What Laboratory-Produced Plasma Structures Can Contribute to the Understanding of Cosmic Structures Both Large and Small

W. H. BOSTICK

Abstract—The tradition of the classical 1901 work by Birkeland [1] on aurora phenomena by laboratory terrella experiments was resumed by Alfvén [2], Cowling [3], Ferraro *et al.* [4], and by Bennett [5] in his terrella experiments. In 1954 [6] when experimenters accidentally produced in the laboratory structures later identified as diamagnetic vortex filaments, and in 1961 [7] when filaments, later identified as current-carrying paramagnetic plasma vortex structures (which are both electric motors and dynamos), were observed in the Z and theta-pinch experiments, this tradition was being further reestablished. It has been successfully argued [6], [8], [11], [20] that both of these types of vortices are force-free minimum-free-energy structures that spontaneously spring to life as readily as do thousands of spherical bubbles and water droplets during the splash of a breaking water wave. The Birkeland aurora filaments are a hybrid combination of these two basic types (paramagnetic and diamagnetic) of plasma vortices. It is to be expected that such structures on a cosmic scale play an important role in the cosmos, and indeed they do in the formation of galaxies, stars, binary stars, solar systems, solar prominences, solar flares, solar wind, comet tails, cosmic "strings" in the Crab nebula, string-like galactic clusters, expansion of the Universe, giant galactic jets, cosmic rays, sunspots, vortex rolls in sunspot penumbra, twinkling of radio stars by the density fluctuations in the ionosphere, turbulence at the interface between the solar wind and the earth's magnetosphere, etc. The penchant that Nature displays in carrying electric current via force-free filaments in laboratory-produced and cosmic plasmas provided in 1958 an otherwise overlooked filamentary or string-like hypothesis concerning the morphology of the electron (and other fermions) as it produces its spin magnetic moment, and deBroglie waves. The result of the development is an electrical engineer's model of the fermion and the photon and other onta in which *all* mass and momentum (including spin) consist of E and H vectors (lump mass is banished) and the quantum mechanical wave functions are transverse waves on the filament. Also in these simple heuristic models of elementary onta (particles), without the help of a gauge theory or the Kaluza–Klein theory, the search for grand unification of the strong force of the nucleus, the electromagnetic force, the electroweak force, and the gravitational force can find a solution based on electromagnetism (with self-gravity). In particular, gravity is merged with electromagnetic phenomena.

   The results of the M•A•N group in Munich are briefly mentioned, in which they claim to have produced tau mesons and gluons with the high-Reynolds-number turbulent vortices which come from a plasma focus.
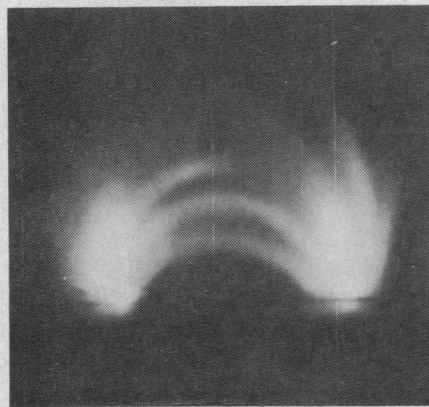
I. DIAMAGNETIC PLASMA VORTICES

FROM the inception (~ 1951) of the CTR programs for various nations, the primary objective has been to heat a deuterium or deuterium–tritium plasma and confine it with a magnetic field, and have as little as possible asymmetrical mass-motion energy (compared with thermal energy). Conventional wisdom has preached that asymmetrical mass motion is invariably invidiously coupled with instabilities. However, it has been demonstrated that interesting basic plasma physics research can be conducted with dynamic plasmas where the directed mass motion energy (especially in vortices) far exceeds its thermal energy. In 1954 [6] the author projected plasma from a small pulsed plasma gun in a direction perpendicular to a magnetic field in a vacuum of 10^{-5} torr. The plasma proceeded across the magnetic field in the form of tight bundles or filaments (with sharp boundaries between plasma and vacuum) which elongated along the magnetic field as they proceeded across the magnetic field. If two guns were fired at one another (as in a duel) across the magnetic field the countermoving bundles would bounce off one another like billiard balls in the center-of-mass coordinate system. Subsequent investigations were to prove that the plasma crosses the magnetic field in a train of paired oppositely rotating diamagnetic vortices which are rotating like rigid (or rubber, no shear) bodies, much as a smoke ring or a pair of tornadoes moves through the atmosphere. This dynamic plasma concentrates itself into clockwise and counterclockwise rotating vortices (electric motors) each one of which is a potential homopolar generator which generates an EMF between its center and its periphery. The ease with which nature can take the electrical energy in the plasma gun, turn it into directed kinetic energy and momentum of the plasma, and then turn a large share of that energy into rotating energy of vortices suggests that most of the rotational motion in the universe (as well as in our solar system) is acquired by the dynamic effects of plasmas moving in, across, and with magnetic fields. These paired rotating diamagnetic plasma vortices are force-free (each one in its own rotating coordinate frame of reference) and each one is a minimum-free-energy construction because it rotates like a rigid body. (It can be shown theoretically that for a fixed

(a)

(b)

Fig. 1. (a) Photograph of nuclear weapon explosion above the earth's atmosphere, in the earth's magnetic field. Note filaments (pairs of diamagnetic plasma vortex filaments). These filaments also occur in upper atmosphere barium release plasmas. (b) Photograph of light from plasma configuration resulting from firing a small plasma gun from each pole piece of a horseshoe magnet. Note filamentation. Magnet and plasma guns are in vacuum of 10^{-5} torr before firing. Spacing between pole pieces is about 8 cm.

angular momentum, a cylinder has minimum kinetic energy when it rotates as a rigid body.) These spontaneously arising sharp-boundaried entities have been called "plasmoids." The explosions (see Fig. 1(a)) of barium canisters or nuclear weapons above the earth's atmosphere can be observed to form pairs of these diamagnetic vortex structures which elongate along the earth's magnetic field as they cross the magnetic field. Fig. 1(b), which shows the spatial plasma distribution from two plasma guns fired simultaneously from the pole pieces of a horseshoe mag-

net, is the laboratory-produced paradigm of the barium-canister type of effect. The rotating cylindrical structures in the penumbra of sunspots are very likely examples of diamagnetic vortices, as also the strings observed must be (in the light of H_α) in the Crab nebula.

The diamagnetic plasma vortices that have been studied in the laboratory are in some sense a macroscopic paradigm of the ''quantum'' phenomenon of Type I superconductivity (see [27, last entry]).

The plasmas in experiments [8] with two plasma guns fired at one another across a magnetic field take on a different morphological pattern and behavior when fired into a ''vacuum'' chamber containing a background gas (air) at about 10^{-3} torr. The background gas is ionized by the ultraviolet from the plasma guns and is coupled to the moving plasma from the guns by the background magnetic field ($\sim$ 3000 G).

Now the plasma from each gun (see Fig. 2(a) and (b)) forms a helical jet, and as these jets approach one another they attach and form a barred-spiral configuration which rotates because of the original angular momentum built into the system by the pointing of the jets. These barred-spiral configurations have helical (long-pitch) arms and forked tails as do many of the observed barred-spiral galaxies. The fact that in our laboratory experiments since 1955–1956 we have easily produced these remarkable plasmoids provides the justification of our hypothesis [8] concerning the origin and structure of the barred-spiral galaxies. That is, not only the morphology but the controlling dynamic elements, electric and magnetic fields, are the same in the laboratory as in the galactic phenomena. In the laboratory experiments the central gravitational force is effectively simulated by the decelerating effect (via the magnetic field) of the background plasma on the fast-moving jets. The astrophysical community, with the possible exception of Alfvén, has largely ignored this hypothesis for the last 30 years. Buneman [9], [10], with his 3-D particle-in-cell fully electromagnetic simulation code, and his coworkers are showing beautiful computer simulation of barred-spiral galactic configurations which have helical arms and which have initial physical boundary conditions that are highly similar to those of our 1955 experiments. A barred-spiral galaxy can be predicted not only to be rotating (as a motor) but it will also be a homopolar generator (essentially ''series wound'') which continually pours gravitational energy via rotational motion into magnetic energy. It is possible to muster credible arguments [8] to show that galaxies expand away from each other because of their increasing interfering magnetic fields. On this basis, galactic red shift does not require a vast explosion like the Big Bang as the necessary originating phenomenon for the Universe. A continuous-creation Universe having both a transient and steady-state phase with galaxies moving away from each other because of increasing magnetic fields can be a competitive hypothesis (attractive, perhaps also, for electrical engineers).

The configuration of galactic amperian currents, which we postulate for the galaxy to be a series-wound homopolar generator that is constantly increasing its magnetic energy, produces a concentrated nexus of current perpendicular to the galactic disc in opposite directions at each side of the galactic disc near the center of the disc (see Fig. 2). Each of these nexuses is an eminently eligible site for a plasma focus effect on a cosmic scale [11], [33]. The plasma focus in the laboratory, as will be shown in the next section of this paper, generates a segmented (chopped) high-energy positive ion beam in the direction of the plasma amperian current and a high-energy (relativistic) electron beam in the opposite direction by a process which has been called the stuttering electromagnetic ram [11] (SER, sometimes called the ''electronic ram''). We are nominating the SER process as a candidate for the source of the segmented gigantic galactic jets [12] which are observed to be emanating from and perpendicular to the centers of the discs of active galaxies. The first known scientific discussion of the electronic ram appeared in *The Wireless Engineer* (1951) [13], and the hypothesis that the SER plays a role in galactic jets (and cosmic ray generation) was presented at the 1985 International Cosmic Ray Conference [11]. The application of the SER concept to the explanation of astrophysical jets is in competition with current astrophysics modeling of the sources of these galactic jets in terms of belching black holes [14]. The entrance of an electrical engineering concept (such as the SER) into the quest for the source of these jets (and cosmic rays) will make more of a well-balanced approach than that which is now prevailing. The relativistic electron beam accelerated by the plasma focus generates electron vortex structures [15]–[17] containing about 10^{11} electrons per structure (see Figs. 3 and 4) traveling through the background gas of $\sim$ 3 torr of deuterium gas. These tightly magnetically bound structures with internal (magnetic fields $\rightarrow 10^8$ G) dimensions of a few micrometers possess a high negative electrical potential and are very effective in accelerating positive ions, by their collective action, to high energies. It is suggested by the authors that this collective [15]–[17] type of acceleration is operating in the SER action in the active galaxies to produce the cosmic rays of very high energy.

II. PARAMAGNETIC PLASMA VORTICES

In the USSR and United States during the mid-1950's it was experimentally recognized that the z-pinch effect, in which a current of several hundred kiloamperes was pulsed through a deuterium gas at pressures of 0.1–5 torr contained in a cylindrical vessel whose axis was the z-coordinate axis, produced neutrons from the $D–D$ reaction. It was also recognized that most of these neutrons were produced not by deuterons heated thermally by an adiabatic compression but by deuterons accelerated by electric fields [18] in the Z direction which were somehow generated by the breakup of the current-carrying column. Kvartskava [7] in 1961 reported that a filamentary fine structure could be seen in framing-camera photographs of the pinch in its various stages. The plasma focus (a z pinch
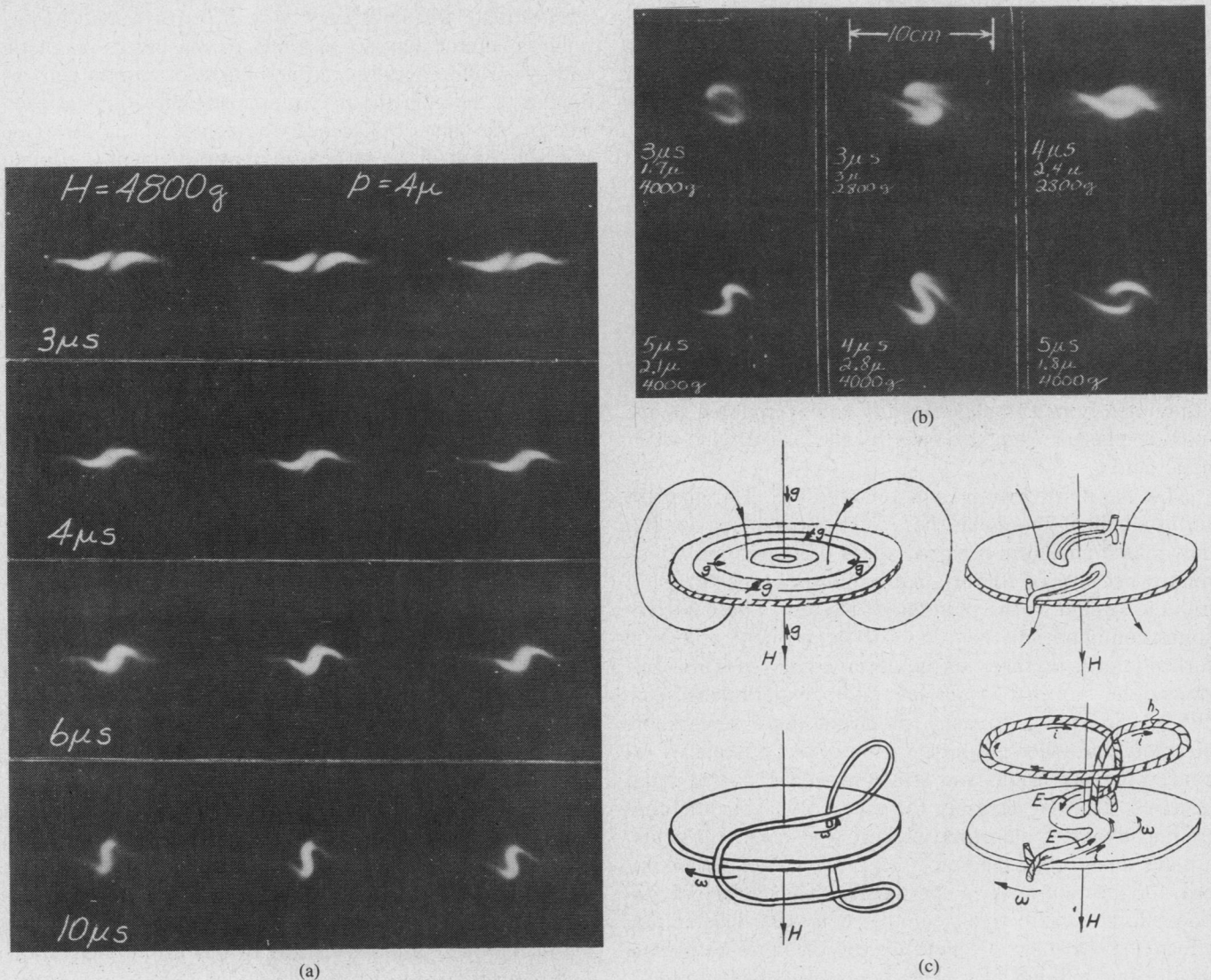
Fig. 2. (a) A sequential study of two plasmoids fired from sources 10 cm apart across a magnetic field of 4800 G. The Kerr-cell exposure times are 2 μs, and the various delay times of the sequence are indicated in microseconds. The pressure in the chamber is 4 μ. Stereographic photos with 10° separation (see [6]). (b) Examples of barred-spiral configurations produced as in (a) but with no stereo arrangement. The parameters of magnetic field, background pressure, and delay were varied as indicated. (c) Hypothesis on the process of formation of a barred-spiral galaxy (see [8]).
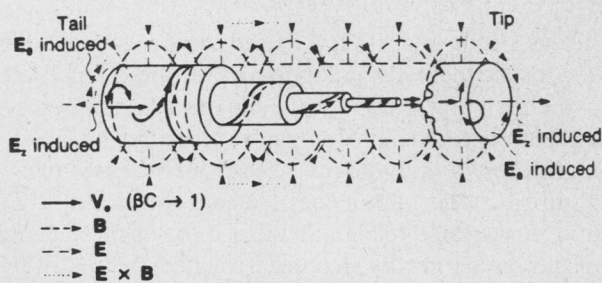

Fig. 3. Propagation of a cigar-shaped electron vortex structure as viewed from the laboratory frame of reference.

with a coaxial electrode geometry) was reported also in 1961 by Filippov and Filippova [19] of the USSR to be 100 times as effective a neutron producer as the conventional z-pinch geometry. Filaments in z pinches with

coaxial electrodes (the plasma focus) and in plasma coaxial accelerators were observed by several workers but they were regarded as a disturbing nuisance to be "tuned out," if possible. However, the Stevens group [20] in 1965 observed that these filaments in the current sheath of the plasma focus were produced in pairs as were the diamagnetic vortices, and correctly concluded from their measurements and analysis that these paired filaments were of the Beltrami type where the j (current density), B, v (mass flow velocity), and $\nabla \times \vec{v}$ (vorticity) (see Fig. 5) were all in the same direction and therefore that the filaments were both Magnus force free and Lorentz force free, and thus [4] also minimum free energy. Furthermore, the vortex filaments behave like energy and plasma-density "vacuum sweepers" which sweep up most of the plasma density, current density, kinetic energy, and magnetic
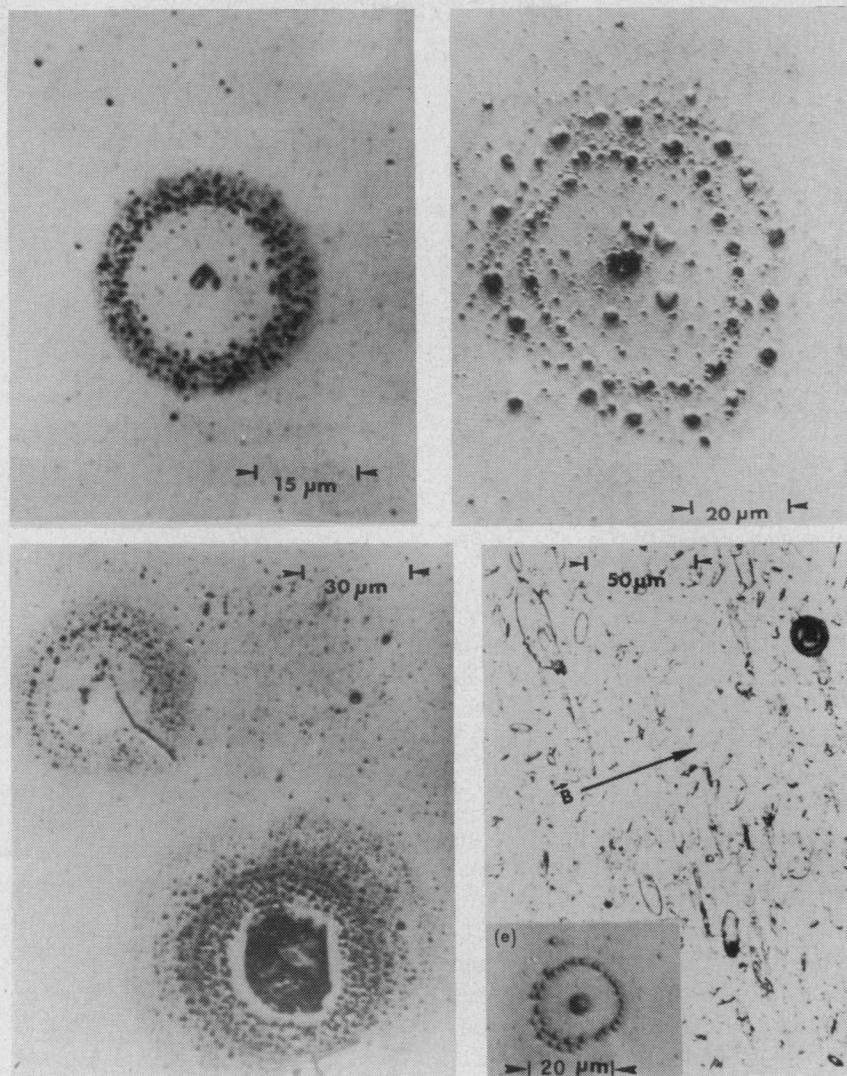
(a)
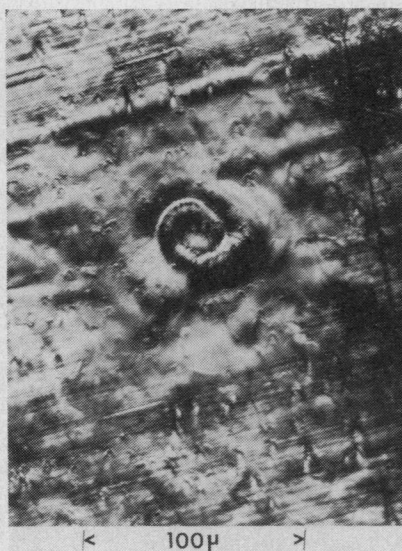
(b)

Fig. 4. (a) Observed damage patterns produced on polystyrene witness foils and target witness surfaces that show that the relativistic electron beam proceeding through the background gas of 3-torr pressure of deuterium was condensing into filaments of 2–300-μm diameter. There is no magnetic field. (b) Melted damage pattern on exposed face of 0.001″ Al foil, produced by a 1.5-MeV electron beam passing through a 1-m-long stainless-steel drift tube in air at 1 torr.
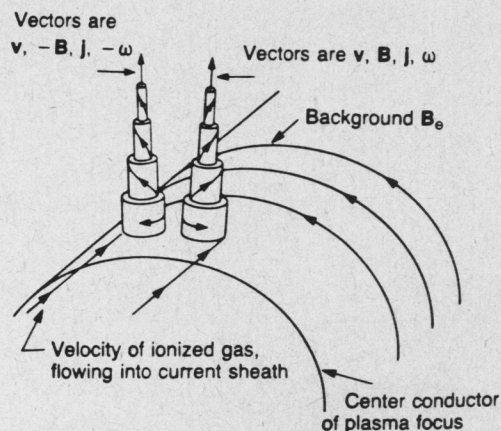
Fig. 5. Dissected diagram of the vector configurations of a pair of paramagnetic vortex filaments formed in the current sheath of the plasma focus; v is mass flow velocity, B is local magnetic induction, j is current density, ω is vorticity, B_g is background magnetic field caused by flow of current in the coaxial electrodes.

field energy into their filamentary structure, leaving nothing but vacuum elsewhere (see Figs. 6–8). The filaments with a collinear flow $(B \parallel V)$, in contradistinction to the diamagnetic vortex filaments, show a great deal of shear. The authors concluded 20 years ago that these force-free minimum-free energy (Beltrami-type) vortex filaments are Nature's preferred morphology for carrying amperian currents in plasmas both in the laboratory and in the cosmos. The Birkeland type [1] of current-carrying plasma vortex which is lined up primarily with an already existing background magnetic field is a hybrid of the paramagnetic and diamagnetic types and is similar to the diocotron effect shown in the flow of electron beams (relativistic and nonrelativistic) parallel to a background magnetic field [21] (see Fig. 9).

The paramagnetic plasma vortices are in some sense a macroscopic paradigm of the "quantum" phenomenon of Type II Superconductivity [27, last entry], [34].

III. PASER EFFECT IN THE PLASMA FOCUS

The particle acceleration by stimulated eruption of resistance effect (paser) represents the effect that occurs in the plasma focus when the force-free current-carrying vortex filaments come together in a compressed cylindrical column of the "pinch." One vortex filament explodes and stimulates explosions of the other filaments around the entire column in a ringlike damage pattern, on a nanosecond or subnanosecond time scale. On this same time scale the resistance of the ringlike region goes from a fraction of an ohm to tens of ohms, producing a potential difference of millions of volts across the gap where the vortex filaments have been cloven. The magnetic energy stored in the inductance of the undamaged portion of the column and the region between the electrodes mandates that the current across the gap must still flow, but the gap current is now largely displacement current which magnetically insulates the gap region so that there is produced a "double-layer" type of plasma capacitor charged to high voltage. During the flow of displacement current the plasma capacitor is insulated magnetically everywhere
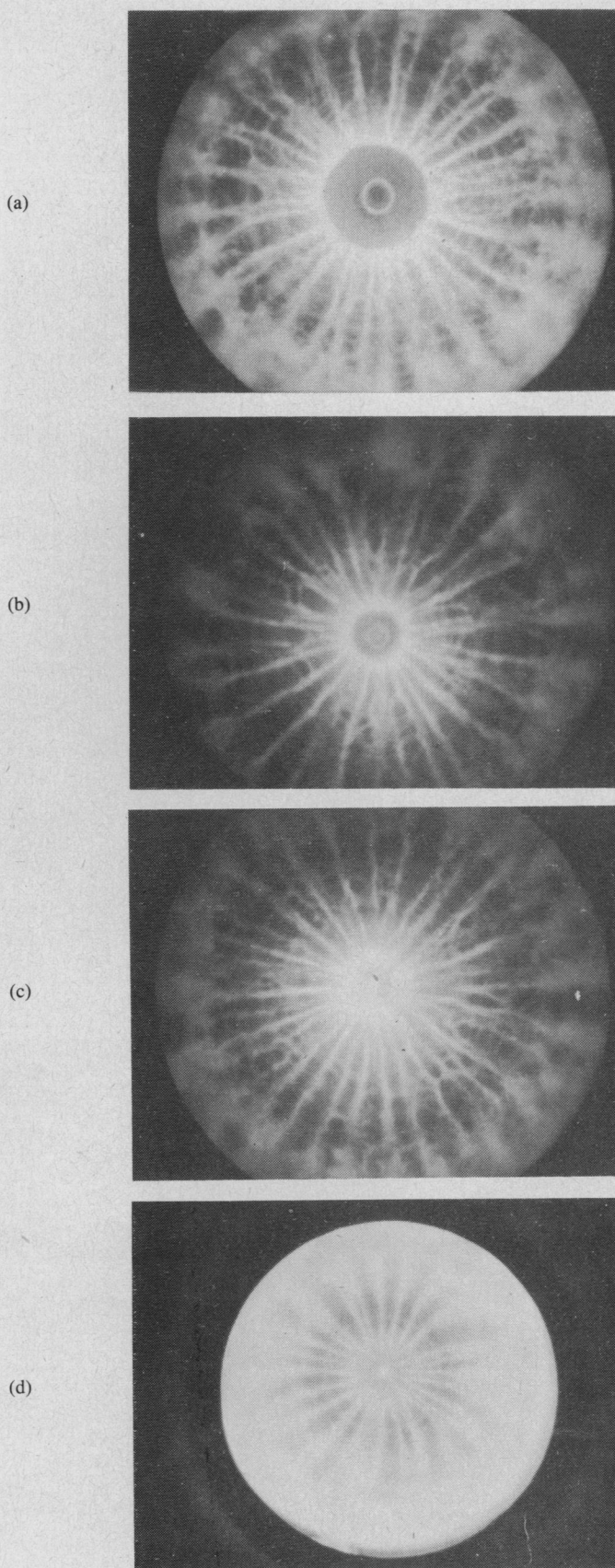

Fig. 6. (a)–(c) Five-ns image-converter photos of "radial" current filaments (paramagnetic, Beltrami-type) flowing from end of plasma focus center conductor (3.4-cm diameter) to 10-cm diameter outer conductor (cathode). (a), (b), and (c) represent a sequence (three different pulses used) during the inward motion of the current sheath. Filaments form in pairs (see (d), 50-ns-exposure photo). Note formation of diamagnetic (azimuthal) filaments in (a)–(c).
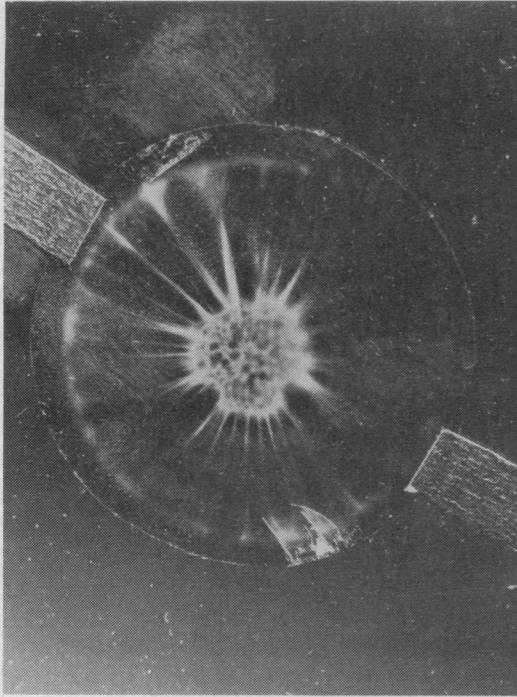
Fig. 7. Bleach pattern produced on blue cellophane placed against the downstream side of a 0.001-in titanium anode foil by the relativistic electron beam, at 1.5-MeV from the $\frac{1}{2}$-diameter carbon cathode in the FX-25 relativistic electron beam machine (25 kA, 40 μs). Radial striations are engraved by the pairs of vortex filaments of electrons that are formed with the help of some plasma that evolves from the electrodes and the background gas in the so-called vacuum diode. The space-charge neutralizing effect of the evolution of plasma permits the vortex filaments to be, as a group, pinched toward the center of the pattern. The flux-tube character of each current-carrying vortex filament is evidenced by the center region where the incoming filaments collide with each other. The magnetic flux along the axis of each incoming flux tube is brought into this center region by the inward radial transportation of the flux-tube-bearing filaments.

One interpretation of the unbleached islands in the center is that there are regions where the local B_z flux tubes are trapped. Another possible interpretation is that the unbleached areas represent regions of "return current" of plasma electrons with a surrounding sheath of unpinch. What is most likely is that both effects are occurring in the same region to produce the islands of unbleach. The photograph shows regions where the unbleached islands or cells are packed in a regular hexagonal pattern like a honeycomb. Here we see what is very likely the most efficient two-dimensional packing of "Beltrami cylinders." Each Beltrami cylinder contains relativistic current (and local B_z) flowing cathode-to-anode axially at its periphery and, perhaps, plasma electron current flowing axially (and local B_z) anode-to-cathode at its axis.
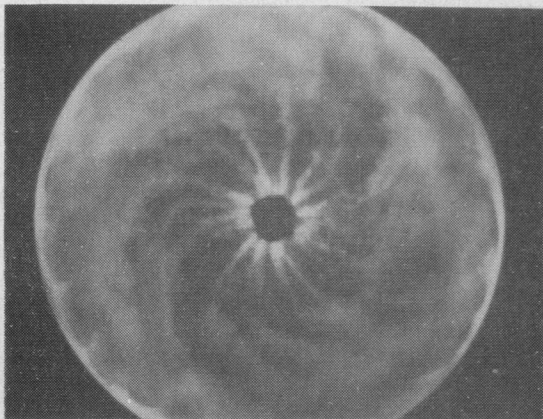

Fig. 8. Similar to Fig. 6, except an axial flared magnetic field at the center conductor is present at the beginning of the plasma-focus action.
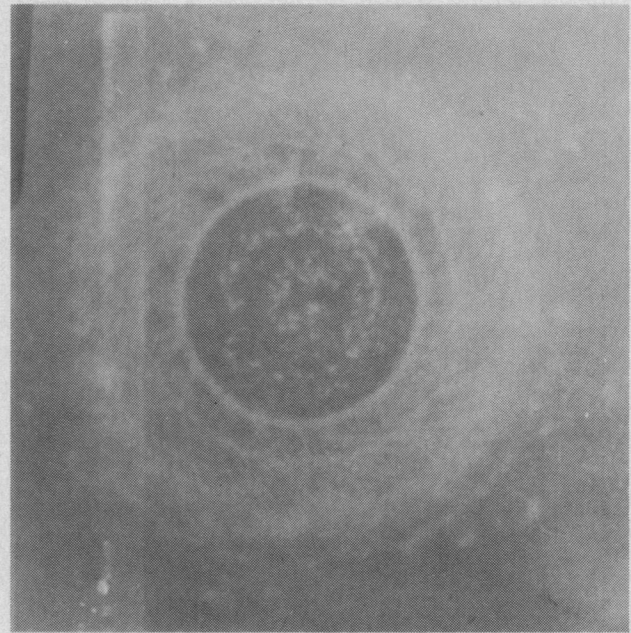

Fig. 9. Blue-cellophane bleach pattern from a relativistic electron beam machine (~ 1 MeV) with an axial magnetic field of about 3000 G with a vacuum of about 10^{-5} torr. Note concentration of electron density into filaments which are of the Birkeland type. (Photo taken by R. Adler and G. Kiuttu of the Mission Research Corp., at the Air Force Weapons Lab. at Kirtland Air Force Base.)

except at the geometrical center axis of the displacement current, where high-voltage concentrated ion and relativistic electron beams (counterstreaming) are formed. When the capacitor charges to its maximum value, the displacement current has dropped to zero and reverses, the magnetic insulation vanishes and reverses, and the capacitor rapidly discharges. This duration of the onta (particle) emission in the form of highly collimated ion and electron beams and the subnanosecond modulation of the beams indicates that the conduction-current-interruption, charge, discharge process may continue for ~ 1 ns, i.e., for several ($\gtrsim 10$) cycles or more. This process, the SER, is in our view responsible for the production of the segmented gigantic galactic jets [11]–[13] and cosmic ray primaries by active galaxies.

IV. THE PLASMAS OF THE VERY SMALL COSMIC SPACE

Measurements of the relativistic electron beam, which proceeds through the hollow anode through the background of 3 torr of deuterium gas, exhibit the electon vortex structure with internal fields of hundreds of megagauss [22], as already mentioned (see Figs. 3 and 4) in connection with the collective acceleration of cosmic ray primaries by the SER. Small-diameter Beltrami-type vortex filaments also occur in the "vacuum" diode of a relativistic electron beam machine (see Fig. 7).

X-ray pinhole photos of the plasma focus show dense plasma structures (nodules) (~ 20 μm in diameter and 100 μm long, see Fig. 10) which are the sites of some of the intense electron beams generated by the SER process. Stream velocities of the electrons and electron densities in these regions provide an estimate of the local magnetic field intensity. This field intensity is indirectly measured
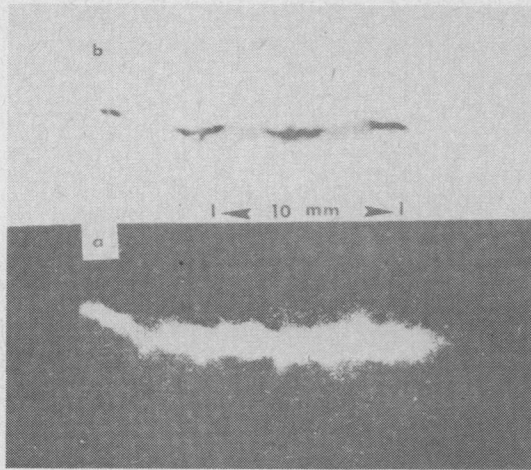
Fig. 10. X-ray pinhole photos of plasma densification sites in plasma focus. *b* is a radiographic print of *a*, which removes much of the obscurity of the saturated image of *a*.
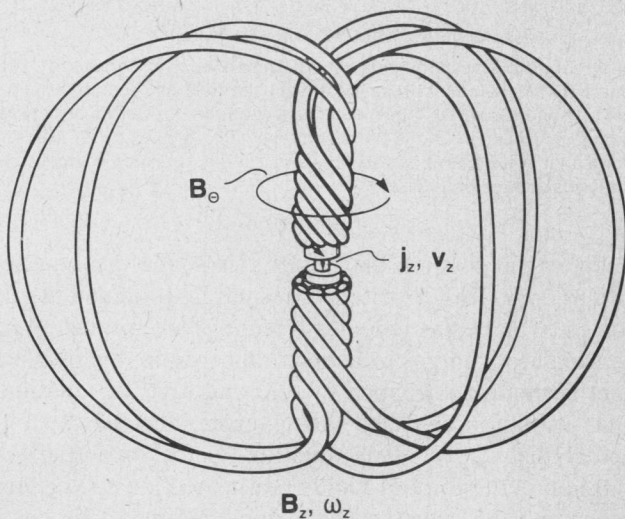

Fig. 11. Diagram of a plasma nodule, a toroidal solenoid wound with a force-free wire carrying current density *j*, vorticity ω, magnetic field *B*, and mass velocity *V*.

to be ~ 200 Mg by measuring [22] the intensity and the anisotropy of the X-ray bremsstrahlung source inside the volume of the site from the absolute deposition of silver on the X-ray film. From the measurements it can be inferred that the magnetic field at the surface of a localized X-ray source has an intensity $B \sim 200$ Mg. It is postulated that these intense pulsed beams produce their own current circulation pattern which can be separated from the external electrodes as drawn in Fig. 11. Investigators [23] working with vacuum arcs reproduce many of the filamentary effects seen in the plasma focus and estimate electron and ion densities up to $10^{21}/cm^3$ in the self-densification that occurs in the plasma modules photographed with X-ray pinhole photography.

The plasma focus group at Stevens has recently studied, with particle track detectors and Thomson spectrometers, the individual megaelectronvolt deuterons and the large clusters [35] of deuterons (solid-state density) that are ejected in all directions from the plasma focus. In producing these large clusters of deuterons (like deuterium

snowflakes, small elm ratio) the plasma focus is showing us that the electrons in the cluster can be cooled by synchrotron radiation in the 200-MG magnetic fields on a nanosecond time scale. Thus the plasma focus is experimentally opening a window on the process whereby cosmic plasma becomes cosmic dust and cosmic ice.

It is recognized by several plasma focus research groups that the microscopic strong turbulence and energy densification is producing the acceleration of onta (deuterons, for example) to energies in excess of 10 MeV. The M•A•N group [24] in Munich, working with a plasma focus employing a pointed center conductor as the cathode (at 50–100 kV on the storage capacitor), has reported (but, as yet, not convincingly) some startling effects in the form of generation of tau mesons and gluons.

The importance of strong turbulence in the acceleration of onta in the plasma focus has been considered in several of their publications, in particular [24]. For the $m = 0$ interchange instability, which they assume to be operative in the later stages of the Stuttgart POSEIDON plasma focus (280 kJ, ~ 60 kV, ~ 2.1 MA), a one-fluid three-dimensional system of magneto-fluid equations was used (in 1981) to calculate the progress of the $m = 0$ instability from a linear perturbation into its nonlinear state. It was shown that after the $m = 0$ flow decays, turbulent packets develop, move along the cylinder axis, and combine. The local Reynolds number (Re) in these packets increases to Re $\approx 2.10^{11}$, the magnetic fields to 5100 T, and the local electric fields to 12 MV/cm. The lifetime of the turbulent packets was calculated to be 160 ns. These results are approximately consistent with experimental results from, for example, the Stevens group and the Stuttgart group.

In 1982 a two-fluid model was used to calculate the compression phase and intermediate phase of the POSEIDON plasma focus and the results were judged to be in fair agreement with the experiments, including the neutron production characteristics.

In 1983 a four-fluid model (Maxwellian ions, fast ions, Maxwellian electrons, fast electrons) to handle the cases of strong electric fields and high currents in magnetoplasmas was developed. Microeffects are treated analytically while macroscopic flows are handled by REDUCE/FORTRAN hybrid codes. Microturbulence is considered in the quasi-linear approximation, while the hydrid code permits complete nonlinear approach via a macroscopic dispersion relation. In 1984 this approach was used for situations involving the time evolution of turbulence by a Fourier transformation from (r, t) space to (k, ω) space.

Meierovich and Sukhorukov [21] predict that a plasma pinch (a plasma focus) can perhaps achieve electron densities $> 10^{30}/cm^3$, and the resulting gigantic "linear atom" containing high-energy degenerate electrons could transfer enough energy to deuterons for the D–D-fusion reaction to occur under conditions satisfying the Lawson criterion for a fusion reactor.

Dijkhuis [25] suggests that the concentrated energy in vortices, such as that seen in the plasma focus with X-ray pinhole photos and reported by the M•A•N group, is responsible for the phenomenon of ball lightning.

The authors have argued in this paper on the basis of laboratory experiments and force-free minimum-free-energy analysis and extrapolation to solar atmospheres, galaxies, and string-like galactic clusters, that Nature's preferred plasma structures for carrying amperian currents are filaments or strings of a Beltrami-type morphology (see Figs. 3–8). It is an interesting coincidence that theoreticians interested in super gravity and grand unification of the "four basic forces" are now working passionately with a 26-dimensional super-string theory [26] which, as yet, seems to shed little light on the real world of fermions, leptons, hadrons, and the four basic forces.

The author (in 1958, 1961, 1978, 1985, and 1986 [11], [27]) has evolved a string-like model of elementary onta (fermions and bosons) with internal structure that may account for the observed values of spin, charge, mass, and magnetic moment of the onta. The model is based on the force-free minimum-free-energy principle that brings macroscopic plasmoids into life. This principle is employed to bring forward a string-like model of the electron (and all fermions) in which all mass energy and momentum consist of the E and H vectors which surround a current-carrying filament (no point, lump mass!). This electron[1] is equilibrated by the self-gravity of its own intense electric and magnetic fields.

The rationale for this effort is as follows.

a) To investigate the extent to which the laboratory-produced self-energy-densification paradigm, the plasmoid, can be conceptually useful in subatomic space as it has already proved useful in extraterrestrial and cosmic space.

b) Out of the ingredients of classical electric and magnetic fields alone, to attempt the construction of electrons, other fermions, and other elementary onta which are not only free of self-energy infinities but which are also in equilibrium (force-free) and stable (minimum-free-energy), and which therefore will spontaneously spring into life as do macroscopic classical entities like spherical water droplets, bubbles, and plasmoids. The morphology and dimensions of such fermions must be chosen so that in spite of their explosive electric and magnetic fields, these fields will be held together by their own self-gravity. These fermions will thus essentially be helical filamentary "dark gray holes."

c) To extend the realm of the classical concepts of electric and magnetic fields as developed by Gauss, Ampere, Faraday, Riemann, Maxwell, and Hertz, plus the self-gravity which general relativity predicts, to the very small dimensions required for equilibrium to obtain in the construction of the fermions.

d) To avoid the renormalization procedures of quantum electrodynamics (QED) in order to escape the inevitable self-energy infinities inherent in point mass and point charge.

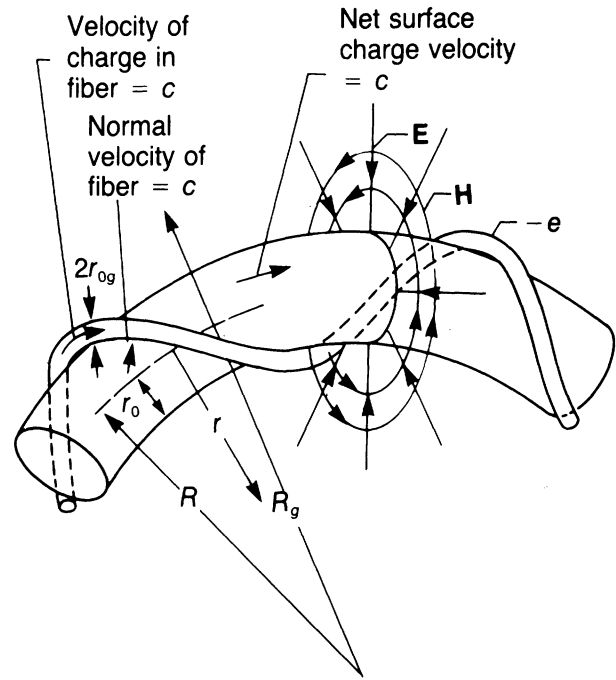e) To clarify the concepts of mass, rest mass, energy,

[1] The author suggests that this electron (or fermion) be called the *l'chaim* or *chaiyah*, "to life" or "living with God" (Hebrew), electron.

Fig. 12. Detail showing the way in which the gravitationally equilibrized charged fiber produces the surface charge and current for the torus core of radius r_0. Note that the surface charge is negative (see [11] and [27] for details).

and momentum. They must all be electromagnetic in character.

f) To search for a physical (as well as a probabilistic) interpretation of the quantum mechanical wave functions which divulges the basic nature of the deBroglie waves and explains why they exist.

The living electron model in its simplest pedagogical form is shown in Fig. 12. The conventionally assumed "Newtonian lump mass" is replaced by energy stored in the E and H vectors. The charge and current are merely instrumental artifices for calculating the E and H vectors. All mass and momentum (including the spin $\frac{1}{2}$) reside in the E and H vectors. The origins of spin $\frac{1}{2}$ and a gyromagnetic ratio of $g = (2e/m_{oe}c)(1 + \alpha/2\pi + \cdots)$ are explained geometrically in Fig. 12 and its caption.

The next pedagogical step beyond Fig. 12 is to show that transverse waves on the tensioned torus of Fig. 12 are really the deBroglie–Einstein waves (the displacements Ψ and Ψ^*) for which deBroglie, throughout most of his career, unsuccessfully sought a physical explanation, in spite of his concept of "the pilot waves." For the simplest case of the solution to the Schroedinger equation for a free electron (no potential wells) traveling in the z coordinate direction, the results for the living electron are shown geometrically in Figs. 13–15 where Ψ and Ψ^* are each one-half of the electron since both are equally acceptable solutions. These deBroglie waves of Figs. 13–15, which have exactly the same dispersion relationship as that for a photon (electromagnetic wave) in a waveguide, can be geometrically compared with the waveguide case of Fig. 16, from which it is obvious that a photon in a waveguide has a rest mass associated with its resonance frequency between the two reflecting surfaces. But the rest
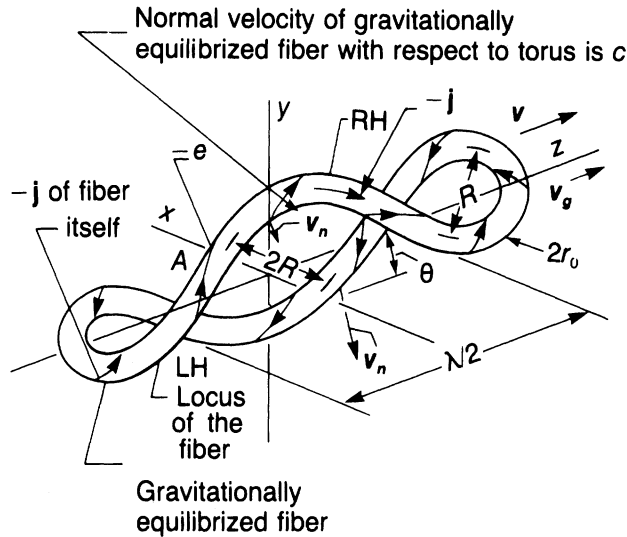
Fig. 13. The helical configurations assumed by the torus of core radius r_0 when it is projected at a velocity v_g with respect to an observer. Note that $v_n = c$ and $v = c$ = net velocity of charge along torus surface.
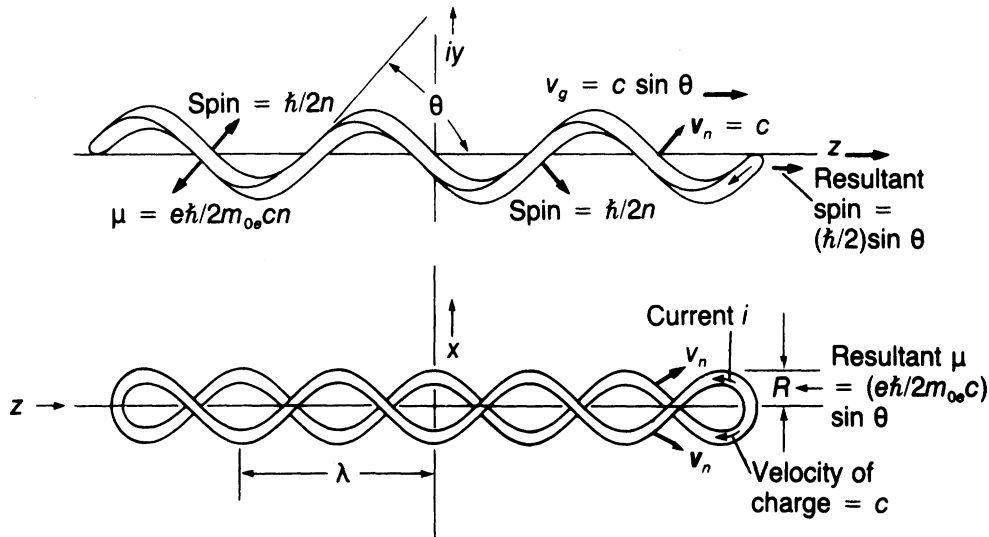

Fig. 14. Elaboration of Fig. 13 showing distributed nature of spin and gyromagnetic ratio μ, where n is the number of half-wavelengths.

mass is *all* electromagnetic in character: no point, lump mass.

A filamentary model of the living photon now follows in Fig. 17, where, as with the *l'chaim* electron of Figs. 14 and 15, there appears the Planck energy equation, $E = h\nu$. With living electrons and photons, where all mass and energy are electromagnetic, it can be stated that, in principle, the search for the unification of all "four fundamental forces" may be solved: all forces must be basically electromagnetic. It is only the morphology that must be worked out. Since morphology is primarily a matter of geometry, it is possible [27] to elucidate, modestly but clearly the author hopes, the geometry that brings together under the unifying umbrella of electromagnetism the strong interaction energy E_{st} of the nucleons, the conventional electromagnetic interaction E_{em}, the electroweak interaction E_w, and the gravitational interaction E_g. Conant's work [28] has been a necessary foundation for this work.

With the help of Conant's analysis, which derives the universal gravitational constant $G = 6.67786 \times 10^{-8}$ dyn $\cdot$ cm$^2 \cdot$ g^{-2} from the fine-structure constant $\alpha = 137.036$ [27, 1986], shows how the l'chaim fermion can very easily produce the "strong force" interaction by telescoping two fermions (such as are diagrammed in Fig. 12) closely on one another. The strong force is then an electromagnetic interaction between the tightly fitting fermions, and the gluons are the squashed electromagnetic fields in between the fermions which can act like a waveguide. The gluons, if they are photons, can acquire rest mass within this waveguide.

Finally, the living photons can be used to illustrate geometrically the gravitons in a gravitational interaction (see Fig. 18).

Thus the filamentary model of living fermions and photons and kindred onta suggests the hypothesis that everything in the Universe is electromagnetism (with self-gravity) and that all four forces are explainable by
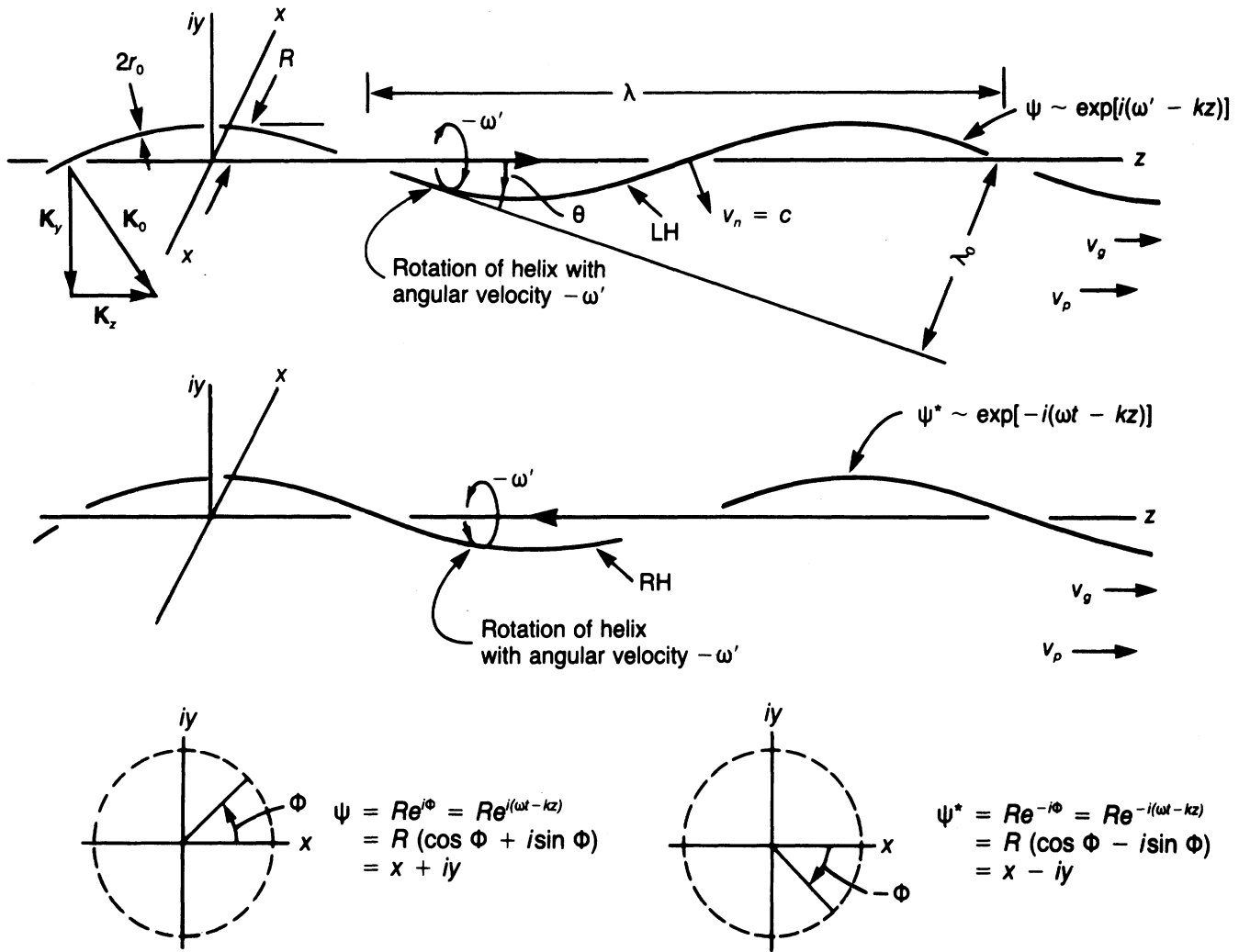
Fig. 15. The wave functions Ψ and Ψ^*, solutions of the Schroedinger wave equation for an electron propagating in the z direction with a group velocity v_g are shown geometrically. The normal velocity of the helical right-hand and left-hand filaments v_n is due to both a rotation and translation of each filament. The propagation vector k_0 can be resolved into its two components k_z and k_y as shown and compared geometrically with the propagation vectors for the photon in a waveguide of Fig. 16, to give a dispersion relationship here of $1/\lambda_0^2 = 1/\lambda_{comp}^2 + 1/\lambda_{deBroglie}^2$ or $\omega^2 = \omega_{comp}^2 + k_z^2 c^2$, which is of the same form as for the photon in a waveguide. Ψ and Ψ^* are, of course, joined by loops at the front and rear of the electron wave packet as shown in Fig. 13. Note that *both* Ψ and Ψ^* are necessary in order to produce a living electron. Note that rotational frequency $\pm\omega'$ is not to be confused with the observed frequency ω.

electromagnetism. This hypothesis, like that of the formation of barred-spiral galaxies, has come from laboratory plasma physics experiments which show filamentary structures that are morphologically similar to those observed in the cosmos.

The author's proposal of such a simple morphologically explicit route toward grand unification theory (GUT's) might be construed by some theoreticians and historians to be a sacrilege. But the author of this paper does not in any way wish to neglect or fail to recognize the groundbreaking cornerstone-laying work and aims of the Masters, both past and present.

- Albert Einstein's drive toward a unification of gravity and electromagnetism from 1915 until his death.
- Herman Weyl.
- Theordor Kaluza [29], the little known Polish phys-

icist, who in 1921 showed that electromagnetism is a form of gravity, the gravity of an unseen dimension in space—a fifth dimension; the gravitational field in this *five*-dimensional universe behaves just like ordinary gravity plus the electromagnetic field when viewed from the perspective of a four-dimensional space-time. Kaluza was saying that in an enlargement of our vision to five dimensions there is only one force field, and that is gravity. Kaluza taught that there are no forces at all, only a warped five-dimensional geometry.

- Oscar Klein [29], who in 1926 answered the question of why we could not directly observe Kaluza's fifth dimension: the fifth dimension is rolled up into such a small size that we cannot see it. Klein calculates, from the charge on the electron and the gravitational G, that the size of the loops of the warping around
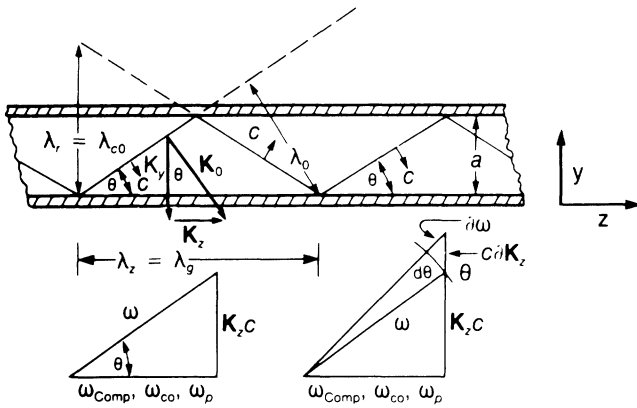
Fig. 16. Electromagnetic wave (made up of photons) with free-space wavelength λ_0 propagating in the TE$_{01}$ mode between two parallel plates (a waveguide) at $y = 0$ and $y = a$: $\lambda_z = \lambda_g = \lambda_0/(\sin\theta)$; $v_p = c/(\sin\theta)$; and $c = \lambda_0\nu$. The cutoff wavelength $\lambda_{c0} = 2a$. Wavefronts are shown popagating at a normal velocity c.
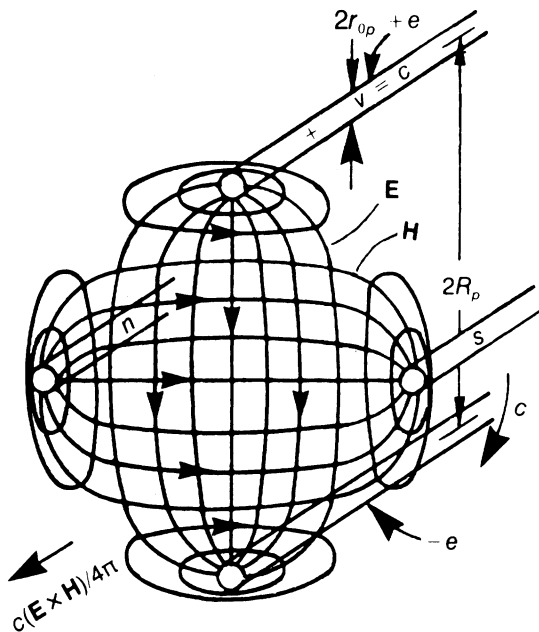

Fig. 17. Model of a right-handed circularly polarized photon made up of two + and − charged filaments and two north and south "charged" filaments projected in the z direction with a velocity c, while at the same time the configuration rotates with a peripheral velocity c.

this fifth dimension are about 10^{-23} cm in circumference—too small to be noticed.

But with the development of nuclear physics in the 1930's the weak force of beta decay and the strong force between nucleons appeared on the scene. There were now not two but *four* forces which would have to be ecumenically accommodated by a unification. Since the Kaluza–Klein theory accommodated only two, gravity and electromagnetism, the theory remained scarcely more than a mathematical curiosity for 50 years until, in the late 1970's, the theorists' quest for GUT's and supergravity prompted a recall of the Kaluza–Klein theory. Kaluza–Klein was remodeled to accommodate the now-extended range of forces.

In the words of P. Davies [29]:

"In GUTs, the theorists' ability to subsume three very different sorts of forces under a single concep-

tual umbrella hinged, as we saw in earlier chapters, on the discovery that all three forces involved can be described in terms of gauge fields. The central property of these gauge fields is the presence of certain abstract symmetries, which is how they attain their power and elegance. The presence of symmetries in the force fields already hinges strongly at some sort of hidden geometry at work. In the revitalized Kaluza–Klein theory the gauge field symmetries become concrete; they are the geometrical symmetries associated with the extra space dimensions.

As in the original version of the theory, the forces are accommodated by grafting more dimensions of space on to known spacetime, but the fact that we now have three forces to accommodate demands several additional dimensions. A simple count of the number of symmetry operations embodied in the grand unified force leads to a theory in which there must be seven extra dimensions, making ten space dimensions in all, plus time, or eleven spacetime dimensions. The modern version of the Kaluza–Klein theory postulates an eleven-dimensional universe."

In a universe of seven spatial dimensions, the range of conceivable topologies is enormous. A "seven sphere" contains many additional symmetries not found in an ordinary three-dimensional sphere. These symmetries are intended to model the underlying symmetries of the "force fields." It has been difficult and tedious to verify the forces because the symmetries are sometimes hidden, distorted, or broken. In the Kaluza–Klein theory this symmetry breaking is achieved by distorting the shape of the seven-dimensional sphere away from exact sphericity. The "squashed" seven sphere is thus emerging as the most favored shape for the compactified extra dimensions.

QED [30], which is the marriage of electrodynamics with the quantum theory uses a mathematical-point electron normalization to sidestep self-energy infinities, fluctuations, and polarization of the "vacuum" to achieve accuracy in agreement with experiments (the Lamb shift, anomalous magnetic moment of the electron). The electromagnetic field is the manifestation of the simplest known gauge symmetry that is consistent with special relativity. Gauge symmetry is intimately related to renormalizability. It was not until the 1970's that the electromagnetic force and the weak force were unified into a single force called the electroweak force through the efforts of Weinberg and Salam working independently and building upon earlier work by Glashow. This theoretical work, which described the weak force in terms of a gauge field and reduced the number of basic forces which are yet to be grand-unified from four to three, was justified in 1982 by Rubbia and Van der Meer who directed experimenters at CERN to produce the intermediate bosons, the W and Z onta, which are identified as the messengers of the electroweak interaction. The worldwide recognition of these latter-day Masters was complete when all five eventually received the Nobel prize.

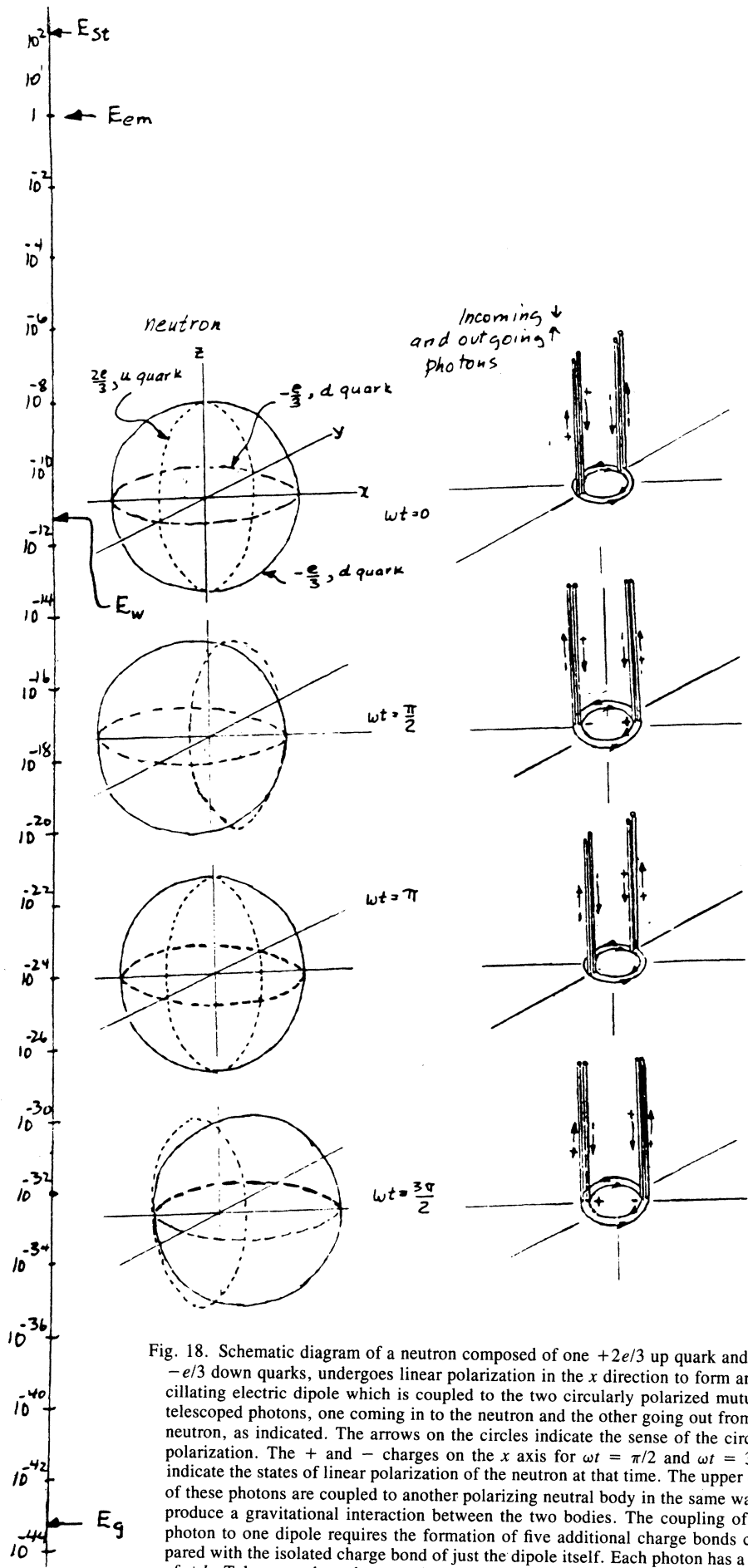The *a posteriore* justifications for the author's currently

Fig. 18. Schematic diagram of a neutron composed of one $+2e/3$ up quark and two $-e/3$ down quarks, undergoes linear polarization in the x direction to form an oscillating electric dipole which is coupled to the two circularly polarized mutually telescoped photons, one coming in to the neutron and the other going out from the neutron, as indicated. The arrows on the circles indicate the sense of the circular polarization. The $+$ and $-$ charges on the x axis for $\omega t = \pi/2$ and $\omega t = 3\pi/2$ indicate the states of linear polarization of the neutron at that time. The upper ends of these photons are coupled to another polarizing neutral body in the same way to produce a gravitational interaction between the two bodies. The coupling of one photon to one dipole requires the formation of five additional charge bonds compared with the isolated charge bond of just the dipole itself. Each photon has a spin of $\pm h$. Taken together, the two photons constitute a graviton. The photon model used here is simpler than that of Fig. 17. The north and south "charged" filaments are absent.

reported implementation of the hypothesis on the living onta are as follows.

a) The hypothesis is based on the successful linkage principle, which relates laboratory-produced minimum-free-energy plasmoids to cosmic structures, and it seems now to be fairly successful also in the realm of the elementary onta.

b) It unifies all mass and momentum under the Filioque of electromagnetism which itself experiences self-gravity.

c) It delineates the basic string-like morphology (in three-dimensional space plus the dimension of time) in which elementary electrical charge and magnetic fields must exist.

d) It identifies the deBroglie–Einstein waves (the wave functions ψ and ψ^*, the solutions to the Schroedinger wave equation) as physical helical waves on the tensioned electromagnetic filament.

e) It describes rest mass for a photon in a waveguide and for an electron in a three-spatial-dimensional geometry that can be simply and clearly illustrated.

f) It can draw a textbook picture of a photon and a gravitational interaction (graviton), and show, with Conant's analysis, how the gravitational constant G can be derived from the fine-structure constant α, thereby showing that gravity is an electromagnetic phenomenon.

g) It can show that the *strong force* can be easily understood as an electromagnetic interaction occurring between two telescoped rings.

h) It shows that the theta pinch, a macroscopic plasma device, ejects, every half-cycle, at each end of its coil, a toroidal structure of magnetized plasma, one torus being left-handed and the other right-handed. The production of these tori depends upon the Hall effect, and it is charge-conjugation parity (CP) invariant. It is a classical laboratory-produced paradigm [32] of beta-ray decay in nuclear physics. In the process of ejecting these tori, the plasma becomes an electrical quadrupole just as Conant [28] assumes is the case when he calculates the electroweak force in terms of the fine-structure constant α.

i) It shows, through the elastic electromagnetic flywheel model, how, if the fermions are to live, they must have a spin $\frac{1}{2}$ carried by the Poynting vector.

j) With a string-like highly elastic living electron constructed of the gravitationally equilibrated fiber (as in Figs. 12–15) the dispersion relationship (Figs. 14 and 15) for the resultant deBroglie waves shows that the wavelength in the z direction (and hence its potentiality for stretching) grows without limit as the velocity (momentum) in the z direction approaches zero. Also, since the momenta in the x and y directions is zero, the uncertainties in the x and y positions, Δz and Δy, are infinite and, therefore, the living electron, as it approaches in the z direction a double slit, will, on the average, behave as a plane wave in the xy plane, just as a conventional quantum mechanical electron is assumed to do. A parade of a succession of a large number of monochromatic living electrons will flesh out the diffraction and interference

patterns produced by plane waves. Each individual living electron, because of its great elasticity and flexibility, can presumably sense the presence and dimensions of the two slits, can pass through both slits at once, and, can reconnect itself on the other side of the slits. (Plasmoids have been observed both to separate and to connect.) The particular spot where the individual electron strikes the viewing screen depends upon its phase as it strikes the double slit. On the average, the electrons will produce the well-known double-slit interference and diffraction pattern.

k) Figs. 13–15 predict that the fractional alignment of the spin and magnetic moment of the electron with its velocity vector is $\beta = \sin \theta$, and this is indeed experimentally the case in beta-ray decay.

In 1440 (400 years before Darwin) the great Cardinal Nicolaus of Cusa, the initiator of the scientific thrust of the Renaissance, stated that the Universe is struggling from chaos towards order, that ontogeny recapitulates philogeny, and that the earth is not standing still but is moving, even as was taught in 300 B.C. by Aristarchus and 18 centuries later in 1540 A.D. by Copernicus. Although these cosmological pronouncements carried a high morphological content, the good Cardinal was not persecuted or castigated for profaning the Holy Scriptures. The great scientist, artist, inventor, and engineer, THE Renaissance man among "Renaissance men," Leonardo da Vinci, in 1520 was making detailed observations and drawings of the helical flow of water (harbingers of the work of Beltrami) and of the human anatomy. Although he was obliged to surround this latter effort with a certain amount of secrecy, in his own mind he did not regard these scientific sorties into the morphology of Nature as a form of profanity or sacrilege. In 1620 Galileo argued that the Copernican theory and the morphology and features he could observe with his new-found telescope, such as prominences and spots on the sun, and moons around Jupiter, added much to the majesty of God's creation and did not run counter to the Scriptures. We would argue that the morphological features shown in the laboratory paradigms of cosmic structures and in the living-onta hypothesis add much to the majesty of God's unified creation and do not necessarily run counter to the contributions of the present day Masters. However, we do concede that stormy weather can be expected from the quarter now occupied by those advocating super strings, super gravity, black holes, and Big-Bang cosmology.

REFERENCES

[1] A. L. Peratt, "Birkeland and electromagnetic cosmology," *Sky Telesc.*, p. 389, May 1985.
[2] H. Alfvén, *Cosmical Electrodynamics*, 2nd ed. New York: Oxford, 1963.
[3] T. G. Cowling, *Magneto Hydrodynamics*. New York: Interscience, 1957.
[4] V. C. A. Ferraro and C. Plumpton, *An Introduction to Magneto-fluid Mechanics*. Oxford, England: Clarendon, 1966.
    R. Lust and A. Schluter, "Kraftfreie Magnetfelder," *Z. Astrophys.*, vol. 34, p. 263, 1954.
    S. Chandrasekhar and E. Fermi, "Problems of gravitational stability in the presence of a magnetic field," *Astrophys. J.*, vol. 118, p. 116, 1953.

S. Chandrasekhar and L. Woltjer, "On force-free magnetic fields," *Proc. Nat. Acad. Sci.*, vol. 44, p. 285, 1958.

S. Chandrasekhar, "On the stability of the simplest solution of the equations of hydromagnetics," *Proc. Nat. Acad. Sci.*, vol. 42, p. 273, 1956.

E. Beltrami, "Considerazioni Idrodinamiche," *Rendiconti del Reale Instituto Lombardo, Serie II*, tomo XXII, p. 121, 1889.

D. R. Wells and J. Norwood, Jr., "A variational approach to the dynamic stability of high density plasmas in magnetic containment devices," *J. Plasma Phys.*, vol. 3, p. 21, 1969.

D. R. Wells *et al.*, "Hydromagnetic confinement of thermonuclear plasmas," *J. Fus. Technol.*, vol. 9, p. 83, 1986.

[5] W. Bennett, "Solar proton stream forms with a laboratory model," *Rev. Sci. Inst.*, vol. 30, no. 2, p. 63, Feb. 1959.

[6] W. S. Bostick, "Experimental study of ionized matter projected across a magnetic field," *Phys. Rev.*, vol. 104, p. 292, 1956.

W. H. Bostick, "Experimental study of plasmoids," vol. 106, p. 404, 1957.

W. H. Bostick, "Plasmoids," *Sci. Amer.*, vol. 197, p. 81, Oct. 1958.

[7] I. F. Kvartskava *et al.*, "Some new data on self-compressed discharges," in *Proc. 1st IAEA Conf. Plasma Phys. and Controlled Nucl. Fusion Res.* (Salzburg, Austria), 1961, p. 533.

V. S. Komelkov *et al.*, "A dynamical current filament," in *Proc. 5th Int. Conf. Ionization Phenomena in Gases*, vol. 2 (Munich, W. Germany), Aug. 1961, p. 2191.

[8] W. H. Bostick, "Possible hydromagnetic simulation of cosmical phenomena in the laboratory," *Rev. Mod. Phys*, vol. 30, no. 3, p. 1090, 1958.

W. H. Bostick, "Experimental study of plasmoids," in *Electromagnetic Phenomena in Cosmical Physics* (IAU Symp. No. 6, Stockholm, Sweden, 1956). New York: Cambridge, p. 87.

W. L. Laurence, "Physicist creates universe in a test tube," *N.Y. Times*, p. 1, Dec. 12, 1956.

W. H. Bostick, "Simulation of astrophysical processes in the laboratory," *Nature*, vol. 179, p. 214, Jan. 1957.

[9] O. Buneman *et al.*, "Principles and capabilities of 3-D, E-M particle simulations," *J. Comput. Phys.*, vol. 38, no. 1., p. 1980.

O. Buneman, "Dynamic evolution of a Z pinch," *Phys. Rev. Lett.*, vol. 42, no. 19, p. 1274, 1979.

[10] A. L. Peratt *et al.*, "Evolution of colliding plasmas," *Phys. Rev. Lett.*, vol. 44, no. 26, p. 1767, 1980.

A. L. Peratt *et al.*, "Are black holes necessary?" *Sky Telesc.*, p. 19, July 1983.

A. L. Peratt *et al.*, "Simulating spiral galaxies," *Sky Telesc.*, p. 118, Aug. 1984.

[11] W. H. Bostick, "The morphology of the electron," *Int. J. Fusion Energy*, vol. 3, no. 1, pp. 45 and 68, Jan. 1985.

W. H. Bostick and V. Nardi, "Electromagnetic ram as a model for production of electron and ion beams in the plasma focus and the cosmic rays and gigantic jets in the cosmos," in *Proc. 19th Int. Cosmic Ray Conf.*, vol. 3 (La Jolla, CA, Aug. 1985), S. C. Jones, Ed. Springfield, VA: NASA Sci. and Tech. Int. Branch, 1985, p. 183.

[12] J. O. Burns and R. M. Price, "Centaurus A: The nearest active galaxy," *Sci. Amer.*, vol. 249, no. 5, p. 56, Nov. 1983.

J. O. Burns *et al.*, "Radio jets in classical double radio sources with strong cores," *Astron. J.*, vol. 283, p. 515, 1984.

[13] W. R. Raudorf, "An electronic ram," *Wireless Engineer*, vol. 28, p. 215, July 1951; also in *Proc. 1st Int. Conf. Energy Storage, Compression, and Switching.* New York: Plenum, 1974, p. 387.

[14] P. V. E. Lovelace, "Dynamo model of double radio sources," *Nature*, vol. 262, pp. 649–652, 1976.

M. J. Rees, "Accretion and the quasar phenomenon," *Phys. Scripta*, vol. 17, pp. 193–200, 1978.

[15] V. Nardi, W. H. Bostick, J. Feugeas, and W. Prior, "Internal structure of electron beams," *Phys. Rev.*, vol. 22A, p. 2211, 1980.

[16] W. H. Bostick and V. Nardi, "Collective acceleration and focusing of fast ion bursts," *Collective Method of Acceleration*, Rostoker & Reiser, Eds. New York: Harwood Academic Publ., 1979, p. 443.

[17] J. S. Luce, W. H. Bostick, and V. Nardi, "LLL experiments in collective field accelerations II," in *Proc. 2nd Int. Conf. Energy Storage, Compression, and Switching.* New York: Plenum, 1978, p. 457.

[18] O. A. Anderson, W. R. Baker, S. A. Colgate, J. Ise, and R. V. Pyle, "Neutron production in linear deuterium pinches," in *Proc. 3rd Int. Conf. Ionization Phenomena in Gases* (Venice, Italy), 1957, p. 62.

[19] N. V. Filippov, J. I. Filippova, and B. P. Vinogradov, in *Proc. 1st IAEA Conf. Plasma Phys., and Controlled Nucl. Fusion Res.* (Salzburg, Austria), 1961, p. 577.

[20] W. H. Bostick, W. Prior, L. Grunberger, and G. Emmert, "Pair production of plasma vortices," *Phys. Fluids*, vol. 9, p. 2079, 1966.

[21] B. Meierovich and S. Sukorukov, "Equilibrium structure of relativistic beams," *Soviet Phys. JETP*, vol. 41, p. 895, May 1975.

[22] V. Nardi, W. H. Bostick, and W. Prior, "Magnetic fields higher than 100MG produced in the current sheath of a coaxial accelerator," in *Proc. Int. Conf. Physics in High Magnetic Fields* (Grenoble, France), Sept. 1974.

W. H. Bostick, V. Nardi, and W. Prior, "Observation of 10^8 Gauss fields and production of 14 Mev D-T neutrons in a deuterium plasma," in *Proc. 5th Int. Conf. Plasma Phys. and Controlled Nucl. Fusion Res.* (Tokyo, Japan), Nov. 1975.

W. H. Bostick, V. Nardi, and W. Prior, "X-ray fine structure of dense plasma produced by a plasma coaxial accelerator," *J. Plasma Phys.*, vol. 8, p. 7, 1972.

[23] Yu. A. Bykovskii and V. B. Lagoda, "Local high-temperature plasma formations in a high-current pinching discharge," *Sov. Phys. JETP*, vol. 56, no. 1, p. 61, July 1982.

[24] A. Hayd and P. Meinke, Eds., *M•A•N Technischer Schnussbericht Forderkennziechen PL1 126610.* "Abschatzung des Technologie potentials hochturbulenter Prozesse," May 20, 1983.

M•A•N = Maschinenfabrik Augsburg-Nurnberg Aktiengesellschaft, D 8000 Munchen 50, Dachauer Strasse 667.

[25] G. C. Dijkhuis, "A model for ball lightning," *Nature*, vol. 284, p. 150, March 13, 1980.

G. C. Dijkhuis, "Plasmoid confinement by charged particle microfields," *Nature*, vol. 290, p. 166, Mar. 12, 1981.

[26] P. Ginsparo and S. Glashow, "Desperately seeking superstrings," *Phys. Today*, vol. 39, pp. 7–9, 1986.

[27] W. H. Bostick, "The gravitationally stabilized hydromagnetic model of the elementary particle," Gravity Research Foundation Essay Contest, Gloucester, MA, fourth prize 1958, first prize 1961.

W. H. Bostick, "Toward understanding the nature of fusion,," *Fusion*, vol. 2, p. 42, May 1978.

W. H. Bostick, "Gravity as an electromagnetic phenomenon," 1986 entry for the Gravity Research Foundation Essay Contest.

W. H. Bostick, "The cosmology and morphology of the electron, photon, and other elementary onta," submitted for publication.

[28] D. R. Conant, *Unified Quantum Field Theory.* Los Alamos, NM: Los Alamos Consultants, 1978, p. 137. (Contact 12903 Camphill Ct., St. Louis, MO 63141.)

[29] P. Davies, *Superforce, The Search for a Grand Unified Theory of Nature.* New York: Simon & Schuster, 1985, pp. 101, 150.

[30] P. Davies, *Superforce, The Search for a Grand Unified Theory of Nature.* New York: Simon & Schuster, 1985, p. 103.

[31] P. Davies, *Superforce, The Search for a Grand Unified Theory of Nature.* New York: Simon & Schuster, 1985, p. 117.

[32] W. H. Bostick and D. Wells, "Azimuthal magnetic field in the conical theta pinch," *Phys. Fluids*, vol. 6, no. 9, p. 135, 1963.

[33] E. J. Lerner, private communications with the author and V. Nardi since 1978.

E. J. Lerner, "Magnetic self-compression in laboratory plasmas, quasars, and radio galaxies, I and II," *Lasers and Particle Beams*, vol. 4, part 2, pp. 193–213, 1986.

[34] V. Nardi, "Structure and propagation of electron beams," in *Proc. 2nd Int. Conf. Energy Storage, Compression, and Switching* (Venice, Italy, 1978). New York: Plenum, 1983, p. 460.

[35] V. Nardi, "Production of ion clusters in MG fields," presented at the *4th Int. Conf. Megagauss Magnetic Field Generation and Related Topics* (Santa Fe, NM), July 1986, Paper 33.