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Search for Tachyon Monopoles*

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We have searched for a magnetically charged particle that travels faster than light. These particles are detected by the Cherenkov radiation they emit while moving in a magnetic field. We find that the cross sections for photoproduction of these particles by 1-MeV γ rays in lead and water are less than 0.6×10^{-36} cm^2 and 2×10^{-36} cm^2, respectively. These results are subject to some assumptions about the hypothetical particles.

INTRODUCTION

Particles traveling with velocities less than that of light are either electrically charged or neutral. Photons and neutrinos travel at the speed of light and are neutral. What electromagnetic fields would be associated with particles that travel faster than light?[1,2] We speculate that tachyons (if they exist) are either neutral or magnetically charged.

Such speculations are not new. Parker has proposed an extended Lorentz transformation relating momenta and fields in the rest frame of the tachyon to observables in the laboratory.[3] The transverse fields of an electrically charged tachyon $q=e$(esu) moving with infinite speed appear in the lab as a magnetic field associated with a particle of magnetic charge g(emu) $=e$(esu).

We are looking for a somewhat different particle. This particle bears a magnetic charge near that of the Dirac monopole ($g\approx 69e$), moves faster than light, and consequently emits Cherenkov radiation even in a vacuum. Let us call this particle a tachyon monopole (TM).

Few previous experiments have any bearing on the existence of tachyon monopoles. The exhaustive searches for monopoles in cosmic rays have set a limit of less than 10^9 monopoles striking the entire surface of the earth in a year.[4] But the most sensitive of these searches demand that the monopole stop in matter from which it is then extracted by a high magnetic field[4] or cycled through a superconducting loop.[5] Clearly these experiments would not have detected a TM. In other experiments the monopole is not stopped but is only thermalized before being accelerated by a magnetic field. Two of these experiments, a cosmic-ray search[6] and an accelerator search,[7] would have been sensitive to a tachyon monopole having a charge $g\approx 69e$. (See the Appendix for a full discussion of the relevance of previous monopole searches to tachyon monopoles.)

Searches have been made for electrically charged tachyons produced in the shield of a γ-ray source,[8,9] in K^--p interactions[10] and in cosmic rays.[11] Baltay, Feinberg, Linsker, and Yeh[12] have looked for neutral tachyons in $\bar{p}$-p and K^--p interactions. Their technique was to measure the momenta of all the charged secondaries and hence determine the square of the mass of the unseen neutrals. If this quantity were negative, at least one of the unseen particles would have to be a tachyon. This experiment could have detected a TM pair if the missing mass squared of the pair were negative. The rate for tachyon production was found to be less than about 10^{-3} of the rate for competing strong reactions. Despite this negative evidence we felt that a sensitive direct search for photoproduced TM's was worthwhile.

TECHNIQUE

Our experimental arrangement is modeled after that used by Davis, Kreisler, and Alvager[9] to detect electrically charged tachyons. Like these authors, we search for tachyons which are photoproduced in lead by γ rays from a ^{60}Co source. Presumably these tachyons are produced as a pair of north and south monopoles. We assume that the north monopole does not recombine with the south, but travels without attenuation through the lead. It emits Cherenkov radiation so copiously that its energy is quickly reduced to much less than an electron volt. In this state the TM arrives at the detector. Here it is decelerated by a longitudinal magnetic field. (When the energy of a tachyon is increased, it is decelerated.) Once in this field, the TM reaches an equilibrium energy such that the rate of energy gained from the magnetic field is equal to the rate of energy lost in Cherenkov radiation. Some of this radiation is in the visible spectrum and is detected by photomultiplier tubes.

Let us examine the assumptions behind this scenario:

Production. We assume that a 1-MeV γ ray can produce a TM pair without the pair recombining. Since tachyons do not have a real mass, there is no threshold for the production of a TM pair.[13] Even if such a pair is produced, however, the strong mutual attraction of the magnetic poles might well lead to immediate annihilation. We assume that this does not happen.

Transmission through the lead shield. Let us assume that magnetic charge is conserved. Thus an isolated TM cannot be lost in a nuclear interaction. Since the tachyon must travel faster than light, it cannot be stopped either. Possibly a TM can form a bound state with either electrons or nuclei. This is not possible for a conventional monopole,[14] and possibly is not for a TM either. It seems most likely that once a tachyon is isolated it will readily pass through matter.

Cherenkov radiation. It is well known that an ordinary charged particle of velocity v emits Cherenkov radiation while moving through an optical medium of index of refraction $n > c/v$. The energy lost per unit length is given by

$$\frac{dE}{ds} = -\frac{z^2e^2}{c^2}\int\left[1-\frac{c^2}{v^2n^2(\omega)}\right]\omega d\omega\,, \tag{1}$$

where ze is the charge of the particle and the integrand is set equal to zero whenever $v < c/n$. Normally $n(\omega)$ becomes less than or equal to one for frequencies much greater than the visible and so the ultraviolet catastrophe implicit in this integral is circumvented. The analogous formula for an electrically charged tachyon (TE) traveling in vacuum ($n = 1$) is

$$\frac{dE}{ds} = -\frac{z^2e^2}{c^2}\left(1-\frac{c^2}{v^2}\right)\int\omega d\omega\,. \tag{2}$$

Since the index of refraction no longer appears, new ways must be found to limit the integral. Two such ways have been proposed.

Beginning with Sommerfeld,[15] several theorists[16-18] have noted that the divergence can be removed by allowing the charge to have a finite radius a. Recently Jones[18] has derived a Lorentz-invariant expression for the energy lost by an electrically charged tachyon

$$\frac{dE}{ds} = -\frac{9}{8}\frac{z^2e^2}{a^2} \approx 10^{+8}\ \text{MeV/cm}\,, \tag{3}$$

if $z = 1$ and a is taken as the rationalized Compton wavelength of the electron. As Jones has observed, the difficulty with such a suggestion is that the tachyon's energy becomes negative at a microscopic distance from the source. Once the energy is negative, the observer will reinterpret the motion as that of a positive-energy antitachyon going the other way,[1] but this reinterpretation provides no source for the once very energetic antitachyon.

Experimentalists[8,9,11] have imposed a more stringent cutoff on the Cherenkov radiation. They assume that no photon can carry away from the tachyon enough energy to make the latter's energy negative. Thus the angular frequencies allowed in Eq. (2) must lie between 0 and $E/\hbar$, and Eq. (2) may be integrated to give[8]

$$\frac{dE}{ds} = -\frac{z^2e^2\mu^2E^2}{2\hbar^2p^2}\,. \tag{4}$$

Here we have taken μ as the mass parameter of the tachyon and have assumed that the tachyon's energy and momentum are

$$E = \frac{\mu c^2}{(v^2/c^2-1)^{1/2}}\,,\quad |p| = \frac{\mu v}{(v^2/c^2-1)^{1/2}}\,.$$

The difficulty with this procedure is that the cutoff on ω is not Lorentz-invariant. (This fact is easily seen by noting that the energies of a tachyon and of a photon transform differently under a Lorentz transformation.) Thus, there are serious problems with both schemes for avoiding the ultraviolet catastrophe.[19] Ultimately nature will have to give the answer and it may well be that neither scheme is correct. For the moment, however, we adopt the second scheme. Then for a TM moving *in vacuo* the formula analogous to Eq. (4) is

$$\frac{dE}{ds}=-\frac{Z^2g^2\mu^2E^2}{2\hbar^2p^2}, \tag{5}$$

where Z is the number of Dirac monopoles possessed by the TM. The energy loss represented by this formula is still very large. For instance, if we assume that the mass parameter for the TM is greater than a few MeV, a singly charged tachyon whose initial energy was 1 MeV will be reduced to an energy of 2 eV in a distance of only 10^{-6} cm. At greater distances from the source, the tachyon will no longer radiate in the visible part of the spectrum.

In order to detect the tachyon efficiently over convenient distances, its energy must be increased to a few electron volts. Then the tachyon's radiation can be detected by photomultiplier tubes of high quantum efficiency. We assume that when in a longitudinal magnetic field H of the proper sign, a TM will gain energy in the amount of ZgH per unit path length.[20] Since the tachyon still emits Cherenkov radiation the net change in energy is

$$\frac{dE}{ds}=-\frac{Z^2g^2\mu^2E^2}{2\hbar^2p^2}+ZgH. \tag{6}$$

We shall be particularly interested in the case where E is a few eV, $\mu c^2 \gg E$, and a steady energy has been attained. For this case, Eq. (6) gives

$$E_0{}^2=\frac{2\hbar^2c^2H}{Zg}. \tag{7}$$

The magnetic fields required are reasonable. A 400-Oe field will maintain a singly charged TM at an energy of 3 eV.

MEASUREMENT

The experiment used a commercial 20 000-curie ^{60}Co source[21] to provide 1.17-MeV and 1.33-MeV γ rays. The active element of this source is distributed in a 1-cm-thick annulus which is 25 cm in diameter and 25 cm high. Surrounding the source on all sides is a 20-cm-thick lead shield. Inside the annulus was placed a 1-liter beaker of water. Thus tachyons could be photoproduced either in the lead shield or in the water. A Helmholtz coil having a bore of 10 cm was positioned 130 cm away from the source. This coil produced a field of 1200 Oe directed along the flight path of the tachyon.

While in this magnetic field, the tachyon emits Cherenkov radiation at an angle arccos (c/v) to its direction of motion. If the mass parameter of the TM is much greater than an electron volt, this angle differs from a right angle by only E_0/μ rad. The Cherenkov radiation travels down a 4 cm diameter evacuated pipe whose axis is perpendicular to the beam direction and whose ends are capped by Phillips 56AVP photomultiplier tubes. (See Fig. 1.)

The number of visible photons arriving at each of these photomultiplier tubes can be easily estimated:

$$N=\left(\frac{\Delta\epsilon}{E_0}\right)\left(\frac{2ZgH}{E_0}\right)\frac{\Delta\phi}{2\pi}\Delta s \qquad \text{if } \epsilon<E_0. \tag{8}$$

In this formula, ϵ is the photon energy, $\Delta\epsilon$ is the range of detectable photon energies, E_0 is the steady tachyon energy, $\Delta\phi$ is the azimuthal angle subtended by the phototube and Δs is the path length

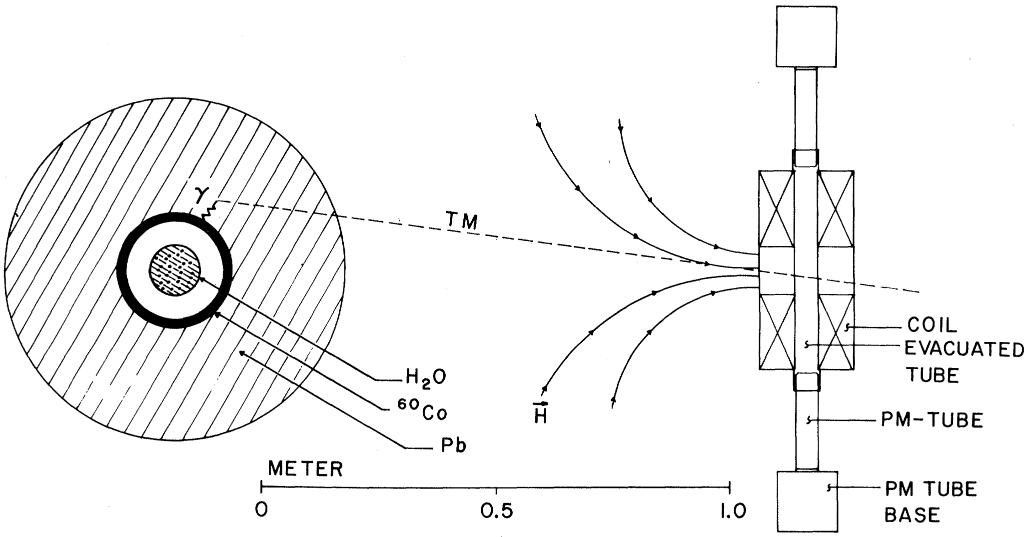

FIG. 1. Schematic drawing of the apparatus, showing a cross section as seen from above. The phototubes were shielded by steel and mumetal cylinders. The entire γ source was encased in a steel shell 1 cm thick.

available for the tachyon to radiate. Using Eq. (7) and assuming a singly charged TM in a field of 1200 Oe, we find $E_0 = 5.2$ eV, and $ZgH = 25$ MeV/cm. For our detector, $\epsilon = 3.0$ eV, $\Delta\epsilon = 0.7$ eV, $\Delta\phi = 0.1$ rad, and $\Delta s = 2$ cm. Thus N is 40 000.

The output of each phototube was analyzed by a discriminator having a threshold of approximately 400 photons. If the TM had a magnetic charge less than $\frac{1}{10}$ that of the Dirac monopole, it would not have given sufficient light to be detectable. Similarly, if Z is greater than 4, E_0 is less than 2.6 eV and the TM does not radiate in the visible. Thus the apparatus is sensitive to tachyon monopoles having a magnetic charge between $\frac{1}{10}g$ and 4g.

Each photomultiplier had a background counting rate of about 40/sec. To record an event, we demanded that the two photomultipliers give pulses which were within 10 nsec of being simultaneous. We recorded 4 counts in 2 hours with the field pointing away from the source, 4 counts in 2 hours with the field pointing toward the source, and 3 counts in 2 hours with no field at all.[22] Thus we are confident that the tachyon associated count rate is less than 5/h.

To derive an upper limit for the cross section for TM production in lead, we write

$$\sigma(\mathrm{Pb}) \leq 4\pi R/pfQ\rho L\Omega\,.$$

Here R is the observed upper limit for the counting rate, 5/h; Q is the activity of the source, 2×10^{18} disintegrations/h; f is the number of 1-MeV γ's/disintegration, 2; p is the probability of the photon entering the lead shield, 0.7; ρ is the number of lead nuclei/cm^3, $3\times10^{22}/\mathrm{cm}^3$; L is the attenuation length for 1-MeV γ's in lead, 1.3 cm and Ω is the solid angle subtended by the detector, 10^{-3} sr. We find

$$\sigma(\gamma-\mathrm{Pb}) \leq 0.6\times10^{-36}\ \mathrm{cm}^2\,.$$

A similar calculation shows that the cross section for TM production in the water inside the cobalt source is

$$\sigma(\gamma-\mathrm{H_2O}) \leq 2\times10^{-36}\ \mathrm{cm}^2\,.$$

CONCLUSIONS

We have failed to detect a tachyon monopole. The detector could have recorded a rate as low as one such particle produced for every 10^{14} γ rays which interact in the source shield. Of course this negative result does not prove that tachyon monopoles do not exist. Alternative possibilities include the following:

(i) The calculation of the energy lost to Cherenkov radiation is wrong.

(ii) The monopole pair recombines immediately after its production.

(iii) Tachyons obey Fermi statistics, but the sea of such particles is already filled to a level higher than an MeV.

(iv) Tachyon monopoles are coupled strongly to nuclear matter rather than to electromagnetic radiation.

We have made a small investigation of possibility (iv). A 2-Ci plutonium-beryllium source was immersed in a 1-liter beaker of water and placed 35 cm away from the Helmholtz coil. The source emits 2×10^6 fast neutrons per sec. Some of these are thermalized in the water and captured in cadmium disks which covered 5% of the surface of the beaker. We detected only 1 count in 2 hours. The real rate is thus less than 1.5 counts/h. The corresponding limit on the cross section for the production of tachyon monopoles by thermal neutrons bombarding cadmium is

$$\sigma(n-\mathrm{Cd}) \leq 2\times10^{-26}\ \mathrm{cm}^2\,.$$

The cross section for intermediate-energy neutrons bombarding water is

$$\sigma(n-\mathrm{H_2O}) \leq 3\times10^{-31}\ \mathrm{cm}^2\,.$$

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We thank Captain R. L. Morrisey for inviting us to use the highly active cobalt source at Fitzsimons General Hospital in Denver, Colorado. The water-cooled coil was designed and built by Gerhard Schultz. The experiment benefited materially from the advice and encouragement of Professor Carl Iddings, Professor Uriel Nauenberg, and Professor Bert Tolbert, and from the help of Jerry Leigh and Merle Ware. Peter Brabeck read the manuscript and made several valuable comments.

APPENDIX

Here we discuss whether previous monopole searches would have been sensitive to tachyon monopoles as well. Particularly relevant are those searches where the monopole was collected in flight by a solenoid and accelerated into a detector. If the "fringing" magnetic field at the detector were high enough, a TM would emit visible Cherenkov radiation. Indeed, the field in the detector may be so high that the TM would have enough energy to ionize atoms either directly or via ultraviolet Cherenkov radiation. Let us examine these two possible ways a TM could have been detected.

Visible Cherenkov radiation: If the velocity of the TM is much greater than that of light, the rate of emission of Cherenkov radiation is independent of the index of refraction of the material. [See Eq.

(1)]. Thus, even when the TM is in matter its equilibrium energy E_0 is given by Eq. (7). (We assume for the moment that this energy is less than the ionization potential of the atoms in the material.) The TM loses energy to Cherenkov radiation as quickly as it is gained from the magnetic field

$$-\frac{dE}{ds} = ZgH \approx 20ZH \text{ MeV/cm}, \tag{9}$$

where H is measured in kOe. Of this energy, a fraction ξ is observable:

$$\xi = \frac{\epsilon_2^2 - \epsilon_1^2}{E_0^2}, \quad \epsilon_1 < \epsilon_2 < E_0. \tag{10}$$

Here $\epsilon_2 \approx 3.2$ eV is the maximum detectable photon energy and $\epsilon_1 \approx 2.5$ eV is the minimum detectable photon energy.

To decide whether a monopole search would have detected a TM, it is necessary to compare the observable energy lost per unit length, $\xi(-dE/ds)$, with the threshold value required by the experiment. This latter value is the product of the quoted sensitivity, dE/ds_q, and the efficiency for converting this energy into visible energy, η. Since the charge of the TM is not known, it is convenient to treat Z as a free parameter. $Z_{\min}$ is the smallest charge a TM could have and still give sufficient light to be detectable. $Z_{\max}$ is the largest charge which would permit the TM to radiate in the visible part of the spectrum. Our evaluation of various experiments is summarized in Table I.

Ionization: If the tachyon monopole's charge is low enough, its equilibrium energy will exceed the ionization potential of the molecules in the detec-

TABLE I. Sensitivity of previous monopole searches to tachyon monopoles.

Experiment	Source	Detector	Magnetic field in detector H (kOe)	Threshold sensitivity of detector dE/ds_q (MeV/cm)	Threshold energy of detector[b] $\epsilon_{\min}$ (eV)	Energy conversion efficiency η	Range of detectable TM charge[a] $Z_{\min}$	$Z_{\max}$
			TM recorded via visible Cherenkov radiation					
Carithers[c]	Cosmic rays	Plastic scintillator	5	60	2.5	0.025	0.4	20
Fidecaro[d]	Accelerator	Argon scintillator	2	3.5	2.5	0.16	0.2	8
Purcell[e]	Accelerator	Xenon scintillator	0.1	5	2.5	0.16	0.25	0.4
			TM recorded via ionization loss					
Carithers[c]	Cosmic rays	Plastic scintillator	5	60	3	···	0.6	13
		He spark chamber	3	···	25	···	···	0.2
Fidecaro[d]	Accelerator	Argon scintillator	2	3.5	16	···	0.08	0.2
Bradner[f]	Accelerator	Emulsion	16	2000[g]	1.6	···	6	160
Amaldi[h]	Accelerator	Emulsion	2	2000[g]	1.6	···	$Z_{\min} > Z_{\max}$	
Malkus[i]	Cosmic rays	Emulsion	0.2	2000[g]	1.6	···	$Z_{\min} > Z_{\max}$	
Purcell[e]	Accelerator	Xenon scintillator	0.1	5	12	···	$Z_{\min} > Z_{\max}$	

[a] $Z_{\max} = 2\hbar^2 c^2 H/(g\epsilon_{\min}^2)$; $Z_{\min}(\check{C}) = (\hbar c/g)[2\eta(dE/ds)_q/(\epsilon_2^2 - \epsilon_1^2)]^{1/2}$; $Z_{\min}(\text{ion}) \approx (dE/ds_q)/gH$.

[b] $\epsilon_{\min}(\check{C}) = \epsilon_1$; $\epsilon_{\min}(\text{ion}) = \epsilon_3$.

[c] See Ref. 6. These authors used scintillator counters to trigger spark chambers. The spark chambers, however, would not be sensitive to TM's having a charge which would be detectable by the scintillators.

[d] See Ref. 7.

[e] E. M. Purcell, G. B. Collins, T. Fujii, J. Hornbostel, and F. Turkot, Phys. Rev. 129, 2326 (1963).

[f] H. Bradner and W. M. Isbell, Phys. Rev. 114, 603 (1959).

[g] The detection threshold for all emulsion experiments has been taken to be that of α rays or about 2000 MeV/cm.

[h] E. Amaldi, G. Baroni, A. Manfredini, H. Bradner, L. Hoffman, and G. Vanderhaeghe, Nuovo Cimento 28, 773 (1963).

[i] W. V. R. Malkus, Phys. Rev. 83, 899 (1951).

tor. The total energy lost per unit length is still given by Eq. (9). But some of this energy is lost to nonionizing Cherenkov radiation,

$$-\frac{dE}{ds}\bigg|_{ni} = \frac{Z^2 g^2 \epsilon_3^2}{2\hbar^2 c^2}\,, \tag{11}$$

where ϵ_3 is the ionization potential of the material. The remaining energy

$$-\frac{dE}{ds}\bigg|_{i} = ZgH - \frac{Z^2 g^2 \epsilon_3^2}{2\hbar^2 c^2} \tag{12}$$

is lost in ionizing the material either directly or by way of energetic Cherenkov radiation. We assume that this energy loss is as detectable as an equal energy loss by a conventional particle. Then the minimum value of Z can be calculated by equating dE/ds_i with dE/ds_q and solving Eq. (12) for Z. The resulting limits on detectable values for Z are tabulated in Table I.

From inspecting the table we see that several experiments could have recorded tachyon monopoles. Two of these[6,7] would have been sensitive to a TM having a charge equal to that of the Dirac monopole ($Z = 1$). In the experiment of Carithers, Stefanski, and Adair[6] a large solenoid searched for monopoles which had been thermalized in the atmosphere. They reported an upper limit of 3×10^{-14} monopoles/cm^2 sec. In viewing this experiment as a search for TM's, however, the upper limit should be increased by a factor of about 30 since only the scintillators and not the spark chambers were sensitive to singly charged TM's. In addition, the search assumed that the monopoles would migrate down magnetic field lines and hence could be collected from an area about 10 000 times larger than the bore of the solenoid. For a thermalized monopole having nearly zero momentum this is a very reasonable assumption. But even a tachyon of zero energy has a momentum μc. Unless $\mu \ll 1$ MeV/c^2, a TM which obeys the Lorentz force equation could not have been collected from an area significantly greater than the bore of the solenoid. However, at present there is no complete theory for the motion of a *radiating* tachyon in an arbitrary field.[20] Thus all we can state is that this experiment establishes an upper limit on the cosmic-ray TM flux somewhere between 10^{-12} TM/cm^2 sec and 10^{-8} TM/cm^2 sec.

Fidecaro, Finocchiaro, and Giacomelli[7] searched for monopoles that were produced when a 19-GeV proton beam struck a copper target. The experiment set an upper limit of 10^{-37} cm^2/nucleon for monopoles that were thermalized in the copper and 3×10^{-35} cm^2/nucleon for fast monopoles that were captured by the magnetic field of the detecting solenoid. Once again our lack of knowledge about the trajectory of a TM in a magnetic field precludes using these limits directly as limits for TM production.

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[2] G. Feinberg, Phys. Rev. 159, 1089 (1967).

[3] L. Parker, Phys. Rev. 188, 2287 (1969).

[4] H. H. Kolm, F. Villa, and A. Odian, Phys. Rev. D 4, 1285 (1971).

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[6] W. C. Carithers, R. Stefanski, and R. K. Adair, Phys. Rev. 149, 1070 (1966).

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[8] T. Alvager and M. N. Kreisler, Phys. Rev. 171, 1357 (1968).

[9] M. B. Davis, M. N. Kreisler, and T. Alvager, Phys. Rev. 183, 1132 (1969).

[10] J. S. Danburg, G. R. Kalbfleisch, S. R. Borenstein, R. C. Strand, and V. VanderBurg, Phys. Rev. D 4, 53 (1971).

[11] P. V. Ramana Murthy, Lett. Nuovo Cimento 1, 908 (1971).

[12] C. Baltay, G. Feinberg, N. Yeh, and R. Linsker, Phys. Rev. D 1, 759 (1970).

[13] Indeed the problem is rather to explain why even low-energy photons do not spontaneously decay into a pair of tachyons (see Refs. 2 and 12). If tachyons obey Fermi statistics, however, the low-lying states are probably already filled (see Ref. 8).

[14] P. A. M. Dirac, Proc. Roy. Soc. (London) A133, 60 (1931).

[15] A. Sommerfeld, Konink. Acad. Wetensch. Amsterdam Proc. 7, 346 (1904). Also see A. Sommerfeld, *Lectures in Theoretical Physics* (Academic, New York, 1954), Vol. 4, p. 328.

[16] R. G. Cawley, Phys. Rev. D 2, 276 (1970). This author is not sympathetic to an extended charge, however, and regards it as a "theoretical dodge" to escape facing more fundamental problems.

[17] H. K. Wimmel, Lett. Nuovo Cimento 1, 645 (1971).

[18] F. C. Jones, Bull. Am. Phys. Soc. 17, 515 (1972), and private communication.

[19] There is even a third solution: namely, that a charged tachyon does not radiate at all in vacuum [M. Glück, Nuovo Cimento 1A, 467 (1971)]. Glück notes that the electric field near a charged tachyon is always radial and points toward the present position of the charge Thus the integral of Poynting's vector over a sphere centered on this position must vanish. We feel that the argument is unsatisfactory, however, because it ignores the pathological behavior of $\vec{E}$ along the Cher-

enkov cone. Specifically E and H are derivatives of potentials which drop abruptly from ∞ to 0 on the Cherenkov cone. In such a circumstance, the integral of Poynting's vector is indeterminate and must be evaluated by other means. For a particularly clear discussion of classical Cherenkov radiation see J. D. Jackson, *Classical Electrodynamics* (Wiley, New York, 1962) p. 495.

[20] An intriguing problem is posed by a TM going into an adverse magnetic field; i.e., one which tends to absorb energy from the particle. The TM cannot stop and retrace its path the way an ordinary particle can. H. K. Wimmel [Lett. Nuovo Cimento 2, 363 (1971)] argues that the tachyon will tunnel through the adverse field until it finds itself in a favorable field. Unfortunately, Wimmel's argument, which was made for electrically charged tachyons, cannot be directly transferred to the magnetic problem and in any event neglects Cherenkov radiation.

[21] Gammacell 220, Atomic Energy of Canada, Ltd., Ottawa, Canada.

[22] These rates are all about 20 times higher than the expected rate from accidental coincidences alone. The elevated rate persists when the source is removed and the phototubes optically shielded from one another. We have searched carefully for a malady in the recording system and have found none. Possibly the extra counts are caused by two correlated electrons in cosmic ray showers. These can interact directly in the photocathodes to liberate photoelectrons. (See Ref. 6 for a discussion of a similar problem.)

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Analysis of the Q in $K^-d \to K^-\pi^-\pi^+d$ and $K^-d \to K^-\pi^-\pi^+np_s$ at 7.3 GeV/c *

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Results from the study of reactions (1) $K^-d \to K^-\pi^-\pi^+d$ and (2) $K^-d \to K^-\pi^-\pi^+np_s$ at 7.3 GeV/c are presented. The interactions are dominated by the production of $K^*(890)$, $\rho(765)$, $Q(1200\text{–}1450)$, and $D^*(2200)$ in (1) and $\Delta^-(1236)$ in (2). Observation of $\rho(765)$ and its possible source as a misidentified $K^*(890)$ is discussed. Evidence is observed of splitting of the Q into two resonances with masses and widths (in MeV) $M_1 = 1228 \pm 21$, $\Gamma_1 = 111 \pm 33$, $M_2 = 1414 \pm 15$, and $\Gamma_2 = 89 \pm 24$. $L(1775)$ is observed in (1). An off-shell one-pion-exchange-model calculation is compared to (2). Cross sections and branching ratios of the Q resonances are estimated on the basis of the model.

INTRODUCTION

We present in this paper a study of K^-d interactions at 7.3 GeV/c. In particular, we are investigating the nature of the production of the $K\pi\pi$ enhancement in the Q region (1200–1450 MeV), as well as the structure and the decay properties of the Q. To date many pertinent questions concerning the Q enhancement remain unanswered and the subject continues to be an area of interest in strong-interaction physics.

The data on the Q available prior to May 1970 have been reviewed by Firestone at the 1970 Philadelphia Conference.[1] It was pointed out that while multi-Regge and Deck-type calculations have shown some success in fitting the data at lower momenta (below 7.3 GeV/c), similar success cannot be achieved when fitting the higher-energy data. In addition, results from most experiments indicate that the Q cannot be fitted by a single Breit-Wigner function. By fitting an accumulation of $K\pi\pi$ data from several experiments, Firestone found the Q to be consistent with a superposition of two peaks having masses and widths $M_1 = 1250 \pm 4$ MeV, $\Gamma_1 = 182 \pm 9$ MeV and $M_2 = 1400 \pm 6$ MeV, $\Gamma_2 = 220 \pm 14$ MeV. The results of our experiment appear to be in agreement with the above conjecture except for the widths of the two peaks which are narrower. The latter observation is in agreement with more recent experiments in K^+d at 9.0 GeV/c by Garfinkel *et al.* and in K^+p at 12 GeV/c by Davis *et al.*[2,3] Enhancements in the Q region have also been observed in nondiffractive experiments.[4-8] Mass and width values are again inconsistent, but the observations support the multiresonance interpretation of the diffractive data.

Uncertainty in a number of the other properties also remains. $K^*(890)\pi$ dominates the Q decay in the diffractive experiments while results on $K\rho(765)$ vary from 0% to 30%. No other modes have been observed. In the nondiffractive $\bar{p}p \to \bar{K}K\pi\pi$ annihilation experiment at rest, 75% $K\rho(765)$ is found for the enhancement observed at 1242 MeV.[7] From our analysis which is based