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The Monopole Concept

P. A. M. Dirac

Department of Physics, Florida State University, Tallahassee, Florida 32306

1. INTRODUCTION: ELEMENTARY THEORY

It often happens in scientific research that when one is looking for one thing, one is led to discover something else that one wasn't expecting. This is what happened to me with the monopole concept. I was not searching for anything like monopoles at the time. What I was concerned with was the fact that electric charge is always observed in integral multiples of the electronic charge e, and I wanted some explanation for it. There must be some fundamental reason in nature why that should be so, and also there must be some reason why the charge e should have just the value that it does have. It has the value that makes $\hbar c/e^2$ approximately 137. And I was looking for some explanation of this 137.

A. S. Eddington at that time was also much concerned with this question. He set up a chain of arguments which led him to conclude that this number was exactly the integer 137. I'm afraid that Eddington's arguments are not really sound. I was never able to follow them, and I don't think anyone else was. I don't think there is any interest in them at the present time. Also, there seems to be pretty good experimental evidence that this number is not 137 exactly.

I was following a different line of argument, which did not lead to any value for this number, and, for that reason, my argument seemed to be a failure and I was disappointed with it. But it did lead to the new idea of the monopole, a concept of great mathematical interest and capable of wide generalizations.

The fact that I was looking for an explanation of e is reflected in the title of the paper that I wrote on the subject, "Quantized Singularities in the Electromagnetic Field." The quantization was a different one from what I expected.

The problem of explaining this number $\hbar c/e^2$ is still completely unsolved.

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Nearly 50 years have passed since then. I think it is perhaps the most fundamental unsolved problem of physics at the present time, and I doubt very much whether any really big progress will be made in understanding the fundamentals of physics until it is solved.

Well, if we consider the arguments that I was following at that time, we start with the Maxwell equations:

$$\frac{\partial E}{c\,\partial t} = \text{curl } H \tag{1.1}$$

$$\frac{\partial H}{c\,\partial t} = -\text{curl } E \tag{1.2}$$

$$\text{div } E = 0 \tag{1.3}$$

$$\text{div } H = 0 \tag{1.4}$$

These are the equations that hold in the vacuum. One can bring in electric charges very easily, by adding on suitable terms to the right-hand sides of the equations. One adds the term $-4\pi j$ to (1.1) and $4\pi\rho$ to (1.3), where j and ρ are the electric current and density.

Now the vacuum equations are symmetrical between E and H, the electric and magnetic fields. One can put E for H and $-H$ for E. Thus one could correspondingly introduce magnetic charge and magnetic current. To do that it would require an extra term $-4\pi k$ in (1.2) and $4\pi\sigma$ in (1.4), k being the magnetic current and σ the magnetic charge density. Just starting from the equations in the vacuum, noticing that they are symmetrical, one would postulate magnetic charge, from the theoretical point of view, just as readily as electric charge. But actually magnetic charge is never observed.

Now, if you do introduce particles with magnetic charge, called monopoles, you can set up quite definite equations of motion for them. For a particle with electric charge e we have the Lorentz equations of motion. In relativistic notation they are

$$m\frac{d^2 v_\mu}{ds^2} = eF_{\mu\nu}\frac{dv^\nu}{ds} \tag{1.5}$$

where v_μ is the velocity 4-vector, s is the proper time measured along the trajectory of the particle, and $F_{\mu\nu}$ is the 6-vector whose components are E and H. For a monopole with magnetic charge μ, the corresponding equations are

$$m\frac{d^2 v^\mu}{ds^2} = \mu F_{\mu\nu}^{\sim}\frac{dv^\nu}{ds} \tag{1.6}$$

where $F_{\mu\nu}^{\sim}$ is the dual 6-vector to $F_{\mu\nu}$ obtained by putting E for H and $-H$ for E. Here we have definite classical equations of motion for a monopole.

Now when you go over to the quantum theory, there is a difficulty coming in, because the equations in the quantum theory involve the use of the electromagnetic potentials. The magnetic potentials A, if you just think of them from a three-dimensional nonrelativistic point of view, are introduced this way:

$$H = \operatorname{curl} A \tag{1.7}$$

and one cannot satisfy this equation in the space around a monopole.

One can follow up a certain line of argument—I will just go through it briefly—that leads to the concept of the monopole appearing as a possibility in the quantum theory. There is a quantized value of the monopole strength which you don't get in the classical theory at all.

We use a wave function, let's call it ψ, to describe the motion of a particle. It is a complex quantity, with the meaning that $|\psi|^2$ can be interpreted as the probability density of the particle being in any place. Now we may make a change of the phase factor in ψ, putting

$$\Psi = e^{i\gamma}\psi$$

with γ any real quantity, and then the square of the modulus of Ψ is the same as the square of the modulus of the original ψ, and gives the same probability density. Now the wave equation satisfied by Ψ will be rather different from the one satisfied by ψ, because

$$\frac{\partial\Psi}{\partial x_\mu} = e^{i\gamma}\left(\frac{\partial}{\partial x_\mu} + i\frac{\partial\gamma}{\partial x_\mu}\right)\psi$$

It means that where Ψ satisfies a certain wave equation involving $\partial/\partial x_\mu$, ψ will satisfy a corresponding equation, where the $\partial/\partial x_\mu$ operator is replaced according to the scheme

$$\frac{\partial}{\partial x_\mu} \to \frac{\partial}{\partial x_\mu} + i\frac{\partial\gamma}{\partial x_\mu} \tag{1.8}$$

Now, if you're at all familiar with the motion of charged particles, you know that if you have equations for a charged particle in the absence of an electromagnetic field, you get the corresponding equations for a particle in the presence of a field by replacing the momentum operators

$$p^\mu \to p^\mu + \frac{e}{c}A^\mu \tag{1.9}$$

You do this both in classical theory, expressed in Hamiltonian form, and in the Schrödinger equation of the quantum theory. In the Schrödinger equation p^μ corresponds to $-i\hbar(\partial/\partial x_\mu)$, so the change (1.9) leads to

$$\frac{\partial}{\partial x_\mu} \to \frac{\partial}{\partial x_\mu} + i\frac{e}{\hbar c}A^\mu \tag{1.10}$$

This corresponds to (1.8) if we identify $\partial\gamma/\partial x_\mu \to (e/\hbar c)A^\mu$. It would seem then, that if you take the wave equation for Ψ and make a change in phase in Ψ, you get a corresponding equation with some different potentials A which you didn't have previously. But this change is pretty trivial, because the A^μ are changed by the gradient of a scalar, which means no change in the field quantities E and H.

I want now to introduce the idea of a more general change in phase, where γ is not an integrable function of position. That is to say, if you know the value of γ at one point, the value of γ at a neighboring point is determined, but the connection between γ at the neighboring point and the original γ is such that, if you go around a closed loop, making the correct changes all the way, the γ that you end up with is not the same as the original one. This is the idea of a nonintegrable function. The analysis leading to (1.8) will then still apply, except that $\partial\gamma/\partial x_\mu$ will be replaced by κ^μ, which is no longer the gradient of a scalar. We shall have from (1.10) and (1.8)

$$\kappa^\mu \rightarrow \frac{e}{\hbar c} A^\mu \tag{1.11}$$

If we take the integral of γ around a closed loop—let's just think of it three dimensionally now—we get from (1.11)

$$\int \kappa_r \, dx_r = \frac{e}{\hbar c} \int A_r \, dx_r = \frac{e}{\hbar c} \int (\text{curl } A, dS)$$

where dS is an element of surface area of the surface which has this closed loop as its perimeter. Now this is equal to $(e/\hbar c) \int (H, dS)$, so

$$\int \kappa_r \, dx_r = \frac{e}{\hbar c} \int (H, dS) \tag{1.12}$$

That means that the change in phase when we go around a closed loop is connected with the magnetic flux through the loop with the coefficient $e/\hbar c$.

So far this is just a new mathematical picture for the Schrödinger equation, and doesn't contain any new physics. We can, instead of introducing the field in the usual way, just express the field in terms of a nonintegrable phase factor in the wave function.

Now I'm going to bring a new feature into the argument, namely, the phase γ is not a well-defined quantity, because you can change it by any integral multiple of 2π, without altering the wave function Ψ. Thus in the expression for the change in γ going around a closed loop, you have to take into account that γ itself is always undefined to the extent that we can add to it any integral multiple of 2π. So, in this formula (1.12), we must add on $2\pi n$ with n an unknown integer. Thus we have the equation

$$2\pi n + \int \kappa_r \, dx_r = \frac{e}{\hbar c} \int (H, dS) \tag{1.13}$$

connecting the change in phase around the loop with the magnetic flux through the loop.

Let us apply this to a small loop. Taking just a very small loop, the magnetic flux through it, under ordinary physical conditions, will be close to zero. So the right-hand side of equation (1.13) is close to zero. Now if the wave function Ψ is continuous in the usual sense, κ_r will be small. Then γ will be such that around a small closed loop it can't change very much. Thus $\int \kappa_r d\, x_r$ will be close to zero. So, under these ordinary conditions, we would just have n equal to zero.

But there is an exceptional case that can arise, namely, in the neighborhood of $\Psi = 0$. Even though Ψ is continuous, the phase may undergo quite a big change when we go around a small loop. One can see this most clearly by an example. Take

$$\Psi = x_1 + ix_2$$

and take a small loop going around the axis $x_1 = x_2 = 0$. Now this Ψ is quite continuous in the neighborhood of $x_1 = x_2 = 0$, but the phase is such that it changes by 2π when we take a very small loop around this axis. So that if we have this kind of singularity, we have a possibility of getting $n = 1$ in equation (1.13). We then have the situation that the integral of κ_r is not small, even for a small loop.

I would like to go on to consider a surface that is not small and apply equation (1.13) to it. Then, if we have this phenomenon of κ_r or the magnetic potentials behaving as above, we have what we may call a nodal line cutting through the surface and we can have the phenomenon of $n \neq 0$.

Suppose that we have a surface whose perimeter is shrunk up to zero, that is to say, a closed surface, like the surface of a sphere. Then the line-integral on the left of (1.13) is zero. But $\int (H, dS)$, the integral being taken over the surface of the sphere, is not zero. That would correspond to some magnetic charge occurring inside the sphere. It gives the idea of the monopole magnetic charge.

Now the magnitude of this magnetic charge is such that total magnetic flux crossing the surface of the sphere is 4π times the strength of the magnetic charge. If we call μ the strength of the charge, we get $(e/\hbar c)4\pi\mu$ for the right-hand side of (1.13). Putting the integral on the left equal to zero, we get

$$2\pi n = \frac{e}{\hbar c} 4\pi\mu$$

That leads to the formula

$$e\mu = \tfrac{1}{2} n\hbar c \tag{1.14}$$

This argument leads to the conclusion that there is a quantized value for e if we have any monopole at all, or alternatively, quantized μ if we have any particle with charge e. We get this condition connecting the quantized singularities of the electromagnetic field. You see that it is not like the condition for $\hbar c/e^2$. It does not fix any value for e.

This theory would show that if there exists any monopole at all in the universe, all electric charges would have to be such that e times this monopole strength is equal to $\frac{1}{2}n\hbar c$. All electric charges would be quantized under those conditions. That is a satisfactory result, but it doesn't tell us the value of e because μ is unknown.

That is the elementary theory of the magnetic monopole. There are different ways of expressing it, but they always lead to this formula (1.14). This work was done in 1931.

2. DEVELOPMENT OF A GENERAL THEORY

More recent work is concerned with the development of this theory, and in particular with getting equations of motion for the charged particles and the monopoles in interaction. Now there is quite a serious difficulty when you face up to that problem, because you have difficulties already when there are no monopoles present. If you just consider electric charges interacting with an electromagnetic field, there is the fundamental difficulty that you have the Lorentz equation of motion for the charged particle, but the field quantities $F_{\mu\nu}$ which are to be inserted in it refer to the field at the point where the particle is situated. And the field there is, of course, infinite, as the Coulomb force for a point particle at the point where the particle is situated is infinite. That leads to the whole problem of quantum electrodynamics.

There has been a big development of this subject of quantum electrodynamics by the procedure that, although the basic equations lead to infinities when you try to solve them, these infinities can be absorbed with a certain technique called renormalization. They can be considered as just changing the value of m into $m + \delta m$ and e into $e + \delta e$, so that the physical values of these quantities m and e are different from the mathematical parameters occurring in the equations. That is quite a sensible idea. But the changes δm, δe have to be infinitely great and that is not a sensible idea.

Even so, people have proceeded boldly along these lines, and have set up working rules for handling these infinities. A very big development has been built up along these lines. It is a theory that I don't like at all, because it's quite alright for mathematicians to neglect small quantities, but it is not alright for them to neglect infinitely large quantities just because they don't want them in the equations. I feel that it is basically wrong, in spite of the successes that this renormalization theory has had.

The successes are really very great. With the infinities handled according to the rules, one has small residual effects like the Lamb shift of the spectral lines of hydrogen, for which the theory gives extremely good agreement with observation. Not just moderately good, but extremely good. Most physicists are very happy with this situation. But I can't be happy with any theory that departs from sound mathematics, and I believe that fundamental physical theory will not make any important advance so long as one follows on lines using unsound mathematics.

I have, during the last few years, been building up an alternative theory in which you get away from the idea of point particles. You have instead a particle consisting of a finite distribution of charge, built up from elements such that each element moves in accordance with the Lorentz equation. If you do that, then of course you'll have each element of charge associated with a field around it which will exert a repulsive Coulomb force on it, so that the particle would not hold together. This extended particle will have its different elements moving apart, accelerating under the influence of the Coulomb repulsion. It will be a sort of exploding particle. But even though the particle is exploding in that way, it does last a finite time, and you can study its equations of motion. You can see that they are sensible, apart from the fact that the whole solution is unphysical because of the particle's not holding together properly. One can build up a theory of sensible equations of motion under those conditions. Now I realize that these equations of motion are departing quite a bit from what the physicist wants, but I think that this blemish in the theory is preferable to the blemish of neglecting infinite quantities.

I would like to talk in more detail about this theory of extended particles, and show you that, once you can accept the fact that the particles are not really stable, but are exploding, everything else works very well, in just the way you would like it to work. You can set up the equations of motion for the electron under those conditions and you can set up corresponding equations for the magnetic monopole. Further, you can set up an action principle which gives the correct equations of motion for the electrically charged particles and for the monopoles, and this action principle can be used as a basis for quantization.

I can't go into the equations in detail—they would be much too complicated and would fill up the whole blackboard—but I would like to tell you what the main ideas are. We consider our particles as extended over space, and in the inside of the particle we have a definite velocity 4-vector v^μ. We can introduce another 4-vector u^μ lying in the same direction as v^μ, such that u^μ gives you not only the direction of motion of the element, but also the amount of mass and charge that is present, in accordance with the formula

$$mu^0\, dx^1\, dx^2\, dx^3$$

for the amount of matter passing through a small element $dx^1\, dx^2\, dx^3$ at a given time, and formulas like

$$mu^1\, dx^0\, dx^2\, dx^3$$

giving the flow of the matter. There are similar formulas, involving the coefficient e instead of m, for the charge density and the flow of charge. This u^μ thus combines in one 4-vector the amount of mass and of charge and its direction.

We can set up the action associated with the mass, the inertial action. It is

$$I_m = -m \int (u_\mu u^\mu)^{1/2} d^4x \tag{2.1}$$

The minus sign is required to make the action increase as the matter moves faster. There is also an action for the interaction of the matter with the electrical field, which is

$$I_e = -e \int u^\mu A_\mu d^4x \tag{2.2}$$

There is the usual expression for the action of the electromagnetic field:

$$I_F = -\tfrac{1}{4} \int F_{\mu\nu} F^{\mu\nu} d^4x \tag{2.3}$$

If there are no other things present, you just take the sum of these three terms as the total action, and then you can apply a variation principle and deduce the equations of motion.

The whole point of this method is to apply the variation correctly. The variation has to correspond to each element of the matter situated at some point x^μ being shifted to a point $x^\mu + b^\mu$, with b^μ small. We have to figure out how the action changes under that displacement. Just from kinematical arguments, one finds that

$$\delta u^\mu = -(u^\mu b^\nu - u^\nu b^\mu)_{,\nu} \tag{2.4}$$

It leads to

$$\delta I_m = m \int u^\nu v_{\mu,\nu} b^\mu d^4x \tag{2.5}$$

and

$$\delta I_e = e \int F_{\mu\nu} u^\nu b^\mu d^4x \tag{2.6}$$

There's a whole new technique of working with the effects on this kind of variation. One gets some curious equations, which are very easily worked out, and which one has to get used to.

If we have monopoles present, how do we bring them in? Well, each monopole is again to be considered as an extended particle. Each bit of magnetic charge is the end of what we might call a string, the end of a line of singularity in three dimensions where formula (1.7) fails. We have many strings coming out from each bit of the extended monopole.

Each string provides a two-dimensional surface in space–time. It will be described by a 6-vector $w_{\mu\nu} = -w_{\nu\mu}$. We have these $w_{\mu\nu}$ variables describing the strings similar to the u_μ variables that describe an extended particle. When we make the shift $x^\mu \to x^\mu + b^\mu$, we find that the change in $w_{\mu\nu}$ is given by a rather similar formula to (2.4) with more terms in it:

$$\delta w^{\mu\nu} = -(w^{\mu\nu}b^\lambda)_{,\lambda} + w^{\lambda\nu}b^\mu_{,\lambda} + w^{\mu\lambda}b^\nu_{,\lambda}$$

This again is just a kinematical formula.

Now if the magnetic monopoles appear at the end of the strings, we get the expression

$$q^\mu = w^{\mu\nu}_{,\nu}$$

describing the density and flow of the extended magnetic particle, like the u^μ for the extended electric particle. We have now automatically the conservation law,

$$q^\mu_{,\mu} = 0$$

The electromagnetic field quantities are now

$$F_{\mu\nu} = A_{\mu,\nu} - A_{\nu,\mu} + g\tilde{w}_{\mu\nu}$$

consisting of the usual expression of the field in terms of the potentials, plus another term depending on the density of the strings, with a numerical coefficient g. The symbol ~ means again the dual 6-vector. We have to use this $F_{\mu\nu}$ in the action I_F for the electromagnetic field, given by (2.3).

For a complete theory we take the sum of the three actions (2.1), (2.2), and (2.3), and then there's one further term which is needed for the inertia of the magnetic pole. This will be of the same form as this term (2.1), with the q's instead of the u's. The total action will consist of those four terms.

Now there's one strange feature that you will notice, namely, that there is the term (2.2) for the interaction of the charged particles with the electromagnetic field. There is no corresponding term for the interaction of the monopoles with the electromagnetic field. You get the correct equations of motion just using these action terms which I have described here, with no further term referring to the monopoles. What that means is that the electromagnetic field doesn't act directly on the monopole, it only acts on the strings. It acts on the strings on account of the $F_{\mu\nu}$ involving the $w_{\mu\nu}$, which involve the string variables. The monopoles are then constrained to be at the ends of the strings.

The theory that you get by varying the total action gives correctly the equations of motion, the Lorentz equation (1.5), and the corresponding magnetic equation (1.6). They all follow from the one action principle. There is no symmetry, because the effect of the field on the monopoles is provided simply through the field acting on the strings and the monopoles being constrained to lie at the ends of the strings.

The equations that follow from the action principle do not in any way tell you how the strings vary. The strings are arbitrary except for the fact that their ends have to be anchored to the monopoles. That is reflected in the fact that the equations of motion do not influence the motion of the strings at all.

There is one condition that has to be observed, however, namely, that the strings must not pass through the regions where there is electric charge present. You must have the monopoles and the electric charges occupying distinct regions of space. The strings, which come out from the monopoles, can be drawn anywhere subject to the condition that they must not pass through a region where there is electric charge present. The equations fail unless you observe that condition.

I don't think there's any point in going into greater detail into this theory, because the equations are too complicated and one just has to study them in detail and pick out all the various terms in the action principle and see how they are to be handled. The details may be found in the references given at the end.

3. THE EXPERIMENTAL SITUATION

I would now like to say a few words about the experimental situation. Two years ago there was a paper by Price, Shirk, Osborne, and Pinsky, where they said they thought they had experimental evidence for a monopole. What they had done was to send up a stack of Lexan plates to a high altitude with a balloon, and then, when the plates were brought back to earth, carried out an etching of them. When ionizing particles pass through the plates, they do some damage, which appears as etch marks on the plates.

Now if you have an ordinary charged particle, as it loses energy, it will increase its rate of ionization. The reason for this is that, as it passes through matter, it exerts a force on the electrons in the matter around it, and the impulse on an electron will depend on how long the force acts. For a rapidly moving particle the force does not act for very long and the impulse will be small. For a slower moving particle the impulse will be greater because the particle spends more time going by. The result is that, with an ordinary charged particle, the amount of ionization increases as the particle moves more slowly.

With a magnetically charged particle, on the other hand, the force that it exerts on an electron in a surrounding atom depends on the velocity, and, as the particle moves more slowly, there is a reduction in this force, which approximately compensates for the fact that the particle is moving more slowly and has more time to exert its force on the surrounding matter. The result is that the ionization produced by a magnetically charged particle is roughly independent of the velocity.

Now Price and Shirk and the others had a stack of Lexan plates, and they observed that the amount of damage done by one particular particle passing through those plates was roughly independent of the velocity of the particle. The etch marks are pretty much the same all the way down the stack. And so they said, there is evidence of a magnetically charged particle, maybe it's a monopole.

They worked out what the strength of the monopole should be. They made some errors in their preliminary paper, which was written very hurriedly, but even after correction of those errors, the results agree fairly well with a monopole, not of minimum strength $n = 1$ in formula (1.14), but with $n = 2$. The results are shown in the diagram (Figure 1). For a monopole with $n = 2$, they should lie on the vertical line.

The objection to interpreting this particle which they observed as a monopole is that other very extensive searches have been made for monopoles and the results are completely negative. If it really is a monopole that they observed, the chances against it are one in many millions, or even billions, and thus it seems most unlikely that they did observe a monopole. If there are

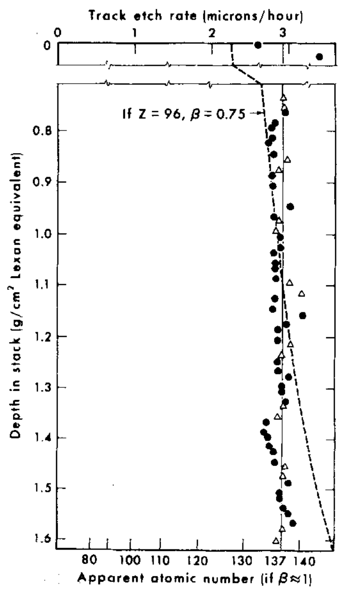

Fig. 1. Diagram illustrating the results found by Price, Shirk, Osborne, and Pinsky. (Reprinted from *Phys. Rev. Lett.* (1975), **35**, 488.)

monopoles that are raining down on us in the cosmic rays, they must end up somewhere. A monopole is conserved just like an electric charge is conserved. It can't disappear; if the monopole particle disintegrates into other particles, one of the products of the disintegration must contain a monopole. It is impossible for a monopole to disappear except by annihilation with another monopole of equal and opposite magnetic strength. People have made very extensive searches for these monopoles, including rocks and sediment at the bottom of the sea, and in places of high latitude near the magnetic poles of the earth. And they always get zero results.

It could be that the monopoles striking the earth go down to very great depths. That would be one reason why it might be that these monopoles are never observed. If there are monopoles at great depths, the way to detect them would be to observe the magnetic flux going out from the surface of the earth all over the surface of the earth and see whether the integral is different from zero. As far as I know, that work has not been done with great accuracy; there's too much irregularity in the earth's magnetic field. But I believe that it ought to be done.

Right at the beginning of the announcement of this Price and Shirk experiment, when people were discussing it, there was strong opposition brought out by Alvarez in particular, along with other people. Alvarez thought that these results might come from some more ordinary particle, such as a platinum nucleus. Now an atomic nucleus would give a curve which moves off to the right as one goes down, such as the dashed curve of Figure 1, representing a particle with $Z = 96$ and velocity $v/c = \beta = 0.75$. This would not fit the experimental points. Alvarez proposed that at a suitable place the ionizing particle underwent a fragmentation, a disintegration, as a result of which it lost some of its charge, to give a curve more nearly vertical. One fragmentation would not have done very well, and maybe two would be needed.

Now I have recently spoken with Buford Price to ask him about the latest information in regard to this experiment. He says that he got some further results because, when he wrote his original paper, he had not carried out the etchings on all his plates. The ones at the top and the bottom of the stack had been kept in reserve, and since then they have been etched and the results they give will not fit the Alvarez explanation. And even Alvarez himself has had to give up this explanation. The further points at the top and the bottom would be too far off this kind of curve.

How can one then explain this particle? It seems that it has to be some very exotic particle, some particle which is not known to physicists at the present time. It might be a super-heavy atomic nucleus, a particle with a charge, say, of somewhere around 110 and a very heavy mass. If you go to a particle like that, the dashed curve becomes more nearly vertical because the particle with a bigger mass would not undergo such a big change in velocity as it goes through the Lexan plates and so it would not be shifted so far to the right. It could be a super-heavy like that.

Alternatively, it could be a particle of antimatter, with perhaps a charge lower than one would need for ordinary matter. If it is antimatter, the charge may be 80 or so. I heard that Alvarez rather likes the idea of antimatter—it would fit the observations very well. But it would be very unusual to have such a particle, and Alvarez, in any case, thinks that one should not believe in it just from this one example. We need to get further specimens of it.

Price is hoping to do further experiments with orbiting apparatus. That is for the future. All one can say at the present is that they certainly found a very strange particle that cannot be explained in terms of the ordinary particles of physics, and we must wait for further evidence before we can be confident of what it is.

They did have some Cerenkov detectors, but unfortunately, they don't give very definite information. Cerenkov detectors should tell you the velocity of the particle, and they have been analyzing the results for a long time, but they still haven't come up with any definite conclusion. That is all that can be said at the present time. There's certainly something very interesting there, even if it's not a monopole. Thank you.

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