8 an atom

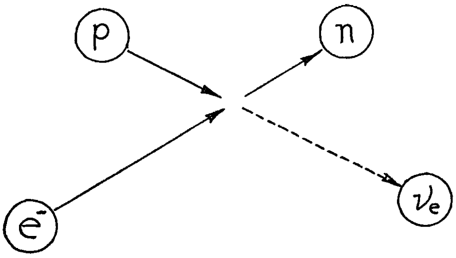


FIGURE 5

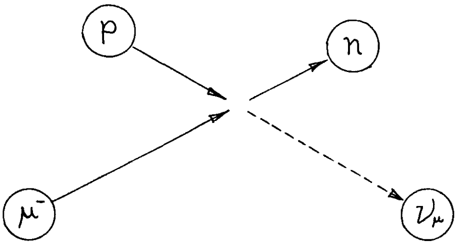


FIGURE 6

FIGURE 5. A proton interacts with a negative electron to produce a neutron and a neutrino. (Cf. fig. 6).

FIGURE 6. A proton interacts with a negative muon to produce a neutron and a neutrino. For every interaction in which one of the participants is an electron there is a corresponding interaction involving a muon. (Cf. fig. 5).

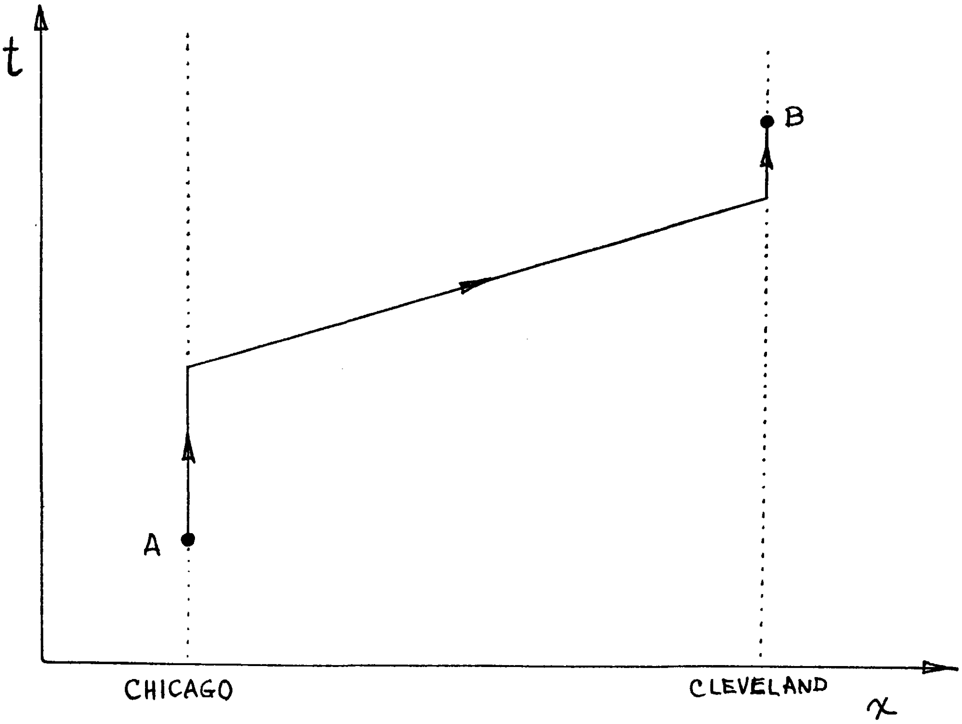


FIGURE 7. A time-distance map of a flight from Chicago to Cleveland. (See text for discussion.)

waits quietly as time passes (perhaps all of a billionth of a second) then suddenly emits a photon. The atom recoils a bit to the left. Both of the post-interaction particles continue to move in a positive direction along the time axis because at this stage time is not reversible, but notice that the closer the world-line is to the horizontal, the faster is the motion of the particle represented by it. The black dot represents the interaction—it locates what is called an event, or an occurrence, or a simple point in space-time. In each of these diagrams you will find some important event of this sort has occurred. The well-known decay of a pion into a muon and neutrino is shown in figure 9. Notice that in the world of

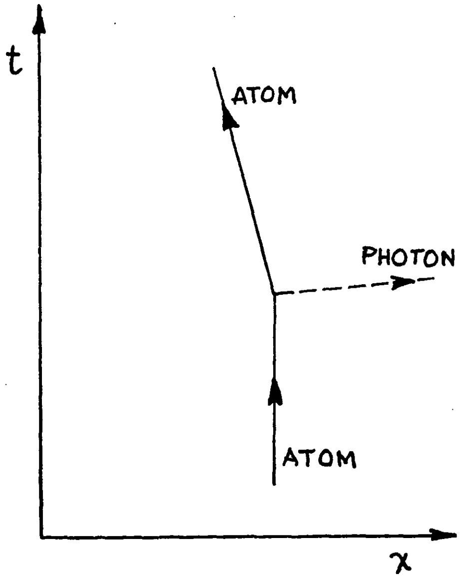


FIGURE 8

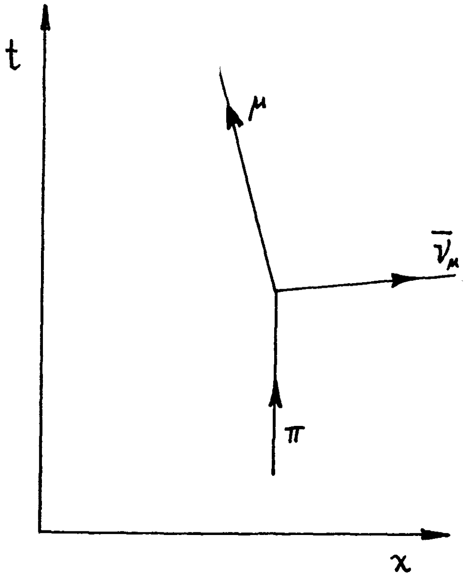
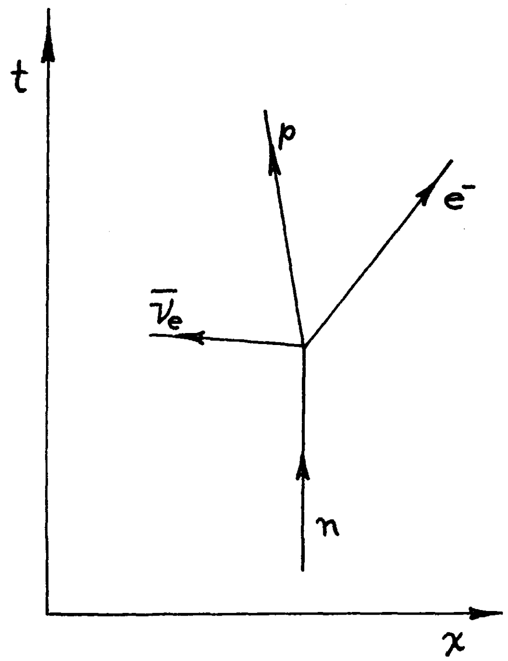


FIGURE 9

FIGURE 8. An excited atom emits a photon and recoils, as represented by a time-space map.

FIGURE 9. A time-space representation of a pion decaying into a muon and a neutrino. (The neutrino is one of four varieties now known. Its full name is: Muon-associated anti-neutrino). The pion may be either positive or negative and the muon produced has the same charge as the pion.



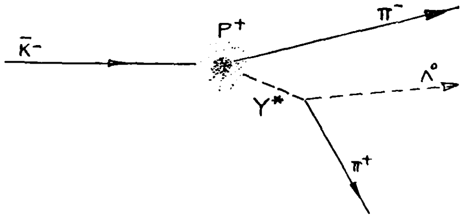


FIGURE 11. Sequence of events in the creation and decay of a resonance particle. A kaon anti-particle interacts with a proton to produce a negative pion and a Y* resonant particle which decays into a positive pion and a Λ°.

FIGURE 10. Beta decay of the neutron. Note the high volocity of the neutrino ($\bar{\nu}_e$), the intermediate velocity of the electron (e^-), and the relatively low velocity of the proton (p).

particles each significant event is marked by the creation and/or the annihilation of particles (in other words, as the pion approached that dot in the middle it was destined to be no longer a pion—it lost its identity as a pion). The beta decay of the neutron is illustrated in figure 10. Here a crucial event in space-time involves the destruction of one particle and the creation of three others.

Now a few remarks about the resonance particles are in order. Information about them is accumulating rapidly. Of the 80 particles now known there are some 50 recognized as resonance particles (Conference Report, 1963). Their masses represent combinations of the masses of several of the simpler particles. They are characterized by a very short life times. One of the many possible resonances is illustrated in figure 11. A negative kaon (the line over it indicates an anti-particle) travels in from the left and strikes the proton. What comes out is a pion and a Y*. The Y* is uncharged and it travels something like three proton diameters before it decays into a Λ° and a π^+. Now this is one of literally 100's of different kinds of reactions that have been observed. Why is this called a resonance particle? Simply because the bubble chambers that take pictures from which this drawing was made have bubbles that are several million times as large as the representation of the proton in the figure. And hence what I have very clearly indicated as a connecting link between the proton and the Y* cannot be observed in a bubble chamber or in any other track recording device. So one is forced to examine analytically the balance of the conservation laws for all three particles emitted, and they arise as peaks on the histogram analysis of the data. Since the graph looks like the old fashioned mechanical resonance peaks,

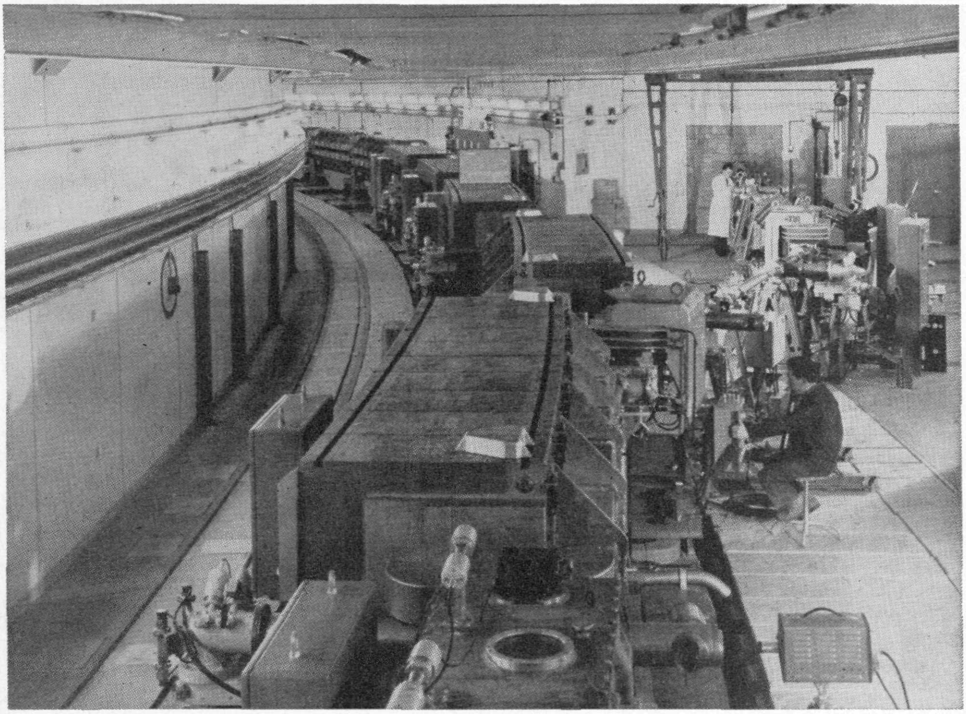


FIGURE 12. Inside the vast ring-shaped tunnel of the CERN proton synchrotron at Meyrin, near Geneva. Some of the magnets enclosing the half-mile circumference of the vacuum "doughnut" are at the left. At the right is the linear "gun" which injects particles into the main ring.

(for example, when Johnny pushed Ellie in the swing at just the proper instants so that she swung higher and higher) we call them resonance particles, simply to cover up our ignorance.

How do we know these things? There are three basic prerequisites for the tremendous boom in knowledge of particle physics that has occurred in the last decade. First, you must produce the particles, second, you must measure them, and third you must analyze the results. All three of these parts of the activity are costly but nowhere near as costly as the moon project. We could have dozens of Brookhaven Laboratories for the cost of one moon shot. A view inside the accelerator tunnel of the CERN proton syncroton near Meyrin, Switzerland, is shown in figure 12 in which the curvature of the circular track is quite evident. The total circumference of the circle is ½ mile. It is difficult to obtain a clear idea of the magnitude of this machine unless you actually get into the tunnel and walk around it. No one picture can really suggest what a tremendous thing it is. The Brookhaven accelerator is similar to the CERN machine.

First we need producers of these particles and the producers are the big machines. Formerly we relied upon cosmic rays but their flux is not great enough to obtain good statistics, so in order to get information in a finite life time we must have beams of many particles per second. These are produced only by the large machines. Secondly, we must have some form of track recording detection.

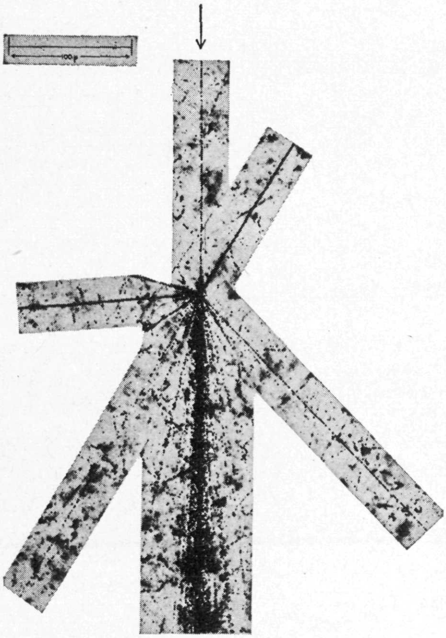


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FIGURE 13. One type of track-recording device is the nuclear emulsion. A cosmic ray alpha particle of high energy (800 Bev) interacts with a nucleus in the emulsion and produces a shower of other particles.

One type of detector is the nuclear emulsion. An interaction in an emulsion is shown in figure 13. (This happens to be a cosmic ray interaction.) A high speed alpha comes in from above and produces something like 50 particles when it collides with a silver nucleus in a nuclear emulsion. A nuclear emulsion is one of the five basic recorders recognized in particle physics. The other four detectors are: the old reliable cloud chamber, the popular bubble chamber, the solid state recorders, and nowadays the spark chamber. One recent development in spark chambers is very interesting. The standard spark chamber is an assembly of parallel plates between which sparks jump whenever a charged particle passes through them. Now we have a decision-making spark chamber in which the outputs of many wires, instead of plates, are piped into tiny magnetic detection devices that behave as simple multi-vibrators or "flipflops." By connecting these to an external circuit one can know exactly how the spark passed through the array of wires. It can decide the number of particles which went through and their trajectories. It takes a small on-line computer to do this, but it can be done now successfully. Another modification is the sonic spark chamber which is a conventional spark chamber plus a sound detection system. It is similar to Loran in the sense that with two detectors you can try to find out exactly where the spark occurred in the big box. Of course all these data must be analyzed and this is done by scanners and modern computers.

Now, I want to introduce a somewhat different thought, but one that I think is exceedingly important, and that is—What implications do these things have for our society? Are we merely clever children who find a different flower, or catch a larger fish, or kill insects by the millions, or invent an artificial kidney which weights 2000 times as much as its prototype, or discover a new particle? Are we citizens of Ohio only? Do we hide behind the protective coloration of our own fields of speciality? Are we afraid to speak out in fields other than our own just because we may receive criticism? As scientists we are also human beings and as both scientists and human beings we wear two hats—we have a double obligation. We cannot ignore the technical advances in the latest issue of our professional journal, but neither can we ignore their implications for society. I conclude with a quotation from Marshall Walker. While the intent of this quotation may be heuristic, as mine has been, and it is perhaps didatic, as I intended to be, I hope neither has been padantic. It may turn out to be the most pragmatic of anything I have said. "Politicians, theologians, and advertising agents have long known that man is only partly rational. Most of his decisions are emotional or instinctive. Having recognized this fact, the unholy three have sought to play upon man's emotions for their own ends. Their motives in some cases may have been good but the results are deplorable. If mankind is to survive much longer each man must be aware of the irrational drives of emotion and instinct within himself. . . . The notion that emotions may be used for good ends is dangerous; so long as any man trusts his emotions those emotions are available for use by an unscrupulous person. . . . The survival technique of the tyramosaurus was ferocity; it is extinct. The survival technique of the dodo was passive resistance; it is extinct. The survival technique of man is science" (Walker, 1963: 177–179.

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