291F

International Journal of Fusion Energy

Vol. 3, No.4 October 1985

Published Quarterly by the Fusion Energy Foundation

International Journal of Fusion Energy (ISSN: 0146-4981) is published quarterly by the Fusion Energy Foundation, P.O. Box 17149, Washington, D.C. 20041-0149. Tel. (703) 771-7000.

Subscription price: $80 per volume (four issues) domestic; $100 per volume foreign. Payment must be in U.S. dollars.

Address all correspondence to IJFE, Fusion Energy Foundation, P.O. Box 17149, Washington, D.C. 20041-0149.

Postmaster: Send address changes to IJFE, Fusion Energy Foundation, P.O. Box 17149, Washington, D.C. 20041-0149.

Abstracted in *Physics Briefs* and *Physics Abstracts*

International Journal of Fusion Energy

Vol. 3, No. 4 **October 1985**

Vol. 3, No. 4 October 1985

Articles

Reports

Principles of Quantum Biology As Demonstrated by Ultraweak Photon Emission from Living Cells

Fritz-Albert Popp
Technology Center
Opelstr 10
D 6750 Kaiserslautern 25
Federal Republic of Germany

Abstract—All living systems emit a very weak quasi-continuous photocurrent (from a few up to some hundred photons per second and per square centimeter surface area in the range from at least infrared to ultraviolet). This is called low-level luminescence or biological luminescence. The spectral distribution, the transparency, the temperature dependence, and the relaxation dynamics after excitation indicate that these "biophotons" exhibit a surprisingly high degree of coherence, with coherence times of the order of at least minutes. The phenomenon is governed by a nonequilibrium phase transition at multimode-laser threshold, thus providing a quite new and reliable basis of quantum biology.

A practical example demonstrates the importance of low-level luminescence in cell biology, in particular for understanding the "teleology" of cancer development. Since a rapid improvement of technical devices can be expected, this phenomenon opens a door for a better understanding of fundamental problems of biology, medicine, and even quantum physics, as well as for solving practical problems of environmental protection, food and drug research, and medical diagnosis and therapy.

Introduction

It is well accepted today that photons of different wavelengths trigger certain biological functions; for example, photorepair (Kelner 1949; Setlow 1966), phototaxis (Häder 1979), photoperiodic clocks (Bünnig 1973), cell divisions (Karu et al. 1982), and multiphoton events (Calmettes and Berns 1983).

For a long time, however, the opposite phenomenon has been less accepted: that all living tissues *themselves* emit a quasi-continuous radiation. This phenomenon of "ultraweak" photon emission from living cells and organisms (Figure 1), which is different from bioluminescence (Mamedow, Popov, and Konev 1969), has been extensively reviewed (Barenboim, Domanskii, and Turoverov 1972; Zhuravlev 1972; Ruth 1979). Recently, some overviews appeared concerning the most modern aspects of biological luminescence and its applications (Slawinska and Slawinski 1983; 1985).

Actually, now there is no longer any doubt that this biological light emission exhibits an intensity from a few photons up to some hundred photons per second and per square centimeter of surface area. Also, its spectral distribution ranges at least from infrared, at about 900 nanometer (nm), to ultraviolet, up to about 200 nm. Relationships of this photon emission to a variety of biochemical (mainly oxidative radical) reactions have been found, and also to physiological and biological functions as, for example, glycolysis, stress, the temperature response, and the control of proliferation and differentiation (Slawinska and Slawinski 1983; 1985; Nagl and Popp 1983; Popp, Li, and Nagl 1984).

However, some essential questions related to this phenomenon, whose discovery can be traced back to the early 1920s (Ruth 1979), are not yet answered completely. One aspect under discussion is the possible source of this radiation. While some authors emphasize that correlations between photon emission and oxidative radical reactions point to dimole transitions of oxygen as the probable origin (Boveris et al. 1980; Cadenas, Wefers, and Sies 1981), other correlations

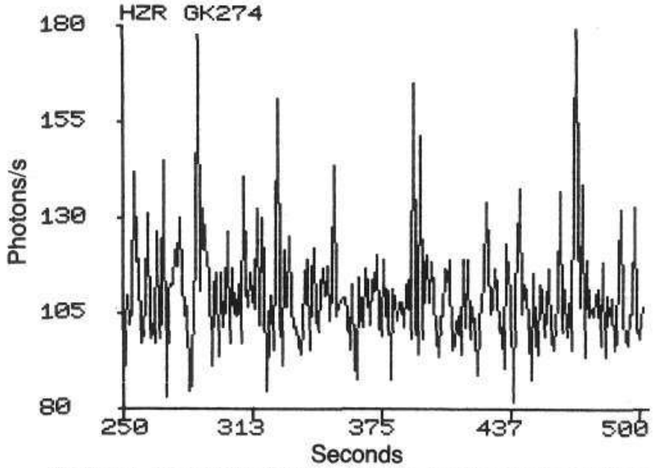


Figure 1. Low-level luminescence of cucumber seedlings (in photons/s), observed between 250 and 500 s in the course of time. The dark-count rate is of the order of 10 photons/s.

of the photon current to deoxyribonucleic acid (DNA) conformational states (Rattemeyer, Popp, and Nagl 1981) or DNase activity during meiosis (Chwirot 1986) support the exciplex (polariton) model of biological luminescence, which has been postulated by Li et al. (1983).

The most fundamental problem concerns the coherence of this radiation. On the one hand, some authors claim that low-level luminescence is due to the continuing attempt of the excited living state to return to the natural thermal equilibrium (Seliger 1973), thus representing some kind of spontaneous chemiluminescence or "imperfection" (Zhuravlev 1972). On the other hand, there are reasons to believe, however, that this phenomenon offers a paradigm of nonequilibrium phase transitions in biological systems where a surprisingly high coherence of ultraweak radiation is involved.

The goal of this paper is to demonstrate that by analyzing biological luminescence in terms of (1) its spectral distribution, (2) its transparency across matter, (3) its dependence on external temperature, and (4) its photo count statistics (PCS), the coherence of this radiation becomes evident. A final example will show that these results are important also for practical applications, in particular for developing sensitive bioindicators, for example, for medical diagnosis and therapy, food control and drug efficiency, and environmental analysis and protection.

The experimental device used for these experiments has often been explained in detail (Ruth 1979; 1977; Ruth and Popp 1976; Bahr 1979; and Popp et al. 1981).

The f = constant Rule

A characteristic property of biological luminescence is the rule

$$f(\lambda) \simeq \text{constant} \qquad (1)$$

where λ is the wavelength.

$f(\lambda) = i_\lambda \cdot \lambda^5/2hc^2$ represents the mean probability of photons to occupy the vacuum phase space cells of energy $h\nu$. h is Planck's constant, c is the velocity of light, and i_λ is the measured stationary spectral biophoton intensity (= emitted photon energy per units of time, wavelengths, and surface area). Eq. (1) is not only the result of our own measurements; at least one other group (Slawinski, Grabikowski, and Ciesla 1981) has experimentally confirmed this typical spectral behavior. Figure 2 shows an example where, for comparison $f(\lambda)$ of blackbody radiation [$f(\lambda) = \exp(-hc/kT\lambda)$] is added. k is Boltzmann's constant and T is absolute temperature.

Apart from the technical difficulties in examining

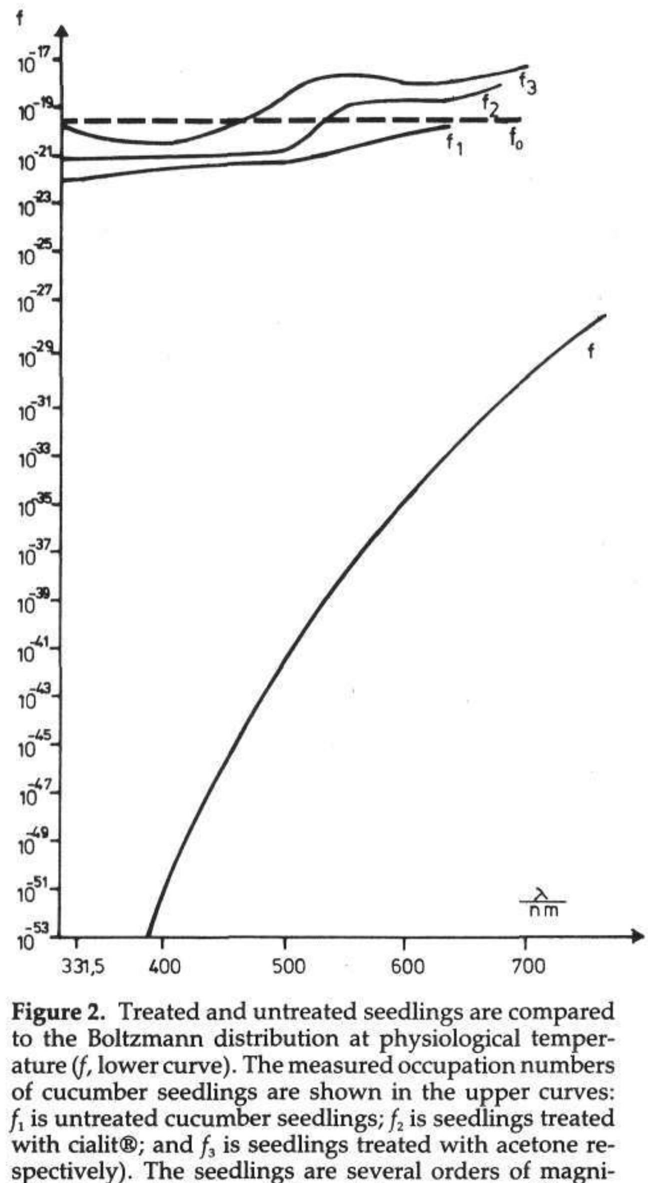


Figure 2. Treated and untreated seedlings are compared to the Boltzmann distribution at physiological temperature (f, lower curve). The measured occupation numbers of cucumber seedlings are shown in the upper curves: f_1 is untreated cucumber seedlings; f_2 is seedlings treated with cialit®; and f_3 is seedlings treated with acetone respectively). The seedlings are several orders of magnitude higher. At the same time, their mean value (f_0) does not depend significantly on the wavelength.

the relation in Eq. (1), the results obtained so far give, in living tissues at least, evidence of optical couplings that are "far away" from thermal equilibrium. Actually, the spectral intensity of biophotons amounts to magnitudes that are up to about 10^{40} higher than those of thermal equilibrium at physiological temperatures. There is no question that, in view of the Arrhenius factor, this fact alone provides the capacity of a much higher chemical reaction rate than is possible in thermal equilibrium systems (Popp and Ruth 1977). Biophotons already have, in view of their capacity of *delivering* the activation energy, a much higher potency of regulating biochemical reactivity than enzymes alone, which enhance the reaction rate by means of *lowering* the activation energy due to the complex binding to the substrate.

Beyond this potency of delivering the necessary activation energy of biochemical reactivity (or its suppression), $f(\lambda)$ = constant, indicates an "ideal" open system, not subjected to any constraint. It is always supplied with sufficient energy (Prigogine 1983); hence it represents a state of an absolute *maximum* of entropy that, on the contrary, may actually become extremely *low* by the only possible way in those systems, namely, the reductions of the degrees of freedom. Since $f(\lambda)$ = constant is at the same time the threshold condition of a multimode-laser system (where the probability of absorption equals that of emission between any two excited energy levels), we are concerned with a nonequilibrium phase transition. Consequently, the numbers of the low frequencies of photon emission ("periodogram," corresponding to the Fourier analysis for the extremely low emission frequencies) are expected to oscillate permanently around some mean value. This is actually the case: Figure 3 shows a typical example, where the Fourier

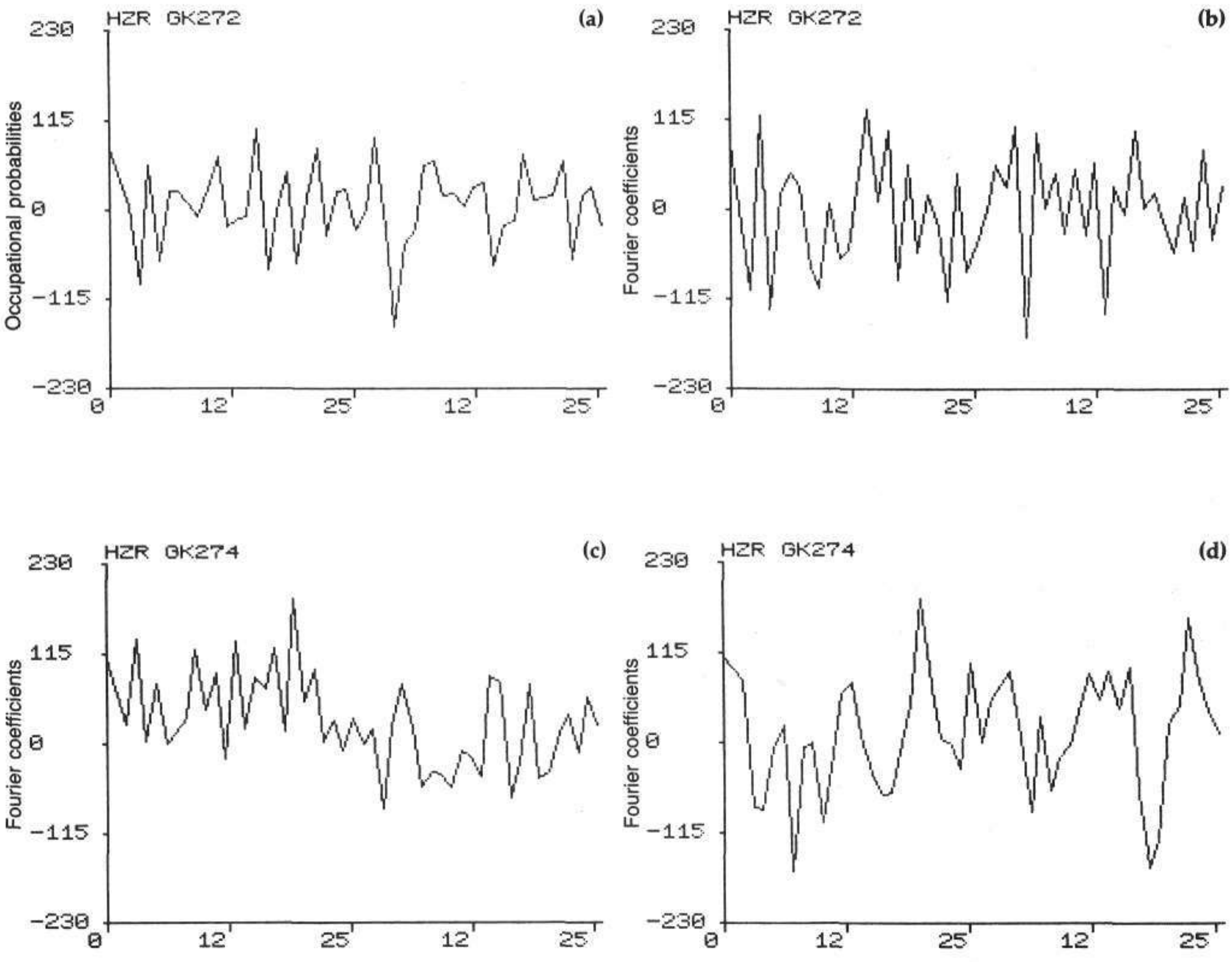


Figure 3. Fourier components of quasi-stationary low-level luminescence (in photons/s) of cucumber seedlings in a time interval of 0-50 s are shown in (a). Since the unit on the abscissa is 1/25 Hz, the cosine coefficients (0-25) and the sine coefficients (again to 25) correspond to the occupation probabilities of the "periodicities" in the frequency range from 1/25 to always 1 Hz. Shown in (b) are Fourier coefficients of low-level luminescence of cucumber seedlings from 50 to 100 s; in (c) they are shown from 200 to 250 s; and in (d) from 250 to 300 s.

coefficients of biophoton emission in a quasi-stationary state always change "spontaneously" to a state of frequency multiplication within about one minute. Again we find the rule $f(\lambda)$ = constant, here in a frequency range of about 1 hertz (Hz) or lower, thus extremely low compared to the optical frequencies of Figure 2. Hence, the rule $f(\lambda)$ = constant may hold over the whole spectrum, at least from ultraviolet to extremely low frequencies, establishing an important principle of quantum biology of living matter and its evolution.

Of course, $f(\lambda)$ = constant displays a ladder of energy levels where the rungs are equally occupied. This system can coherently convert energy not only downwards, but also upwards, giving rise to multiphoton events. Since it represents at the same time a necessary condition for the optimum signal-noise ratio (SNR), it can explain the well-known, considerably higher, sensitivity of biological systems with respect to external influences. Of course, the optimization procedure $\delta(SNR) = 0$, with $SNR = \dot{n}/4\Delta\nu \cdot 1/f(\lambda)$ ($\dot{n}$ representing the number of registered quanta per unit of time, and $\Delta\nu$ the bandwidth of the receiver) yields with respect to λ (or ν) just $f(\lambda)$ = constant. By considering Bose-condensation like photon storage (Popp 1979), we even then obtain an amplifier mechanism with the highest possible optimum value

$$SNR = -\dot{n}/4\Delta\nu. \qquad (2)$$

The Transparency of Biophotons

The radiative transfer within a system (Popp 1979; Thomas 1961) is generally described by Eq. (3)

$$di_\lambda/d\tau_\lambda = i_\lambda - \varsigma_\lambda. \qquad (3)$$

$i_\lambda(R,t)$ represents the differential spectral photon intensity (=emitted photon energy per units of time, area, wavelength, and solid angle.) The quantities "optical thickness" τ_λ and "source function" ς_λ are defined as follows:

$$d\tau_\lambda \equiv -B_\lambda\,[m_L\phi_\lambda - (t_L/t_u)\,m_u\,\psi_\lambda]\,(\lambda/c)\,(dl/4\pi) \qquad (3a)$$

$$\varsigma_\lambda \equiv \frac{hc^2}{4\pi\lambda}\,\frac{A_\lambda}{B_\lambda}\,\frac{m_u j\lambda}{m_L\phi_\lambda - (t_L/t_u)m_u\psi_\lambda}. \qquad (3b)$$

The following notations have been used:

A_λ, B_λ : Einstein's coefficients of spontaneous and induced transitions, respectively,

l : geometrical distance between source and detector,

m_u, m_L : Population density of upper and lower energy levels, respectively, that take part in transitions of energy hc/λ,

t_u, t_L : Degeneracy factors of the corresponding states,

ϕ, ψ, j : Profile coefficients of absorption, stimulated and spontaneous emission, respectively, normalized so that their integral over λ and solid angle is 4π.

Since B_λ according to

$$B_\lambda = \frac{8\pi^3\lambda t_u}{3h \cdot t_L}\left|\mathbf{M}_{Lu}\right|^2 \qquad (3c)$$

can be calculated from molecular properties of matter, where $\mathbf{M}_{Lu}$ is the transition momentum, Eq. (3) can be solved in principle. Let us confine ourselves for simplicity to an isotropic and homogeneous medium so that ς_λ does not depend on depth and the ϕ_λ, ψ_λ, j_λ are equal.

The solution of Eq. (3) then takes the form

$$\begin{aligned} &i_\lambda(\text{where } \tau_\lambda = 0) \\ &= \varsigma_\lambda + [i_\lambda\,(\text{where } \tau_\lambda = x) - \varsigma\lambda] \cdot \exp(-x). \qquad (4)\end{aligned}$$

Since a cell population usually has been regarded as an "optically thick" medium, in which light is absorbed to about the e-th part over a distance of a cell diameter, Eq. (4) would mean that low-level luminescence has to be assigned essentially to photon emission from the surface of living tissue:

$$i_\lambda\,(\text{where } \tau_\lambda = 0) \simeq \varsigma_\lambda. \qquad (5a)$$

However, from $f(\lambda)$ = constant we learn that there are manifolds of excited states with $m_L = m_u$ (where, for simplicity, we followed the usual assumption that $t_L = t_u$).

While from Eq. (3a) then we get $\tau_\lambda \to 0$ for all distances l, from Eq. (3b) $\varsigma_\lambda \to \infty$ is obtained. This is a typical behavior at threshold. However, if i_λ exceeds a certain value $\tau_\lambda \cdot \varsigma_\lambda$, which means that it has to exceed the noise of spontaneous transitions, we achieve a region of transparency. Of course, for considerably large penetration depths $l \neq 0$, the case $x \to 0$ in Eq. (4) is obtained so that ς_λ cancels out and we obtain

$$i_\lambda(\text{where } l = 0) \simeq i_\lambda(l) \qquad (5b)$$

for considerably high values of l. The matter becomes then transparent.

Experimental data of low-level luminescence point to just this case (Popp et al. 1984): One set of experiments was made with a Gilford 250 spectrophotometer. Cuvettes of various diameters were either filled with wet sea sand, or with soybean cells in suspension. A second set of experiments was made with the photomultiplier system, using double cuvettes. The photomultiplier-faced chamber was filled with sand and soybean cells, respectively, in varying thickness, whereas the rear chamber was filled with cucumber seedlings. So the photons emitted by the cucumber seedlings had to pass through the front chamber to reach the photomultiplier.

The extinction coefficient E/d (mm^{-1}) for these experiments is represented in Figure 4. The two upper curves (P_{sand} ; P_{cells}) display E/d of 550 nm photons from the Gilford spectrometer; the two lower curves (C_{sand} ; C_{cells}), the E/d of cucumber biophotons traveling through the layer of sand and soybean cells, respectively, for varying thickness d (in mm) of the layers.

From these results, the following conclusions have been drawn:

(1) The considerably lower extinction coefficient of biophotons compared to that of artificial light cannot be explained in terms of the wavelength dependence of optical absorption.

In fact, in the registered wavelength range of biophotons from 200 to 800 nm, E/d of known optical absorption decreases from 500 nm to 800 nm by an amount of about 10 percent, while from 550 nm to 200 nm it can only increase. Consequently, the E/d of 550 nm photons of the Gilford photometer (which is not altered by change of intensity) could never exceed the E/d of biophotons more than 10 percent. Actually, it is at least about one order of magnitude higher.

(2) This difference does depend on the optical medium, since control experiments by using nonscattering neutral density filters exhibited the same expected Beer-Lambert law for both photometer and biological light.

(3) However, this significant E/d difference of artificial light and biophotons cannot depend on the optical medium *alone*, since the same wet sand layers (P_{sand} ; C_{sand}) and the same soybean cultures (P_{cells} ; C_{cells}) have been used for both photometer light and biophotons.

(4) Rather, the very low extinction coefficient of biophotons is a consequence of their coherence. This is supported by a further characteristic of Figure 4; namely, the decreasing extinction coefficient with increasing thickness d of the layers, thus violating the Beer-Lambert law (with the exception of C_{cells}). As has been pointed out by Wolf (1969), multiple propagation and diffraction can considerably improve the coherence of light. Consequently, the transparency increases with increasing penetration into the layer, as it is actually shown in Figure 4. Biological light traveling through biological media seems then to exhibit the highest achievable degree of coherence (C_{cells}).

All these conclusions coincide with findings on "light piping" in plant tissues (Mandoli and Briggs 1982). Coherent photons can be transferred there without significant loss over distances of at least some centimeters. This result, which has been interpreted in terms of coherence (Smith 1982), consequently confirms at the same time the rule $f(\lambda)$ = constant that has been taken as the governing principle of transparency in living matter.

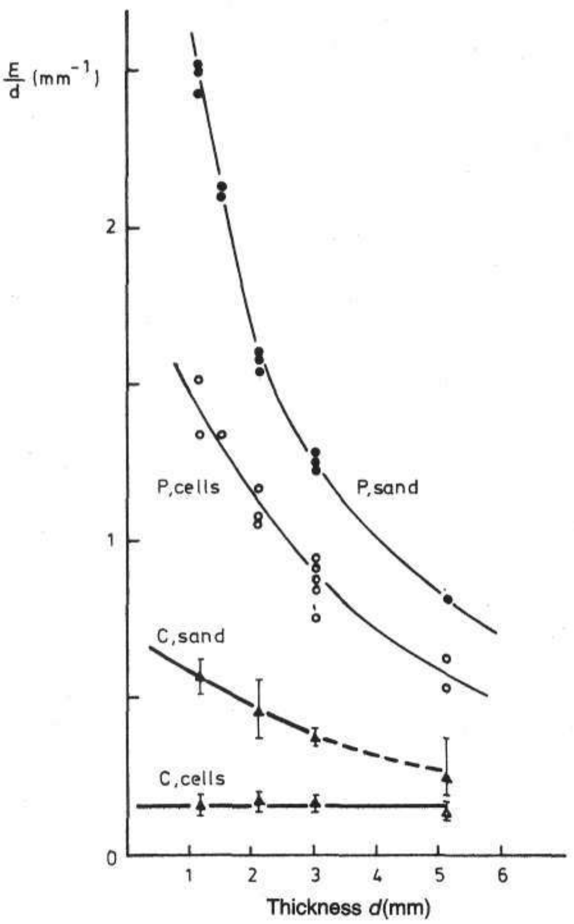


Figure 4. Experimental data indicating the transparency of biophotons. The extinction coefficient E/d(mm^{-1}) of sea sand (P,sand) and soya cells (P,cells) of various thickness d(mm) was first measured at 550 nm wavelength in a Gilford 250 spectrophotometer, and then the E/d of photons emitted by cucumber seedlings, passing through the same layers of sand (C, sand) and soya cells (C, cells), respectively, was determined.

The Temperature Dependence of Biophoton Emission

Recently, we were successful in calculating the distances of stacked bases in the A- and B-form of DNA (2.6 and 3.4 Å respectively) with sufficient accuracy by taking into account Li's exciplex (polariton) model (Li et al. 1983; Popp and Nagl 1986). Instead of a more fundamental thermodynamic model based on the $f(\lambda)$ = constant rule [that has been discussed by Böhm (1980), leading to the following results], let us now use Li's exciplex model as an ideal open system in order to understand the known experimental results of the temperature dependence of biophoton emission (Popp et al. 1981; Böhm 1980; Slawinski et al. 1974).

As has been shown in previous papers (Popp et al. 1984; 1981), an open exciplex system obeys Eqq. (6a) and (6b)

$$\dot{\rho} = h\nu \{Am_u - \rho B (m_L - m_u)\} \quad (6a)$$

$$kTm_L + \{\mu(\nu) + C_1(\nu)\} m_u = C_0(\nu). \quad (6b)$$

Eq. (6a) is the well-known Einstein relation, where ρ represents the photon density within the exciplex system with occupation probability m_L and m_u for lower and upper energy levels, respectively. $h\nu$ is the energy difference of these levels, and A and B Einstein's coefficients of spontaneous and induced transitions, respectively.

Eq. (6b) is an energy conservation equation for the stationary open system, where the thermal energy of dissipatively separated ground-state exciplexes kTm_L plus the binding energy of excited exciplexes μm_u plus the energy necessary for pumping them, namely $C_1(\nu)m_u$ add up to a constant $C_0(\nu)$.

Since the stationary state is the subject of maximum entropy (and at the same time of maximum free energy), the optimization requires

$$(\partial m_u/\partial\rho)\rho_0 = 0. \quad (7)$$

After straightforward calculations from Eq. (7), Eq. (7a) follows

$$\rho_0 = A/B. \quad (7a)$$

This means that the system stabilizes at laser threshold, where $f(\nu) = 1$ for the radiation field.

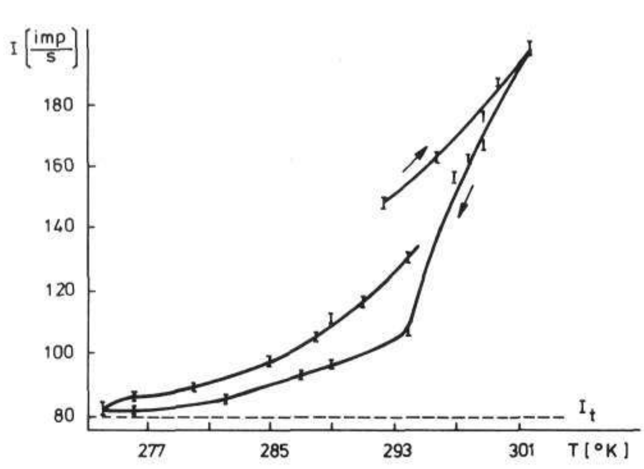


Figure 5. Temperature hysteresis of plant seedlings. The count rate of low-level luminescence (counts/s) always has higher values for increasing temperature than for decreasing one (from Slawinski, Grabikowski, and Milczarik 1974).

The number of excited exciplexes may change rapidly at this point. It is given by

$$m_u = \frac{\rho \cdot B\,[C_0(\nu)/kT]}{A + \rho B\,\{\ln(\rho B/A) + [C_2(\nu) - C_1(\nu)]/kT\}}, \quad (8)$$

where $C_2(\nu)$ (which equals $h\nu$ for $\mu = 0$) accounts in addition for mode coupling in complicated systems.

From Eq. (8) then we obtain the temperature dependence of photon emission by simple differentiation with respect to the time at fixed ρ (which works as a control quantity):

$$\dot{m}_u = (\alpha/N_0)\dot{T}\, m_u^2, \quad (9)$$

where

$$\frac{\alpha}{N_0} \equiv -\frac{A + \rho B \ln(\rho B/A)}{\rho B C_0(\nu)}. \quad (9a)$$

The solution of Eq. (9) takes the form

$$m_u = m_u^{(0)} \cdot \{1/[1 - \alpha\,\dot{T}\,(t - t_0)]\}. \quad (10)$$

By evaluation of the temperature-hysteresis loops of biophoton emission that have been measured by Slawinski et al. (1974, see Figure 5), we (Popp and Slawinski in preparation) found the rule

$$\dot{\theta}/\theta^2 = \varkappa\alpha\dot{T}/[1 - \alpha\dot{T}\,(t - t_0)], \quad (11)$$

where θ is the excitation temperature defined by Eq. (11a) and $\varkappa$ represents a constant quantity, dependent on the system under investigation.

$$\varepsilon/k\theta = [\varepsilon - \mu\,(\nu)]/kT. \quad (11a)$$

Since $i_\lambda \propto \exp(-\varepsilon/k\theta)$, then we can write

$$\dot{m}_u = -\frac{k}{\epsilon\varkappa}\left[\frac{\partial}{\partial t}\left(-\frac{\epsilon}{k\theta}\right)\right]m_u = \frac{\alpha}{N_0}\,\dot{T}\, m_u^2 \quad (12)$$

where $\varkappa$ is a proportionate constant, dependent on the transparency of the system and the location and other properties of the exciplex system. After insertion of Eq. (10) into Eq. (12), we again get Eq. (11), hence agreement to the experimental facts.

It should be noted that this result is again in line with the more general relation $f(\lambda) =$ constant. It describes at the same time the well-known overshoot (or undershoot) reactions of temperature dependence of biophotons as well as of most of the physiological functions (Popp, Li, and Nagl 1984; Precht et al. 1973). As a consequence, these results again indicate that biophotons are more originate regulators of biochemical reactivity than, for instance, enzymes (Popp 1984).

Direct Proof of Coherence

In 1979, we found by spectral analysis of delayed luminescence [= photon emission from living tissues after light illumination, for example (Malkin 1977)] that the different modes which were selected with the aid of interference filters behave just as if they originated from only one source molecule (Popp et al. 1981). Actually, the different modes decay according to the same decay law, namely a hyperbolic function. It was, in addition, not possible to describe the spectral decay of the different modes by an exponential function or even by a superposition of exponential functions with different and *independent* decay constants (Popp et al. 1981; see Figure 6).

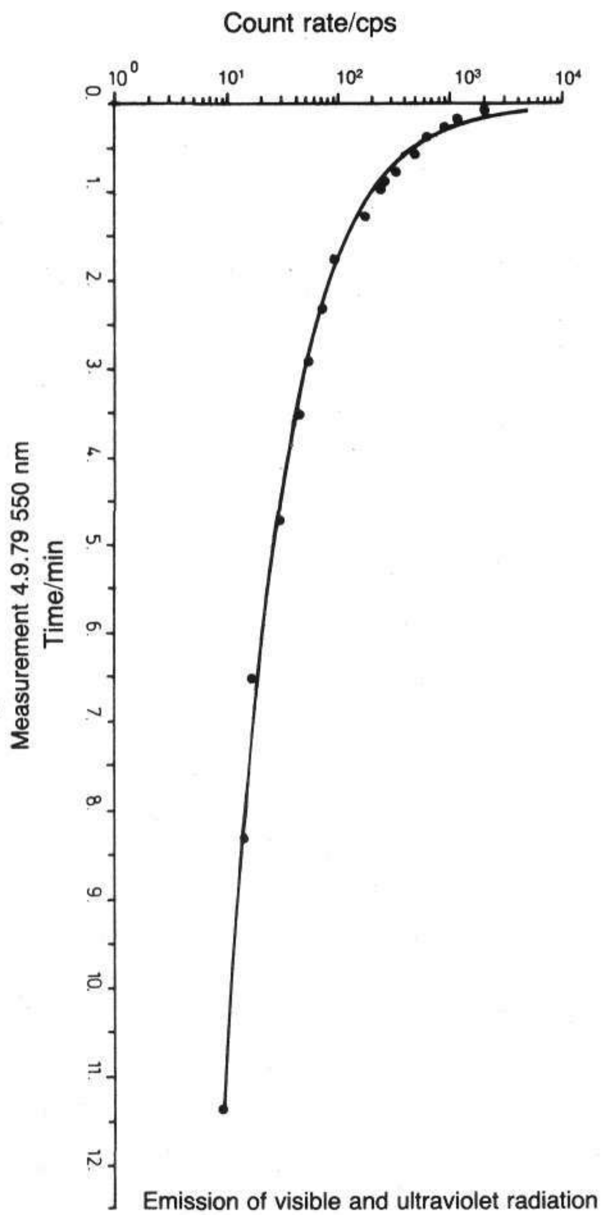


Figure 6. "Delayed luminescence" of a bryophylum daigremontanum leaf at a wavelength of 500 nm (Popp et al. 1981). The measured count rate can be approximated by a hyperbolic decay law, while an exponential one (or even a superposition of exponential functions with different independent decay constants) has to be significantly rejected.

Since the rule $f(\lambda)$ = constant turned out to perform a reliable base of understanding the spectral behavior, phase transition phenomena of the "periodogram," the transparency and the temperature dependence of low-level luminescence, the question becomes important whether this strong mode coupling and the hyperbolic decay law are consequences of this principle, too.

The rule $f(\lambda)$ = constant suggests the following Masters equation

$$\dot{n}_\lambda = C_\lambda \, n_\lambda{}^\beta + \sum_{\lambda' \neq \lambda} D_{\lambda'} \, n_{\lambda'}{}^\beta, \tag{13}$$

where $\dot{n}_\lambda$ is the spectral photon intensity and C_λ and D_λ are in general wavelength-dependent constants of the system. The equality of the exponents β reflects the uniformity of modes coupled also by $f(\lambda)$ = constant.

Since the measurements yielded about the same temporal behavior for all the modes under study, we can separate the time-dependent function $d(t)$ due to

$$n_{\lambda'} = a_{\lambda'} \, d(t), \tag{14}$$

where $d(t)$ is the same for all modes. The solution of Eq. (14) after insertion into Eq. (13) takes the form

$$d(t) = t^{-\gamma} \text{ with } \gamma = 1/(\beta - 1), \tag{15}$$

hence delivering just the hyperbolic decay that has been made evident by the experimental results (Figure 6). Recently, Chwirot and Dygdala have confirmed these results by demonstrating that synchronized cell cultures at meiosis exhibit, after exposure to white light illumination, a more or less hyperbolic decay. The agreement to the hyperbolic law is correlated to the cooperativity within the different stages of the cell cycle, appraised from the biological point of view (Chwirot et al. 1985).

A detailed analysis (Li and Popp 1983; Popp 1985, in press; Popp in preparation; Popp and Li 1985) shows that the spectral hyperbolic decay is, under the usual ergodic conditions, a *necessary* and *sufficient* condition for the full coherence of the biophoton field. All these arguments cannot be repeated here. Let us therefore confine ourselves to a classical and a quantum-statistical proof.

It is well known that a classical oscillator satisfies the condition

$$\langle \ddot{x} x \rangle = \langle \dot{x} \rangle^2, \tag{16}$$

where $x(t)$ represents the amplitude, $\dot{x}$ its velocity and $\ddot{x}$ the acceleration. $\langle \ldots \rangle$ denotes the average over time, for oscillations over at least one period. The solution of Eq. (16) takes the well-known form

$$x = x_0 \exp(\omega t), \tag{17}$$

where ω is a complex constant. For a decaying system with real ω, Eq. (16) is valid at any instant. Eq. (16) reflects the fact that the kinetic energy and the potential energy of the system are equal. If, on the other hand, a definite part of kinetic energy is restored by coherent rescattering, we have Eq. (18) instead of Eq. (16)

$$\langle \ddot{x}x \rangle = (1 + \varkappa)\langle \dot{x} \rangle^2, \tag{18}$$

where $\varkappa \neq 0$ is a measure of the coherent coupling. The solution of Eq. (18)

$$\langle x \rangle = a_0(t + t_0)^{-1/\varkappa} \tag{19}$$

is actually the hyperbolic decay law. a_0 and t_0 are constant values. As soon as chaotic rescattering runs into coherent rescattering, under the same (ergodic) conditions, an exponential decay turns over to a hyperbolic one.

This holds true also for the description of an unstable *quantum* system that has been carefully analysed, for instance, by Fonda, Ghirardi, and Rimini (1978), Davies (1975), Fain (1981), Ngai et al. (1983), and Bunge and Kalnay (1983) for the exponential decay law.

Let us start with the variance of photocounts $\langle (\Delta n)^2 \rangle$ that is registered during a measuring time interval Δt always by sampling the count rates $\dot{n}_1$, $\dot{n}_2$, $\dot{n}_3 \ldots$, $\dot{n}_i \ldots$. Hence, by definition, we have

$$\langle (\Delta n)^2 \rangle = (\Delta t)^2 \sum_i (\dot{n}_i - \langle \dot{n} \rangle)^2. \tag{20}$$

Imagine that Δt can be reduced by extending the number of ensembles to such low values that it is about of the order of coherence time of the emitted photons. In order to determine $\langle \dot{n} \rangle$, the change of $\langle \dot{n} \rangle$ during time, we may either keep Δt constant and register $\langle \dot{n} \rangle$ for all t, or we change slightly at fixed t the length of Δt and register the alteration of $\langle \dot{n} \rangle$. Since t and Δt are independent quantities for an ergodic field, it doesn't matter what method is preferred.

Noting that the derivation $(\dot{n}_i - \langle \dot{n} \rangle)$ does not contribute to $d\langle (\Delta n)^2 \rangle / d\langle \dot{n} \rangle$, we obtain from Eq. (20)

$$\frac{d\langle (\Delta n)^2 \rangle}{d\langle \dot{n} \rangle} = 2\,\frac{\langle (\Delta n)^2 \rangle}{\Delta t}\,\frac{d(\Delta t)}{d\langle \dot{n} \rangle}. \tag{21}$$

An ergodic system provides the homogeneity of t and Δt so that we always have a linear relation

$$d(\Delta t) = \beta dt \tag{22}$$

for constant $d\langle (\Delta n)^2 \rangle / d\langle \dot{n} \rangle$.

β is a generally complex constant for a preset time interval t, for definite coupling parameters and a fixed number of ensembles, including $\beta = 0$ for a stationary system that represents a special case of an ergodic field.

From the theory of photo count statistics (Arecchi 1969; Perina 1971), it is well known that a Gaussian field obeys the relation

$$\langle (\Delta n)^2 \rangle = \langle \dot{n} \rangle^2\, \Delta t^2 + \langle \dot{n} \rangle\, \Delta t, \tag{23a}$$

while a coherent field is subject of

$$\langle (\Delta n)^2 \rangle = \langle \dot{n} \rangle\, \Delta t. \tag{23b}$$

These relations are valid at any instant t for any Δt. The degree of freedom here [in contrast to a stationary field (Popp 1985, in press; Popp in preparation)] does not play a decisive role, as we will see in the following.

By calculating $d\langle (\Delta n)^2 \rangle / d\langle \dot{n} \rangle$ of Eq. (23), substituting the general relation Eq. (21) into these derivations and taking into account Eq. (22), then we arrive at

$$\frac{d\langle \dot{n} \rangle}{dt} = \frac{\beta}{\Delta t}\left(\frac{\langle \dot{n} \rangle}{1 + 2\,\langle \dot{n} \rangle\, \Delta t}\right) \tag{24a}$$

for chaotic fields and

$$d\langle \dot{n} \rangle / dt = \beta / \Delta t\, \langle \dot{n} \rangle \tag{24b}$$

for a fully coherent field, respectively.

The difference between Eq. (24a) and Eq. (24b) would disappear for multimode fields with M independent modes and $M \to \infty$, since the term $2\langle \dot{n} \rangle \Delta t$ in the denominator of Eq. (24a) had to be substituted by $2\langle \dot{n} \rangle \Delta t / M$. However, this does not bother the remarkable differences in the relaxation dynamics between a chaotic and a coherent field. In fact, in the case of a chaotic field we have $t >> \Delta t >> \tau$ where τ is its coherence time. This means that $\beta / \Delta t$ of Eq. (24a) can be looked upon as a constant, giving rise to an exponential (or quasi-exponential) decay. In contrast to this case, for a coherent field we have $t \simeq \tau \simeq \Delta t$, so that in Eq. (24b) Δt can be substituted by t itself. Obviously, this yields the expected hyperbolic decay law:

$$\langle \dot{n} \rangle = A(t + t_0)^{\beta}. \tag{25}$$

It should be noted that the coherence of biophotons has been made evident also for a stationary emission in case that the degrees of freedom M are much less than 10^5, Eq. (24). This means that if biophotons originated from forbidden states of lifetimes $>>10^{-5}$s ($M \simeq \Delta t/\tau$, $\Delta t = 1$s), their coherence is evident even from photo count statistics of stationary states.

An Application in Cancer Research

Recently, Schamhart, Slawinski and van Wijk (in preparation) have shown that the total number of counts that are emitted by cell cultures after exposure to white light illumination (1) *increases* with increasing cell densities for malignant cell cultures, and (2) *decreases* with increasing cell densities for the corresponding normal ones.

Thereby, they are confined to a definite first part of the decay curves immediately after irradiation. Figure 7 shows these results (courtesy of Dr. Schamhart).

At the same time, Schamhart has shown that the relaxation dynamics of the normal cells agree better with the hyperbolic law than those of the corresponding malignant ones, which display a more rapid decay (see Popp et al. 1981).

Before presenting our own recent results on human cell cultures, let us briefly discuss the results of Figure 7.

This system consists of an ensemble of radiating cell layers in a cubic quartz cuvette within a colorless nutrition fluid. The total surface area of the cuvette is $6F$, the diameter $d = F^{1/2}$.

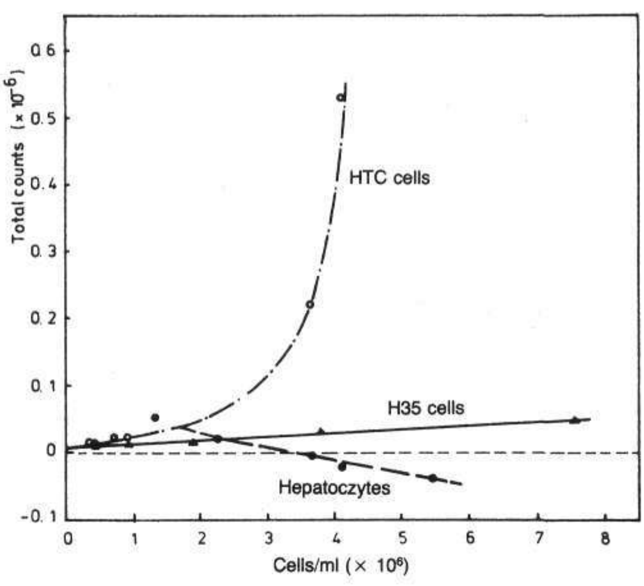


Figure 7. The total number of counts of "delayed luminescence" of cells in suspension after a definite time interval depends on the cell density. This dependence is principally different for normal liver cells (hepatoczytes, lowest curve,) for the most malignant liver cells (HTC cells, upper curve,) or weakly malignant ones (H35 cells, intermediate curve,) according to Schamhart, Slawinski and van Wijk (in prep.)

Let p represent the contributed photo count rate of one cell and ρ the cell density, we then obtain an increase di of the measured photon intensity by the contribution of a cell layer of thickness dx at a distance x from the counter according to

$$di(x) = \rho\, Fp[1 - W(x)]dx. \qquad (26)$$

$W(x)$ is the probability that the radiation is absorbed within the system on the way to the counter at point $x = 0$. From the outset there is no reason to expect $W(x)$ values deviating from the Beer-Lambert law:

$$W(x) = 1 - \exp(-\mu x)\exp(-\rho\,\varkappa x). \qquad (27)$$

μ is a constant extinction coefficient of the device that is always the same for all of the experiments. $\varkappa$ represents the extinction coefficient per unit of cell density for the cells within the medium. After insertion of Eq. (27) into Eq. (26) and integration, we then get

$$i(0) = \frac{\rho F p}{\varkappa\rho + \mu}\{1 - \exp[-(\varkappa\rho + \mu)d]\} \qquad (28)$$

where $i(0)$ is the measured radiation intensity.

The result of Figure 7 describes $i(0)$ as a function of ρ. It exhibits a principally different behavior for normal and malignant cells. From Eq. (28) we obtain

$$\frac{\partial i(0)}{\partial\rho} = \frac{i(0)}{\rho}\left[1 - \frac{\rho}{\rho + (\mu/\varkappa)}\right] + \frac{\rho F p}{\varkappa\rho + \mu} \times \exp[-(\varkappa\rho + \mu)d]\,. \qquad (29)$$

Since both terms of the right-hand side of Eq. (29) are positive definite, this model can never explain first, $\partial i(0)/\partial\rho < 0$, which is observed at higher cell densities of normal cells, and second, $\partial i(0)/\partial\rho >> 0$, which is observed for malignant cells at higher densities despite the fact that for $\rho \to \infty$ we get according to Eq. (29) $\partial i/\partial\rho \to 0$.

Figure 8 demonstrates the differences with the theoretical model due to the most reasonable assumptions and the real behavior.

To explain these results, there remain only two possibilities, namely either $(\partial p/\partial\rho) \neq 0$ or $(\partial\varkappa/\partial\rho) \neq 0$.

In any case, we have to conclude that: (1) There is a sensitive dependence of biophoton emission from living cells on mutual long-range interactions at a distance from about at least ten cell diameters on. (2) In view of the very low intensities ($p << 1\ s^{-1}$), this dependence cannot be explained in biochemical terms, that is, photochemical reactivity. These nonlinear effects at very large distances between the single cells ($\rho v << 1$, where v is the volume of a cell) correspond actually to stimulated emission and absorption of radiation within the cell population at very weak intensities. They have to be interpreted in terms of coherence properties of the interacting field. Taking into account the interaction distance of at least 10 cell diameters, the coherence volume of biophotons is, according to these results, at least a thousand times the cell volume.

Recently we studied the relaxation dynamics of human cells after white light illumination under the same conditions chosen by Schamhart, Slawinski and van Wijk (in preparation). We compared human amnion cells with corresponding malignant ones, namely, wish cells. After we had ascertained that the decay functions were in good agreement to a hyperbolic law, the decay curves after exposure to white light illumination were fitted by use of a computer program according to Eq. (25). t_0 is the time delay between the end of excitation and the first measuring point. It has been fixed at 3 s. The values $-\beta(\rho) \propto k ln X$ are plotted in Figure 9.

Again it can be seen that the normal cells display a behavior just the opposite to that of malignant ones. While in the case of normal cells, $|\beta|$ decreases with increasing cell density, $|\beta|$ increases nonlinearly with increasing density for malignant cells, approaching at the same time more and more a chaotic exponential decay law.

Figures 7-9 show us a quite new story of malignancy: While normal cells become, with decreasing mutual distance, more and more aggregative, malignant cells do more than only disregard each other. Although they have the same origin, it seems that they *refute* the formation of a cooperative communication base.

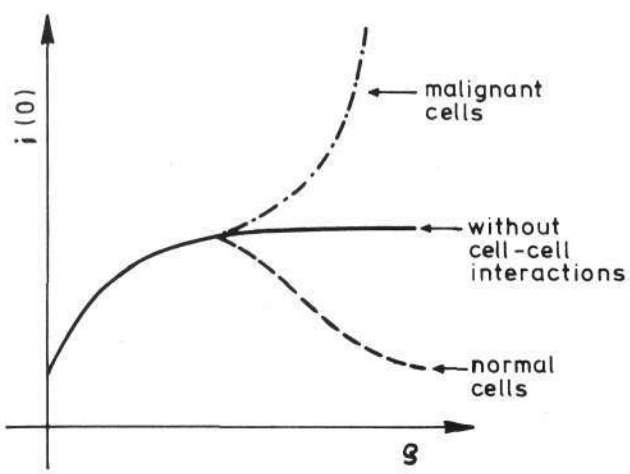


Figure 8. The dependence of the intensity $i(0)$ at the outside of a cell suspension is shown here for three cases: (1) no interaction between the cells takes place, (2) the intercellular interactions are aggregative, and (3) the intercellular interactions are disaggregative.

These results not only confirm the importance of coherence even in biology, and in particular, in the case of weak effects [that by no means can exclude high degree of coherence (Popp and Nagl in press)], they also turn out to be fundamentally significant for solving the cancer problem and related questions. A more profound discussion of these aspects has been presented elsewhere (for example, Nagl and Popp 1983, Popp and Nagl 1983).

It may be worthwhile to note that nonexponential decay is sometimes observed also in condensed matter physics. As has been shown by Fain (1981), in these cases nonrandom processes, including instabilities of the environment, are significant. As Ngai et al. (1983) emphasized, in these cases of coherent rescattering, a single linear exponential form is as unphysical as a superposition of them.

Outlook and Some Applications

The rapid development of photodetection techniques allows us at present to expect a great future of low-level luminescence research and its applications.

Actually, the spectral analysis, including all the other spectral ranges, as infrared, microwave and radio-

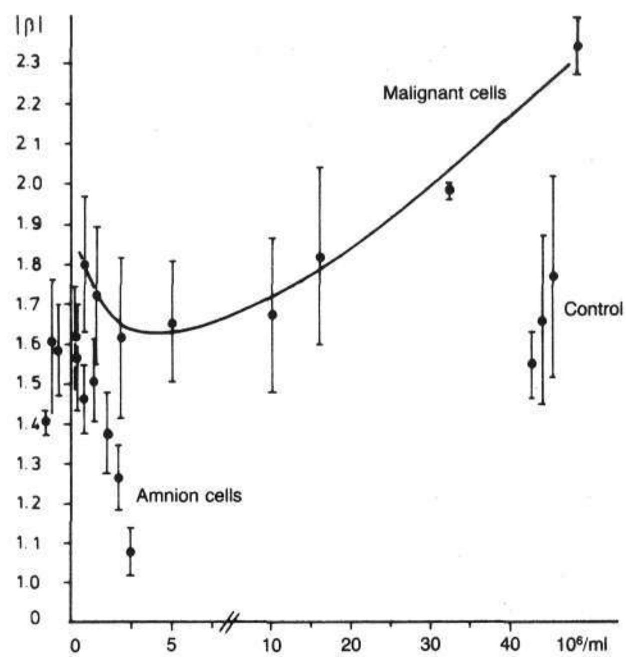


Figure 9. The decay parameter of cell suspensions of different human cells (amnion cells and the corresponding malignant ones) after a 2-minute exposure to white light illumination is calculated from the measured intensities for different cell densities. The three measured values at the right refer to the control (cuvette with medium.)

waves, will lead to a wide extension of our knowledge on "electromagnetic bio-information."

The temperature dependence of spectral biophoton emission provides a further powerful tool that was not applied until now with the efficiency actually possible. Further new methods can be derived, for instance, from periodic and spectral light illumination as well as from induced changes of the Fourier patterns (see Figure 3).

These techniques will put forward new insights into problems of biology (differentiation, photorepair, and so forth), medicine (immunology, cancer research), environmental protection (pollution protection), physics (phase transition phenomena, Bose-condensation-like phenomena, coherence at low intensities), engineering (improvement of efficiencies, biodetectors), and information theory (broad-band information transfer, optical information).

Right now there are some hopeful trials of applying low-level luminescence techniques.

So the luminol-dependent luminescence of polymorphonuclear leukocytes to various stimuli that have been introduced for examining immunological response (Allen, Stjernholm and Steele 1972) can now be compared in its progress to the *native* luminescence of this system which sometimes yields different or even contradictory results (Roschger, Graninger, and Klima 1984).

Klima (1981; Klima and Popp 1982) has found that the quality factor of ionizing radiation, including alpha beams, correlates to the increase of biophoton intensity induced by ionization.

Ruth (Popp et al. 1981) has been successful in using biophoton emission for discovering antagonists to poisons. He has also demonstrated by use of this system the actual reversibility or irreversibility of damage after treatment with reversible and irreversible poisons, respectively.

Weingärtner et al. (1985) have shown that even at very low concentrations synergetic effects of different compounds can be made evident by using low-level luminescence technique.

Teubner (1983) has investigated the biophoton emission of certain plants in dependence on fertilization, preparation and storage. In cases where all of the other influences could be kept constant, he has been successful in demonstrating distinct differences of biophoton emission for different fertilization (Teubner, Rattemeyer, and Mehlhardt 1981).

Staszkiewicz (1985) was able to select the optimum method of canning from a variety of different methods with the aid of biophoton analysis of canned vegetables. A further careful study on correlations between biophoton emission and quality of fruits and vegetables is under way.

Less successful until now were trials using photon emission from urine (Gisler, Diaz and Duran 1982), blood (Gisler, Diaz and Duran 1983), or breath (Williams, Leight and Chance 1982) for clinical diagnosis. However, even these results are encouraging enough to claim that with technical improvement, success finally could be achieved also in the biophoton analysis of human skin for clinical diagnosis and therapy.

References

Allen, R.C., R.L. Stjernholm, and R.H. Steele. 1972. *Biochem. Biophys. Res. Commun.* **47**: 679.

Arecchi, F.T. 1969. In *Quantum Optics*. Ed. R.J. Glauber. New York: Academic Press.

Bahr, W. 1979. Diplomarbeit, *Exp. Physik*. Marburg.

Barenboim, G.M., A.N. Domanskii, and K. K. Turoverov. 1972. *Luminescence in Biology*. Moscow: Moscow Society of Naturalists.

Böhm, J. 1980. Diplomarbeit, *Exp. Physik*. Marburg.

Boveris, A. et al. 1980. *Proc. Natl. Acad. Sci. USA* **77**: 347.

Bunge, M. and A.J. Kalnay. 1983. *Nuovo Cimento* **778**: 1.

Bünnig, E. 1973. *The Physiological Clock*. 3rd Ed. Berlin: Springer.

Cadenas, E., H. Wefers, and H. Sies. 1981. *Eur. J. Biochem.* **119**: 531.

Calmettes, P.P. and W. M. Berns. 1983. *Proc. Natl. Acad. Sci. USA* **80**: 7197.

Chwirot, W.B. 1986. *J. Plant Physiol.* **122**:81.

Chwirot, W.B., S. Dygdala, and S. Chwirot. 1985. *Cytobios* **44**:239.

Davies, E.B. 1975. *Helv. Phys. Acta* **48**: 365.

Fain, B. 1981. *Phys. Rev.* **24A**: 933.

Fonda, L., G.C. Ghirardi, and A. Rimini. 1978. *Rep. Prog. Phys.* **41**: 587.

Gisler, G.C., J. Diaz, and N. Duran. 1982. *Physiol. Chem. Phys.* **14**: 335.

______. 1983. *Arq. Biol. Tecnol.* **26**: 345.

Häder, D.P. 1979. Photomovement. In *Encyclopedia of Plant Physiology*. Eds. W. Haupt and M. Feinleib. New Series **7**: 268. Berlin: Springer-Verlag.

Karu, T.T. et al. 1982. *Nuovo Cimento* **6**: 828.

Kelner, A. 1949. *Proc. Natl. Acad. Sci. USA* **35**: 73.

Klima, H. 1981. *Dissertation*. Atominstitut, Wien.

Klima, H., and F.A. Popp. 1982. In *Medizinische Physik '81*. Ed. E. Bunde. Heidelberg: Hüthig.

Li, K.H. and F.A. Popp. 1983. *Phys. Lett.* **93A**: 262.

Li, K.H. et al. 1983. In *Coherent Excitations of Biological Systems*. Eds. H. Fröhlich and F. Kremers. Berlin: Springer.

Malkin, S. 1977. In Photosynthesis I. *Encyclopedia of Plant Physiology* **5**. Berlin: Springer.

Mamedow, T.G., G.A. Popov, and V.V. Konev. 1969. *Biophysics* **14**: 1102.

Mandoli, D.F. and W. Briggs. 1982. *Proc. Natl. Acad. Sci. USA* **79**: 2902.

Nagl, W. and F.A. Popp. 1983. *Cytobios* **37**: 45.

Ngai, K.L. et al. 1983. *Phys. Rev.* **288**: 6073.

Perina, J. 1971. *Coherence of Light*. London: Van Nostrand Reinhold Company.

Popp, F.A. 1984. *Biologie des Lichts*. Berlin-Hamburg: Paul Parey.

______. 1979. In *Electromagnetic Bio-Information*. Eds. F.A. Popp, G. Becker, H.L. König, W. Peschka. München-Wien-Baltimore: Urban & Schwarzenberg.

______. 1981. *Laser Elektroopt.* **3**:34.

______. 1985. In press. *Proceedings of the ISG Conference on Self-Organization and Dissipative Structure*. London: Whitsun Meeting.

______. In preparation. In *Weak Electromagnetic Effects in Biology*. Ed. R.K. Mishra. World Scientific.

Popp, F.A. and K.H. Li. 1985. In *Synergie et Coherence dans les Systemes Biologiques*. Eds. Z.W. Wolkoski and J. Vigneron. Paris: University of Paris.

Popp, F.A., K.H. Li, and W. Nagl. 1984. *Z. Pflanzenphysiol.* **114**:1.

Popp, F.A. and W. Nagl. In press. *Cell Biophysics*.

______. 1986. *Polymer Bulletin* **15**:89.

______. 1983. *Cytobios* **37**: 71.

Popp, F.A. et al. 1984. *Cell Biophysics* **6**: 33.

Popp, F.A. and B. Ruth. 1977. *Arzneimittelforsch./Drug Res.* **27**: 933.
Popp. F.A. et al. 1981. *Collective Phenomena* **3**: 187.
Popp, F.A. and J. Slawinski. In preparation.
Precht, H. et al. 1973. *Temperature and Life.* Berlin-Heidelberg-New York: Springer.
Prigogine, I. 1983. Personal communication.
Rattemeyer, M., F.A. Popp, and W. Nagl. 1981. *Naturwissensch.* **68**: 572.
Roschger, P., W. Graninger, and H. Klima. 1984. *Biochem. Biophys. Res. Commun.* **123**: 1047.
Ruth, B. 1977. Dissertation, *Exp. Physik.* Marburg.
______. 1979. In *Electromagnetic Bio-Information.* Eds. F.A. Popp, G. Becker, H.L. König, and W. Peschka. München-Wien-Baltimore: Urban & Schwarzenberg.
Ruth, B. and F.A. Popp. 1976. *Z. Naturforsch.* **31c**: 741.
Schamhart, D., A. Slawinski, and R. van Wijk. In preparation. *Cancer Res.*
Seliger, H.H. 1973. In *Chemiluminescence and Bioluminescence.* Eds. M.J. Cormier, D.M. Hercules and J. Lee. New York: Plenum Press.
Setlow, J. 1966. The Molecular Basis of Ultraviolet Radiation and Photoreactivation. In *Current Topics in Radiation Research, II.* Eds. M. Ebert and A. Howard. Amsterdam: North-Holland Publishing Co.
Slawinska, D. and J. Slawinski. 1985. In *Chemiluminescence and Bioluminescence.* Ed. J.G. Burr. New York: Marcel Dekker.
______. 1983. *Photochem. Photobiol.* **37**: 709.
Slawinski, J., E. Grabikowski and L. Ciesla. 1981. *J. Luminescence* **24/25**: 791.
Slawinski, J., E. Grabikowski and I. Milczarik. 1974. *Zeszyty Naukowe Akademii Rolniczej W Szczecinie* **42**: 307.
Smith, H. 1982. *Nature* **298**: 423.
Stazskiewicz, U. 1985. Personal communication.
Teubner, R. 1983. Dissertation, *Agrarwissenschaften.* Göttingen.
Teubner, R., M. Rattemeyer, and W. Mehlhardt. 1981. *Ärztezeitschr. f. Naturheilverf.* **4**: 204.
Thomas, R.N. 1961. *Some Aspects of Non-Equilibrium Thermodynamics in the Presence of a Radiation Field.* Boulder, Colorado.
Weingärtner, O. et al. 1985. *Ärztezeitschr. f. Naturheilverf.* **10**: 670.
Williams, M.D., J.S. Leight, Jr., and B. Chance. 1982. *Ann. N.Y. Acad. Sci.* **386**: 478.
Wolf, E. 1969. *Phys. Lett.* **3**: 166.
Zhuravlev, A. I., ed. 1972. *Ultraweak Luminescence in Biology.* Moscow: Moscow Society of Naturalists.

The Helicity Connection

by Daniel R. Wells
Department of Physics
University of Miami
Coral Gables, Florida 33134

Abstract—A prescription for finding the most stable state of a plasmoid is developed. It is demonstrated that the state evolves naturally by a process that minimizes the free energy of the plasma vortex structure. Hamilton's principle is utilized to obtain the Euler-Lagrange equations of the flow. These equations are the field equations for a stable structure. It is further demonstrated that the Lagrangian must include a set of constraints that build the necessary flow restrictions into the problem if it is to be well posed. It is this subtle point that constitutes the helicity connection.

The problem of the containment of controlled, sustained thermonuclear reactions arises naturally in astrophysics. The study of the detailed balance of forces in stars and the plasmas surrounding stars motivated the first important work in this field.

Chandrasekhar and Woltjer (1958; 1956; Lust and Schluter 1954) studied these problems utilizing a magnetohydrodynamic model of the stellar and interstellar plasmas. They observed that the interstellar plasma had both electric current and magnetic field filaments, but it was either stationary in its local environment or was moving with a steady velocity embedded in its structure.

In the magnetohydrodynamic model, a plasma element (differential element of volume) with a center of mass velocity $\mathbf{v}$, obeys a momentum equation (Newton's Second Law),

$$\rho\, \partial \mathbf{v}/\partial t = \nabla(p + \tfrac{1}{2}\rho v^2) + \mathbf{j} \times \mathbf{B} - \rho(\nabla \times \mathbf{v}) \times \mathbf{v}, \quad (1)$$

where

p = scalar pressure
$\mathbf{j}$ = current density
ρ = magnetofluid density
$\nabla \times \mathbf{v}$ = vorticity
$\mathbf{B}$ = magnetic induction field.

From Eq. (1), the acceleration of the fluid element, $\partial\mathbf{v}/\partial t$, will be zero if all the body force terms on the right hand side cancel, or are each identically zero. The first term will be zero if

$$p + \tfrac{1}{2}\rho v^2 = \text{constant}. \quad (2)$$

This is simply Bernoulli's equation for flow along a stream tube in the fluid. The $(\mathbf{j} \times \mathbf{B})$ term is the Lorentz force on the fluid element; while the $\rho(\nabla \times \mathbf{v}) \times \mathbf{v}$ term is the "Magnus force" (Prandtl 1952). This is the hydrodynamic force due to the interaction of the fluid flow and the local vorticity field (Wells, Ziajka, and Tunstall 1986).

If $p + \tfrac{1}{2}\rho v^2$ = constant for the fluid, it will not be accelerated if the Lorentz and Magnus forces are both identically zero, or if they are equal and opposite. Considering these two problems separately, what are the physical requirements for the Lorentz and Magnus forces both to be identically zero?

Chandrasekhar and Woltjer invoked Hamilton's principle of least action to solve the problem of little or no mass motion in the plasma of interest. They posed the problem: What configuration of plasma currents, magnetic fields, flow fields, and vorticity filaments would correspond to minimum free energy in an arbitrary closed volume of the plasma?

Using the standard formulation of the calculus of variations (Lust and Schluter 1954), they proceeded to vary the free energy subject to an appropriate set of constraints on the flow (Wells and Norwood 1969). The variation leads to a set of Euler-Lagrange equations for the fields (Rund, Wells and Hawkins 1978)

$$\nabla \times \mathbf{B} = \Omega \mathbf{B} \quad (3)$$

$$\mathbf{v} = \pm\beta\mathbf{B}. \quad (4)$$

Eq. (3) is the "force-free" equation. It makes the ($\mathbf{j} \times \mathbf{B}$) term in the momentum Eq. (1) identically zero since by Maxwell's equations $\nabla \times \mathbf{B} = \mathbf{j}$, if the displacement current in the plasma is neglected, which is usually a good assumption in the magnetohydrodynamic model.

Eq. (4) is the equation of "collinearity" (Wells and Norwood 1969). It means that in the minimum energy state flow, the velocity and magnetic induction field are everywhere parallel. It also means that the Magnus force will be identically zero.

$$\nabla \times \mathbf{B} = \Omega \mathbf{B}$$
$$\nabla \times \mathbf{v}/\beta = \Omega \mathbf{v}/\beta$$

Let $\nabla \times \mathbf{v} = \boldsymbol{\eta} \stackrel{\text{def}}{=}$ vorticity vector. Then, since β can be considered a constant for our purposes (Wells and Norwood 1969), $\boldsymbol{\eta} \times \mathbf{v} = 0$. The Euler-Lagrange equations for minimum free energy correspond to a "force-free" plasma state in which all four fields, $\mathbf{v}$, $\boldsymbol{\eta}$, $\mathbf{j}$, and $\mathbf{B}$ are parallel or antiparallel. The second Euler-Lagrange Eq. (4), has other interesting implications.

In the general case of non-force-free field, this field equation implies that $\mathbf{j} \times \mathbf{B} = \rho(\boldsymbol{\eta} \times \mathbf{v})$. The Lorentz force and Magnus force are in equilibrium. This situation is depicted in Figure 1 for two vortex filaments at right angles to the plane of the paper, one moving parallel and the other antiparallel to a magnetic guide field. The Magnus force is labeled F_m and the Lorentz force F_L. The filament traveling parallel to the guide field is called a contrarotational structure and the filament moving antiparallel to the guide field is a corotational structure. These names and motions are motivated by the $\pm$ signs in Eq. (4). The positive and negative signs in this equation are an indication of the essential nonlinearity of Eq. (1).

A study of the field Eq. (3) was first made by Beltrami and Trakal in connection with normal fluid flow problems (Bjorgum and Godal 1952). The solutions are given in several coordinate systems and several geometric configurations. If Ω is $\Omega(x,y,z)$ the flow is called "Beltrami"; if a constant, the flow is called Trakalian.

Busemann applied Eq. (4) to studies of vortex filaments in plasmas produced by reentry vehicles (1962).

I first became interested in the work of Chandrasekhar and Woltjer in connection with studies of the winding of force-reduced and force-free coils. A multilayer coil can be wound with the pitch of each layer of the winding arranged so that the ($\mathbf{j} \times \mathbf{B}$) (Lorentz) forces are zero everywhere in the winding. The coil must be placed in a magnetic field generated by an external winding. The external coil then takes the forces and relieves the working coil of the intense pressure gradients generated by the interaction of the currents and fields inside the windings. The work of Shafranov (Bjorgum and Godal 1952) and others suggested the possibility of generating a ring of plasma with similar force-free properties. Plasma rings had been generated by Lindberg et al. (1961). Wainek (1959) suggested the possibility of generating plasmoids with a conical, theta-pinch device. I built a conical, theta-pinch gun and studied the plasma structures that were generated, identifying these toroidal structures as plasma vortex rings with a quasi-force-free geometry (Wells and Norwood 1969). The geometry of the rings generated by the conical theta pinch is shown in Figure 2. A single ring can be propagated down a long solenoid as shown in Figure 3, or two rings can be fired at each other to meet at the center of a second set of coils, as shown in Figure 4. In the latter case, the rings are guided to the center of a primary mirror system. After they meet, they form a magnetic cush-

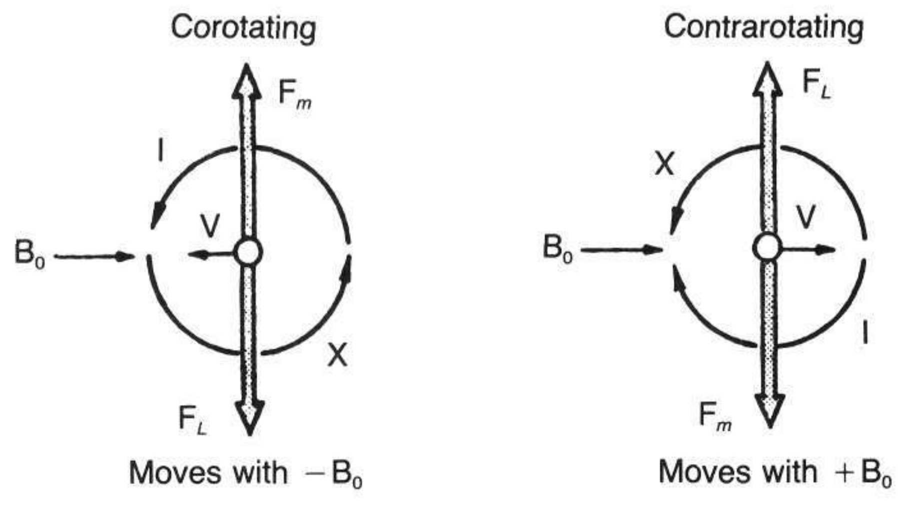


Figure 1. Lorentz force and Magnus force in equilibrium. Here are two vortex filaments (at right angles to the plane of the paper) with one moving parallel, contrarotating, and the other moving antiparallel, corotating.

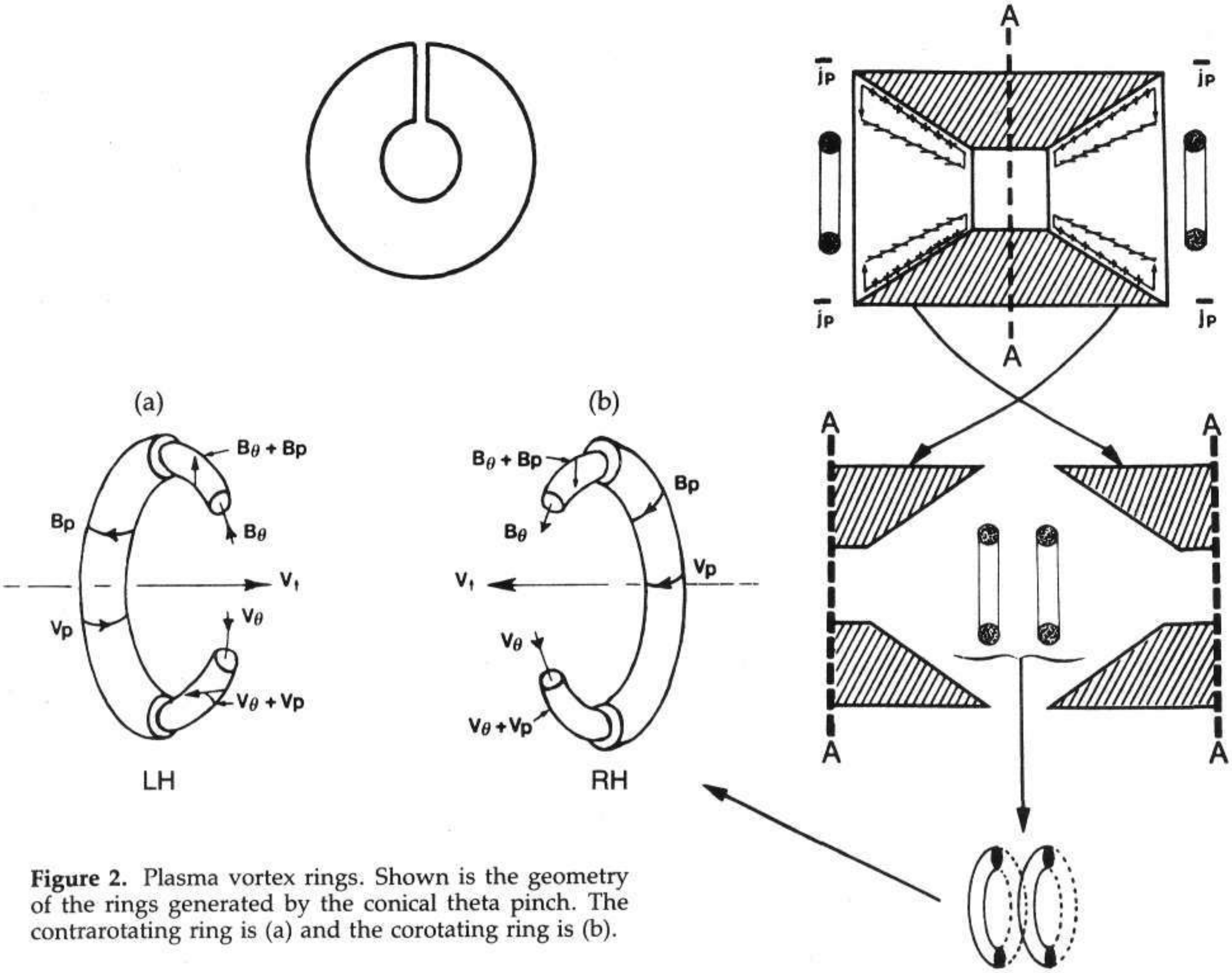


Figure 2. Plasma vortex rings. Shown is the geometry of the rings generated by the conical theta pinch. The contrarotating ring is (a) and the corotating ring is (b).

ion or "septum" which holds them apart until they decay (Wells and Norwood 1969). They persist for times of the order of milliseconds.

I conjectured that the plasma produced by the conical pinch was pushed into the mass of unstructured gas in front of it and lost energy by transferring some of its rotational and translational energy to the surrounding plasma (Wells and Norwood 1969). Losses due to other dissipative processes are also present. The structure loses energy until it reaches its lowest free-energy state and then becomes a relatively stable quasi-force-free structure. It was further suggested that the plasmas in most other laboratory fusion experiments also would attempt to reach low, free-energy states if they were placed in an environment that allowed the process to take place. If they are forced into some other geometry, global instability of the plasma inside the machine is highly provable. The work begun at Princeton in 1960 on the machine shown in Figure 4 was continued on a machine at the University of Miami called TRISOPS (Wells, Ziajka, and Tunstall 1986; Wells and Norwood 1969). This series

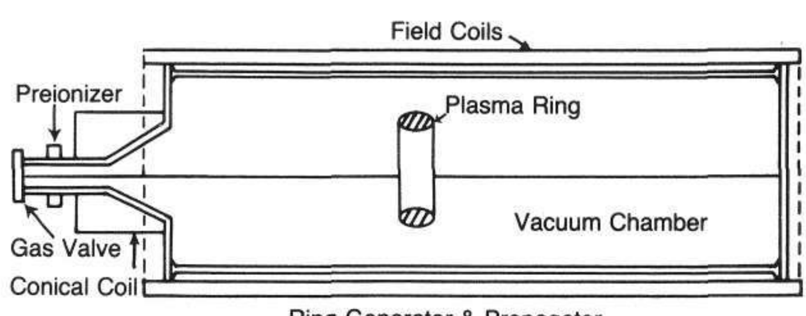


Figure 3. Single ring generator and propagator. A single ring is propagated down a long solenoid.

of experiments culminated in TRISOPS IIX. The plasma in this machine was injected into the secondary magnetic compression coils as a series of plasma vortex rings generated by the conical theta pinches at each end of the primary mirror system. The rings are then compressed to a 2-millimeter plasma fireball at peak compression. The plasma reaches a peak temperature of 6 keV and 10^{10} neutrons are produced on each compression. This experiment and the plasma parameters are discussed in detail by Wells, Ziajka, and Tunstall (1986). The most interesting aspect of this experiment is that the ion temperatures implied by the neutron yield and spectral line broadening correspond to a plasma temperature and pressure too high to be in equilibrium with the magnetic field pressure. That is, the β is much greater than unity. How can this be? One possible explanation is that since the ($\mathbf{j} \times \mathbf{B}$) forces are not large enough to hold the pressure gradients, perhaps the Magnus forces are playing a major role in obtaining the balance of forces. These forces are similar to those responsible for the lift on an airplane (Wells, Ziajka, and Tunstall 1986). Another explanation considered by the Miami group (Wells 1981) and also investigated at the University of Washington, is the possibility that most of the neutron flux is generated by counterstreaming deuterons at the center of the rings during compression. The plasma flow at the center of each ring is in the forward direction as they propagate toward the center of the mirror. The rings from one end of the machine are all contrarotational and those from the other end are all corotational. All the "contras" and "cos" coalesce to form one composite ring from each end which collides at the center of the machine. At collision and during compression, the plasma at the center of the rings is being pumped forward. This results in a relative counterstreaming of the plasma at the center of the machine. The velocity of collision of the deuterons is twice the velocity of the colliding particles (2×10^6 cm/sec) and this increases the cross section for fusion. As the rings are compressed, the velocities are greatly amplified and neutron production increases. The result of this interaction is nonthermal fusion; that is, the fireball is not at thermonuclear temperature, but there is a fusion region surrounded by a warm plasma. This process could result in ignition and heating of the surrounding fireball. There is still some question about exactly what is happening in the compressed fireball. The temperature as determined by Doppler broadening measurements of impurity spectral lines at Miami indicate a hot fireball. Similar measurements made at the University of Washington do not. An attempt to clarify the problem is under way at the University of Miami.

In the meantime, other investigators throughout the world have recognized the importance of the minimum energy stability concept. Taylor (1974) reanalyzed the results obtained with Zeta and recognized that the plasma configuration obtained in this pinch discharge was a force-free geometry. His analysis uti-

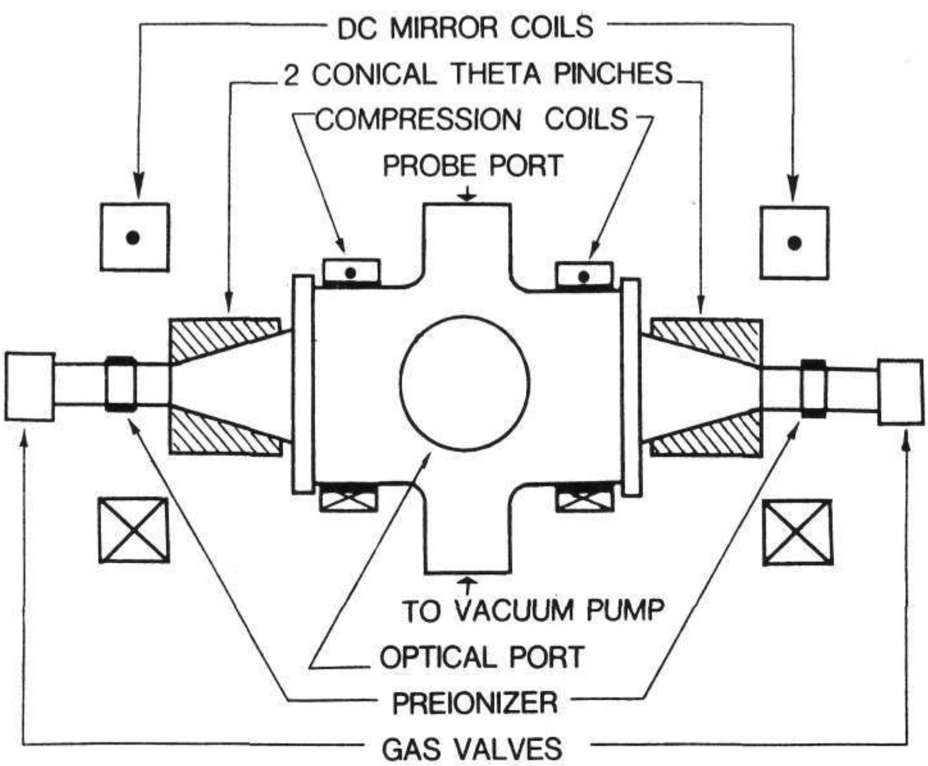


Figure 4. Schematic of Trisops with mirror coils. Two rings are fired at each other and meet at the center of a second set of coils. The rings are guided to the center of a primary mirror system.

lizes a simplified form of Woltjer's original theory in which the velocity terms in Eq. (1) are ignored. Wells and Norwood in their 1968 analysis kept the velocity terms which play a major role in vortex ring generation, propagation, and heating. In his application of this theory, Taylor varied the Lagrangian (energy) of a fluid element subject to the integral constraint $\int_v \mathbf{A} \cdot \mathbf{B} dV$. His energy to be varied is $\int_v B^2/2\mu_0 \, dV$, the magnetic energy. Thus one has

$$\delta \int_v \{(B^2/2\mu_0) + \lambda \mathbf{A} \cdot \mathbf{B}\} dv \qquad (5)$$

where λ is a Lagrange multiplier.

Wells and Norwood (following Woltjer) varied the free energy, including the mass flow energy and the internal energy subject to two constraints,

$$\int_v \{(B^2/2\mu_0) + \tfrac{1}{2}\rho v^2 + \lambda_1 \mathbf{A} \cdot \mathbf{B} + \lambda_2 \mathbf{B} \cdot \mathbf{v}\} dv. \qquad (6)$$

The Euler-Lagrange equation generated by Eq. (5) takes the form of Eq. (3); while that generated by Eq. (6) results in both Eqq. (3) and (4). The minimization of the total free energy predicts a force-free, collinear, plasma vortex structure.

Taylor discusses the magnetic field reversal on the outer layers of the plasma column in the Zeta machine. The solutions of the force-free Eq. (3) given in Beltrami's paper (Bjorgum and Godal 1952) illustrate that this is an eigenvalue equation. It has a whole hierarchy of solutions corresponding to higher and higher energy states. Each state has a different value of Ω. The geometry of the various states indicates that the lowest state has a sheared helical structure across the whole cross section of the plasma column. The next highest state has two separate field configurations. One, at the center of the cross section, is a modified form of the first eigenvalue field. The second is a helical field in the opposite direction, that is, a "reversed field." Since a reversed field at the outer layers of the plasma in the discharge of the Zeta device had been observed for a long time (Kawai, Pietrzyk, and Hunter 1984), Taylor was able to identify and interpret the Zeta machine plasma configuration in terms of the minimum energy principle applied to machine configurations that were previously conjectured by Wells and Norwood (1969).

A whole new fusion effort was launched in 1975 based on the concepts of minimum free-energy configurations, force-free fields, and reversed field pinches. Before tracing the history of these experiments, however, we must return to an interpretation of Eqq. (5) and (6). What is the physical meaning of the two integral constraints $\int_v \mathbf{A} \cdot \mathbf{B} dV$ and $\int_v \mathbf{B} \cdot \mathbf{v} \, dV$?

The answers to this question are given in a series of papers by various authors (Seliger and Whitham 1968; Henyey 1983; Moffatt 1969; Lin 1963). The arguments may be summarized as follows: The functions $(\mathbf{A} \cdot \mathbf{B})$ and $(\mathbf{B} \cdot \mathbf{v})$ are a measure of the local helicity of the fields, that is, the tightness of the wrapping of the helix or each layer. Moffatt (1969) has pointed out that $\int \mathbf{A} \cdot \mathbf{B} dV$ and $\int \mathbf{B} \cdot \mathbf{v} dV$ are a measure of the "knottedness" of the fields inside the volume V. "Knottedness" is, in turn, a measure of the tangling of the field lines, that is, can two field lines be separated without cutting either one of them? Moffatt further shows that there is a connection between the concept of "knottedness" and the famous Lin constraint (Lin 1963; Moffatt 1969).

Moffatt shows that the general functional form of the knottedness can be written

$$\int_v \mathbf{u} \cdot \mathbf{w} \, dV \qquad (7)$$

where $\mathbf{u}$ and $\mathbf{w}$ are any of the relevant fields, that is, $(\mathbf{B}, \mathbf{v}, \boldsymbol{\eta}, \mathbf{j})$.

Eq. (7), in turn, leads to the equation (Lin 1963), $D/Dt(\mathbf{u} \cdot \mathbf{w}/\rho) = 0$.

If one writes, $\mathbf{u} \cdot \mathbf{w}/\rho = s$, then,

$$\partial s/\partial t + \mathbf{v} \cdot \boldsymbol{\nabla}_s = 0. \qquad (8)$$

This is the equation governing Lin's constraint. Lin (1963) pointed out that Eq. (8) must be included, as a constraint, in the application of Hamilton's principle to a fluid, if an Eulerian description of the flow is used. For an Eulerian description,

$$\rho D\mathbf{v}/Dt = \rho \partial \mathbf{v}/\partial t + \rho \mathbf{v} \cdot \boldsymbol{\nabla} \mathbf{v} = \Sigma_i F_i \qquad (9)$$

where ΣF_i is the sum of all body forces on the fluid element, Eq. (1) Lagrangian description follows the motion of each individual fluid particle during its motion along the stream tubes (Lamb 1932). There is a set of parameters $(\alpha_0, \beta_0, \gamma_0)$ associated with the initial position of each fluid particle. The requirement that the motion of each individual particle be identified is automatically satisfied by the Lagrangian flow description. If the Eulerian description and Eq. (9) are used, any application of Hamilton's principle must include Eq. (8) as a constraint condition. But we have shown that Eq. (8) is equivalent to the use of the helicity integrals as constraints. This is the "helicity connection."

There are numerous applications of the helicity concept in ongoing work on the development of potential fusion reactor designs. These applications are both theoretical and experimental. Many of them are described in abstracts of papers presented at the 1985 fall meeting of the American Physical Society's Division of Plasma Physics in San Diego, Calif., Nov. 4-8, 1985. The rest of this article is a survey of some of these abstracts.

Direct application of the concept to experiment is being pursued at Los Alamos National Laboratory in the CTX spheromak program (Tarboe et al. 1985). In this experiment, magnetic helicity is generated in a plasma by currents drawn from electrodes. The magnetized plasma is then forced into a magnetic flux conserver where a spheromak (structured plasmoid) is formed and sustained. Reversed field pinches are also sustained by the continuous injection of helicity, in this case by inductive means (Baker 1985). They show that the helicity balance can explain the time dependence of the magnitude of the spheromak fields for many resistive decay times. The magnitude of the helicity is identified as the most important factor in determining the magnetic field strength of the spheromak equilibrium. The concept of helicity and knottedness now takes on a very real meaning. Once generated, it is sustained in a natural way by dynamo (self-generating) effects inside the plasmoid. As long as it is present in the plasma, the structure tends toward the minimum energy (quasi-force-free) configuration.

A group at Texas Tech University (Ikuta 1985) is investigating helicity injection by use of a pump field, $\mathbf{B} = \mathbf{a}(r)\sin \omega t + \mathbf{b}(r)\cos \omega t$, where $\mathbf{a}(r)$ and $\mathbf{b}(r)$ are the poloidal and toroidal components, respectively. They formulate the scalar Ω in Eq. (3) as a function of the pump field.

At Columbia University (Kwok 1985), minimum energy equilibria in tokamaks and stellarators are under investigation. They speculate that their method may be of use in studying relaxation of a stellarator with imperfect surfaces. They mention the method of "least constraint." This concept was discussed previously (Wells and Norwood 1969; Wells 1970). Current work at UCLA by D. Jovanovic is concerned with nonlinear Alfvén waves and plasma vortices. There is a close relationship between Alfvén waves and plasma vortices because Eq. (4) is the Euler-Lagrange equation corresponding to a free-energy extremum. The proof that this extremum is a *minimum* involves another procedure (Wells and Norwood 1969; Rund, Wells, and Hawkins 1978) which results in

$$\beta = (\mu_0\rho)^{-1/2}$$

$$\mathbf{v} = \mathbf{B}(\mu_0\rho)^{-1/2}. \tag{10}$$

However, Eq. (10) is just the definition of Alfvén speed. It is easily shown that all internal flow velocities *and* the velocity of propagation, are at Alfvén speed. I discussed this type of Alfvén wave in an early paper (1970). The waves discussed by Jovanovic are of a different type, which travel at right angles to the applied magnetic field. Winston Bostick (1965; Wells and Norwood 1969) has described vortex roller pairs (paravortices) that rotate in opposite direction in order to conserve angular momentum. They move across the magnetic field. I have shown that these structures correspond to the Euler-Lagrange equations resulting from the use of the conservation of angular momentum constraint along with the two helicity constraints discussed above (Wells and Norwood 1969).

An invited paper from Los Alamos (Tarboe et al. 1985) discusses recent advances in spheromak physics at the laboratory. This paper is concerned with new results on helicity injection into an oblate mesh flux conserver by a magnetized coaxial plasma source.

An invited paper from Princeton (Xamada 1985) describes recent results on the S-1 spheromak device at that laboratory. This is a complicated experiment in which the plasma configuration is formed by inductive transfer of magnetic flux from a toroidal-shaped "flux core." The plasma relaxes to the minimum free-energy state. A careful experimental check with magnetic probes was made by measuring $\mathbf{j}\cdot\mathbf{B}/B^2$ throughout the plasma volume. Magnetic fluctuation with toroidal mode numbers $n = 4,3,2$ are identified as responsible for the attainment of the low-energy state. The mechanism is thought to be the conversion of poloidal to toroidal flux. The electron density and temperature were $1 \times 10^{14}\ \mathrm{cm}^{-3}$ and 100 eV respectively.

A group at GA Technologies (Wojtowicz 1985) has investigated the plasma formed by helicity injection into a cylindrical, conducting shell. They point out that the minimum energy state in such plasma should be the state discussed by Taylor (and previously by Wells). Of course we know that this is really a Trakalian field (a Beltrami field with Ω = constant in $\nabla \times \mathbf{B} = \Omega\mathbf{B}$). This configuration is really a double helix as discussed at the beginning of this paper; that is, there is a center helix surrounded by a reversed helix in the second eigenvalue state of Eq. (3). The authors of the paper attempt to verify the configuration experimentally.

An interesting paper by F.L. Yin et al. (1985) at Columbia University attempts to analyze recent results from the CTX experiment at Los Alamos. This experiment on helicity injection into a spheromak was discussed earlier. They found that the plasma seemed to relax into a minimum-energy state which deviates considerably from the force-free (Trakalian) field. The measured states seem to be described well by a numerical model in which $(\mathbf{j}\cdot\mathbf{B}/B^2)$ is a linear function of the poloidal flux multiplied by a constant whose numerical value depends on the dominant resistive modes. They claimed that this result is consistent with a theory of Bhattacharjee et al. (1980), which proposed that the plasma relaxes to a state of minimum energy $W = \int_\tau B^2/2\mu_0\, d\tau$ subject to the invariance of $K_0 = \int d\tau\, \mathbf{A}\cdot\mathbf{B}$ and $K_1 = \int d\tau \gamma \mathbf{A}\cdot\mathbf{B}$, where γ is the helical flux that depends on the pitch of the dominant mode. The relaxed states show a linear dependence on γ.

It should be noted that in the early work of Wells and Norwood (1969) and Nolting, Jindra, and Wells (1985) experimental measurement of the poloidal and toroidal flux distribution showed that the fields are quasi-force-free; that is, they follow the general force-free (Trakalian) field configuration, but correspondence is not exact. Apparently, again there is the strong indication that the dominant poloidal mode drives the toroidal field generation by a dynamo effect. Compare these recent concepts with an early paper by Bostick and Wells on the generation of toroidal field in the vortex structures generated by the conical theta pinch (1962).

There are rival theories concerned with toroidal field generation. Pietyzh et al. (1985) have postulated that this dynamo is driven by pressure gradients across the dynamic plasma profile. A series of papers by the Princeton group (Janos et al. 1985; Hart et al. 1985; Jardin and Janos 1985) again is concerned with the details of the formation of the minimum-energy state from some initial higher energy configuration. They stress the fact that the initial state formed in the S-1 Spheromak is far from the minimum-energy state. The comparison is made by measuring the parameter μ, which they define as $\mu = \mu_0 \, \mathbf{j} \cdot \mathbf{B}/B^2$.

During plasma formation, μ varies by a factor of 2.5 across the plasma. After formation, μ is constant to within the error bars of the measurement. For μ to be a constant, both the pressure gradient in the plasma must be zero and $I(\Sigma) = RB_t$ must be a linear function of Σ, the poloidal flux. They find $I(\Sigma)$ linear after formation, but not during formation. The measurement of ∇p is accomplished with a Langmuir probe. After formation, the gradient goes to zero except near the plasma boundaries. This should be compared to the results obtained by Nolting et al. (1973).

G. Marklin (1985) presented a paper on the $m = 1$ Source Experiment at Los Alamos. This experiment consists of an unstable magnetized z-pinch used as a helicity generating source. It is connected to a flux conserver through an entrance region. Probe data indicate the presence of a spheromak configuration (force-free configuration) with axisymmetric, nested, toroidal flux surfaces in the flux conserver and a helical structure in the entrance region. They describe the numerical computation of the 3-D minimum-energy state and show how the magnetic field and flux surfaces connect up in the transition region.

A series of papers from Los Alamos (Gribble 1985; Phillips and Gribble 1985; Watt et al. 1985) discusses the generation of a force-free state with reversed field outer layer in the ZT-40 reversed field pinch. Reversed field pinch work throughout the world seems to follow the force-free parameters for these pinches as originally analyzed by J.B. Taylor (1974).

Work at GA Technologies (Schaffer 1985) is concerned with helicity transport and connection and the mechanics that produce the dynamo that drives the conversion of poloidal to toroidal field. In reversed field pinches, current drive techniques can be utilized to produce steady state or quasi-steady state plasma because the plasma responds to the externally driven modulations in a way that maintains a relaxed or "near-minimum energy" state. The mean magnetic fields and hence the plasma currents are maintained.

Careful study of the many current efforts at attaining a minimum free energy configuration makes the original suggestion by the author and the University of Miami group very relevant to future activity in attaining a suitable configuration for a controlled thermonuclear reactor. In outlining the method, the 1969 paper (Wells and Norwood) states:

> What actually happens in any real plasma experiment in the laboratory is that the plasma is produced in the machine or injected from outside the machine in a violently dynamic state: that is, the center of mass of a typical fluid element in the plasma is usually in a state of rapid motion. In this dynamic state, the plasma interacts with the externally applied electromagnetic fields as well as any fields trapped in the plasma and proceeds to lose energy until it either reaches a state of dynamic equilibrium in which the currents can decay without producing a violent mass motion in the plasma, or the plasma decays into a configuration which is unstable and anomalous diffusion or "pump out" results.
>
> The point is that the currents and/or fluid motions inside the plasma continue until the plasma is completely thermalized or until the plasma leaves the magnetic bottle at some earlier time owing to a gross instability. If the plasma is to degenerate from a state of initial dynamic instability to one of hydrodynamic or hydrostatic stability, then it must be possible to calculate by some variational procedure the allowable stable configurations which the plasma can assume. If there is dynamic energy in the plasma when it is first produced, then this energy must be directed into a dynamically stable or statically stable configuration which exists until all currents decay and the plasma is thermalized. If the plasma is actually produced in a quiescent state, then the currents within the plasma must not generate mass motions and currents as they decay (unless, of course, the resulting current and flow structure is stable).
>
> If a thermonuclear reaction is to be sustained within a plasma which is confined by a magnetic bottle, the confining action will be effective only so long as currents within the plasma are interacting with the externally applied fields. Complete thermalization, of course, results in complete loss of plasma. Thus it is during the dynamic decay period after injection or heating that one

must calculate the stability. If the stability is to exist in a static configuration, then static stability must be shown to evolve out of the original dynamic state. The assumption that the system is conservative (that is, that the effective potential is not an explicit function of the time) is justified only for a limited number of special configurations and plasma parameters. . . .

One must realize, however, that the stable equilibria obtained in the plasmoids produced by the conical theta-pinch, and apparently those produced in some coaxial gun experiments, are unique in that they result from very special geometries with a high degree of symmetry. On the other hand, the appearance of similar structures in other unrelated experimental configurations indicates that these special circumstances often are present on other laboratory experiments.

The 1969 paper goes on to develop the variational techniques required to find the global stability of plasma configurations *with mass flow* and *with* and *without* conservation of angular momentum. If the mass flow terms are dropped, the resulting Euler-Lagrange equations reduce to the simple force-free field equations.

This is the basic concept that was applied by Taylor in his 1974 paper on stability in the Zeta device. He gives a simplified version of the theory in which the mass-flow terms are considered negligible.

References

Baker, D.A. 1985. "Theoretical Parametric Studies of Oscillating Field Current Drive." Session 2R19, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Barnes, C.W. et al. To be published in *Phys Fluids*. "Determinations of the Conservation and Balance of Magnetic Helicity between Source and Spheromak in the CTX Experiment." LA-UR-85-2993.

Bhattacharjee, A. 1980. *Phys. Rev. Lett.* **45**:347.

Bjorgum, O. and Godal, T. 1952. "On Beltrami Vector Fields and Flows." *Naturvitenskapelig* NY. 12, Universitetet I. bergen. (Part II. The case when Ω is constant in space.) Rekpe No. 1. (Part I).

Bostick, W.H. and Wells, D.R. 1962. *Phys Fluids* **6**:1325.

Bostick, W.H. et al. 1965. *Phys Fluids* **8**:745.

Busemann, A. 1962. "Plasma Physics and Magnetohydrodynamics in Space Exploration." *NASA SP-25*,1.

Chandrasekhar, S. 1956. "On the Stability of the Simplest Solution of the Equations of Hydrodynamics." *Proc. Nat. Acad. Sci.* **42**:273.

Gribble, R.F. 1985. "Simulation of ZT-40 Using the Culham Coupled Model." Session 2R23, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Hart, G.W. et al. 1985. "Verification of Minimum Energy State in the S-1 Spheromak." Session 4P11, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Henyey, F.S. 1983. *Phys Fluids* **26**:40.

Ikuta, K. 1985. "Force-Free Configurations Generated by Helicity Injection." Session 2Q24, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Janos, A. et al. "Global Magnetic Fluctuations in S-1 Spheromak Plasmas and Relaxation toward a Minimum Energy State." Session 4P10, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Jardin, S.C. and Janos, A. 1985. "Amplification of S-1 Spheromak Current by an Inductive Current Transformer." Session 4P15, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Kawai, K., Pietrzyk, Z.A. and Hunter, H.T. 1984. "Generation of Poloidally Rotating Spheromaks by the Conical Theta Pinch." University of Washington. To be published in *Phys Fluids*. See also *Proc. 8th Annual Compact Torus Conference*, Princeton, New Jersey, 1984.

Kwok, Y. 1985. "Minimum-energy Equilibria in Tokamaks and Stellarators." Session 2Q24, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Lamb, H. 1932 *Hydrodynamics*. New York: Dover, 6th ed.

Lin, C.C. 1963. "Liquid Helium." *Proc. Int. School of Physics*, Course XXI. New York: Academic Press.

Lindberg, L. and Jacobsen, C. 1961. *Astrophys. J.* **533**:1043.

Lust, R. and Schluter, A. 1954. "Kraftfreie Magnetfelder." Z. *Astrophys.* **34**:263.

Marklin, G. 1985. "Three Dimensional Taylor States in the m = 1 Source Experiment." Session 2R23, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Moffatt, H.K. 1969. *J. Fluid Mech.* **35**:117.

Nolting, E.E., Jindra, P., and Wells, D.R. 1973. *J. Plasma Physics* **9**:1.

Phillips, J.A. and Gribble, R.F. 1985. "Termination of RFP Discharges." Session 2R27, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Prandtl, L. 1952. *Essentials of Fluid Dynamics*. Authorized translation. London: Blackie and Son Limited, pp. 70-72, 143.

Rund, H., Wells, D.R., and Hawkins, C.H. 1978. "Clebsch Representations in the Theory of Minimum Energy Equilibrium Solutions in Magnetohydrodynamics." *J. Plasma Physics* **20**:329.

Schaffer, M.J. 1985. "Helicity Transport and Power Dissipation by Dynamo Fluctuations in RFP." Session 2R40, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Seliger, R.L. and Whitham, G.B. 1968. *Proc. Roy. Soc. A.* **305**:1.

Tarboe, T.R. et al. 1985. "Recent Advances in Spheromak Physics from the Los Alamos Spheromak Program." Session 3I: Alternate Concepts, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Taylor, J.B. 1974. "Relaxation of Toroidal Plasma and Generation of Reverse Magnetic Fields." *Phys. Rev. Lett.* **33**:1139.

Wainek, R.W. 1959. *Proc. Int. Astronautical Congress*, London, 131.

Watt, R.G., et al. 1985. "International RFP Experimental Results: A Synthesis." Session 2R36, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Wells, D. 1970. "Dynamic Stability of Closed Plasma Configurations." *J. Plasma Phys.* **4**:645.

______. 1981. "Method and Apparatus for Heating and Compressing Plasma." U.S. Patent 4334876.

Wells, D.R. and Hawkins, C.H. To be published. "Containment Forces in Low Energy States of Plasmoids." *J. Plasma Phys.*

Wells, D.R. and Norwood, J., Jr. 1969. "A Variational Approach to the Dynamic Stability of High Density Plasmas in Magnetic Containment Devices." *J. Plasma Phys.* **3**:21.

Wells, D.R., Ziajka, P.E. and Tunstall, J.L. 1986. "Hydrodynamic Confinement of Thermonuclear Plasmas." *J. Fusion Technology*. **9**:83, January 1986.

Wojtowicz, S.S. 1985. "Experimental Investigation of a Double Helix Plasma." Session 4P1, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Woltjer, L. 1958. "A Theorem on Force-free Magnetic Fields." *Proc. Nat. Acad. Sci.* **44**(9):489.

______. "On Hydromagnetic Equilibrium." *Proc. Nat. Acad. Sci.* **44**(9):833.

Xamada, M. 1985. "Investigation of the Spheromak Configuration in the S-1 Device." Session 3I2, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Xiu, F. 1985. "Relaxation of Magnetic Fields in a Spheromak." Session 4P5, fall meeting of the APS Division of Plasma Physics, San Diego, Calif., Nov. 4-8.

Newton's Gravitational Constant and the Structure of Science

by B.A. Soldano
Department of Physics
Furman University
Greenville, S.C. 29613

Abstract—A derivation of Newton's universal gravitational constant G is shown to involve a local terrestrial reference frame range dependency which is ultimately traceable to a fractional nonequality $[(m_i - m_G)/m_G = 5.05 \times 10^{-12}]$ between inertial and gravitational binding mass. The major and invariant component of G obtained when $r = \infty$, that is, $G_\infty = (6.734 \pm 0.002) \times 10^{-8}$, is shown to originate in the generalized electrical properties of matter. The order of magnitude of G_∞ is set by the ratio of electrical transition times T relative to the lifetime τ of atomic excited states, this ratio being fixed by the cube of the fine structure constant. This quantum mechanical derivation of G_∞, which agrees with the above value of G_∞ to 27 parts in 100,000, involves the unification of all four forces. The fifth force, proposed by Fischbach et al. to save the equivalence principle that was challenged by the nonnull result of their Eötvös analysis, is shown to represent a confirmation of a gravitational binding mass nonequality.

Introduction

Newton's universal law of gravitation has been called the greatest achievement of the human mind. Mathematically, Eq. (1) states that the force of attraction **F** between any two bodies m_1 and m_2 varies inversely with the square of the distance r_{12} between their centers of mass and directly as the product of their two masses.

$$\mathbf{F} = - G(m_1 \, m_2/r_{12}^2)\hat{\mathbf{u}}_r \qquad (1)$$

The magnitude of this force is fixed by the size of Newton's universal constant G. After 200 years, the nature of this constant remains enigmatic.

Interestingly, the same inverse square form appears in the laws of electricity. No one, however, has succeeded in demonstrating electromagnetism and gravitation to be different aspects of the same thing. This results in part from the fact that gravitational coupling of the electron is some 43 orders of magnitude smaller than that of electricity. Further, no one has successfully incorporated the microscopic quantum theory into the macroscopic law of gravitation.

Recent developments suggest that the time is ripe for an attempted resolution of the above questions (Fischbach et al. 1986; Long 1980 and 1974; Gibbons and Whiting 1981; Stacey and Tuck 1981; and Holding and Tuck 1984). First, we shall address the question of the recently discovered minute range (λ) dependency of the laboratory gravitational constant G. Second, we will show that our theory, based on a gravitational binding mass nonequality between inertial mass ($\mathbf{F} = m\,\mathbf{a}$) and gravitational mass, Eq. (1), not only resolves the laboratory range question in Eq. (2), but provides a general framework for the derivation of G_∞ itself. Our approach will involve a role for the quantum h, classical electromagnetism, and the hierarchy of four forces.

Specifics of the Variable *G* Question

Fischbach et al. (1986) have very recently claimed confirmation of the existence of a *fifth force*, hypercharge, based in part on a nonnull result obtained upon reanalysis of the Eötvös gravitational acceleration experiments.

Geophysical measurements of Newton's gravitational constant suggested by the pioneering work of Long (1980 and 1974) consistently find G values higher than those measured in the laboratory, which we shall denote as G_0. Long, Stacey, and others have argued that the discrepancy between these two sets of G values is real (Stacy 1981; Gibbons and Whiting 1981; Holding and Tuck 1984), leading to Eq. (2).

$$
\begin{aligned}
V(r) &= -(m_1\, m_2/r_{12}) G_\infty \left[1 + \alpha\, e^{-r/\lambda}\right] \\
&= V_N(r) + \Delta V(r)
\end{aligned}
\tag{2}
$$

$V_N(r)$ is the usual Newtonian expression for potential energy of two masses m_1 and m_2 separated by distance r_{12}. Recently Fischbach concluded that the discrepancy between the G value at infinity (G_∞) and that found in the laboratory (G_0), Eq. (2), can be accounted for by a hypercharge-related fifth force, which he suggests constitutes the basis for the nonnull Eötvös results obtained in his reanalysis of the data. Fischbach agrees with Stacey and others that the best fit for Eq. (2) requires that the empirical constants α, λ have the following values: $\alpha = -(7.24 \pm 3.6) \times 10^{-3}$ and $\lambda = (200 \pm 50)\, m$. Further, he interprets the fact that the empirical constant α in Eq. (2) is less than zero as evidence that the fifth force described by the second term is repulsive with the exponential r dependence characteristic of a massive hypercharge field (Weinberg 1964). The quanta of this field are hyperphotons of mass m_γ given by $1/\lambda \cong 1 \times 10^{-9}$ eV, with their exchange being described by a potential of the form of $\Delta V(r)$, Eq. (2).

A UPI press release (Ziegler 1986) carried a report on Fischbach's public assurances that his "own theory does not contradict Einstein, but that hypercharge will have to be accounted for when calculating the acceleration of objects to the center of the Earth." Such assurance that the equivalence principle, so key to general relativity, was not jeopardized by his findings is quite surprising, in view of the fact that any deviations from the Eötvös null result heretofore have always been interpreted as evidence for a nonequality between inertial and gravitational mass. Further, as we shall show, nonequivalence between inertial and gravitational binding mass would lead to an antibinding repulsion that behaves exactly as that required by the fifth force proposed by Fischbach.

The suggestion that the equivalence principle has been spared by the Fischbach interpretation of Eq. (2) is refuted by the following considerations. First, if the Newtonian gravitational constant at infinite range is different from that found in the laboratory, then the factor α in Eq. (2) should represent a statement, *characteristic of our terrestrial reference frame*, that details how this local range-dependent change in G occurs. Some of the attempts to characterize changes in G have involved an examination of the role of time factors or time ratios. (We will use the latter in our analysis.) Of paramount importance, however, is the fact that any nonnull Eötvös effect strongly suggests that the principle that absolutely equates inertial and gravitational mass, the equivalence principle, must now be restricted. The consequences of a nonequality between inertial and gravitational mass restricted to the gravitational binding fraction of mass alone that pervades the entire structure of science has been addressed in detail (Soldano 1985).

In turning to the specific elements to be introduced in order to account for the empirical α and λ in Eq. (2), we begin by making the following crucial point. General relativity, a theory uniquely linked to the equivalence of inertial and gravitational mass, permits no variation in the gravitational constant (Bondi 1961). The fact that Eq. (2) represents a change in the Newtonian gravitational constant clearly underscores the fact that the repulsion inherent in the second term, involves a nonequivalence phenomenon that is alien to general relativity. Further, it strongly suggests that the two empirical constants in the equation must be related to nonequivalence.

It is not surprising, therefore, to find that our terrestrial reference frame, nonequivalence expression for the fine structure constant, Eq. (3), with a value equal to 7.297351×10^{-3} (Soldano 1985),

$$
\alpha = 1 \text{ rad } \dot{\eta}_{\oplus,\gamma}/2\,\pi\, \dot{\xi}_{\oplus,e^-}
\tag{3}
$$

is comparable in magnitude to the empirical constant α. Further, it is composed of two terrestrial reference frame elements; that is, $\dot{\eta}_{\oplus,\gamma}$ and $\dot{\xi}_{\oplus,e^-}$, where $\dot{\eta}_{\oplus,\gamma}$ is given by Eq. (4),

$$
\begin{aligned}
\dot{\eta}_{\oplus,\gamma} &= \frac{f_{g_\oplus}\,[(m_i - m_G)/m_G]\; \hat{\mathbf{u}}_n \cdot \vec{\omega}_\oplus}{[20.''496 = \text{Earth's aberration constant}]} \\
&= -\frac{5.0 \times 10^{-14}}{\text{yr}}
\end{aligned}
\tag{4}
$$

The term $f_{g_\oplus} = -4.67 \times 10^{-10}$ is the Earth's gravitational packing fraction, a hypercharge dependent quantity given by Eq. (5),

$$
f_{g_i} = -1.99 \times 10^{-44} A^{2/3}
\tag{5}
$$

with A being the nucleon number. The key term of our nonequivalence model, $(m_i - m_G)/m_G = 5.05 \times 10^{-12}$, is a universal difference between the inertial and gravitational binding mass that is directly linked to the dynamics of the universe. The fact that $m_i > m_G$ and $f_{g_\oplus}$ is negative, ensures that $\dot{\eta}_{\oplus,\gamma}$ will be negative as required by Eq. (2). Of greater significance, however, is the fact that the term $\dot{\eta}_{\oplus,\gamma}$, which describes a photon interaction, represents a binding nonequivalence deviation from the Lorentz invariance inherent in the description of the Earth's aberration constant, 20.″496 in Eq. (6) (Soldano 1985),

$$\begin{bmatrix}\text{Constant of}\\ \text{aberration}\end{bmatrix} = 20.''496$$

$$= 2\pi \frac{[(2.06265 \times 10^5 \text{ arcsec})/\text{rad}]\ 1 \text{ A.U.}}{c\ P_{\oplus,\text{orbit,sidereal}}\ (1-e_\oplus^2)^{1/2}} \qquad (6)$$

where $e_\oplus$ is the Earth's orbital eccentricity and c the velocity of light.

Since the light aberration process involves the photon, any deviation from it could be related to the process of hyperphoton emission due to mass nonequivalence in gravitational binding. It should also be noted that the magnitude of the gravitational binding fraction $f_{g_\oplus}$ in the term $\dot{\eta}_{\oplus,\gamma}$ in Eq. (5), that is required to describe the size of binding nonequivalence, is proportional to the number of nucleons or the hypercharge; see Eq. (2). So our explanation involves hypercharge, as does Fischbach's, but our position is that it is the nonequivalence in this nucleonic gravitational binding effect that gives rise to hyperphoton emission quantified by the term $\dot{\eta}_{\oplus,\gamma}$.

Further support for identification of our expression for the fine structure constant (Soldano 1985) with the empirical term α in Eq. (2) arises from the fact that Eq. (3) also contains the term $\dot{\xi}_{\oplus,e^-}$, which represents the fractional difference between ephemeris and atomic time, Eq. (7),

$$_N\dot{\xi}_{\oplus,e^-} = (dt_{\text{ephemeris}} - dt_{\text{atomic}})/(t - t_0)\ dt_{\text{atomic}}$$
$$= 0.1090 \times 10^{-11}/\text{year} \qquad (7)$$

where t_0 is any initial *atomic* time. The value of our constant $\dot{\xi}_{\oplus,e^-} = 0.1090 \times 10^{-11}$/year, based upon the latest value of the fine structure constant, compares favorably with Heilings' upper limit of $\dot{\xi}_{\oplus,e^-} \leqq (0.1 \pm 0.8) \times 10^{-11}$/year (Heilings et al. 1983).

We wish to emphasize that the term $_N\dot{\xi}_{\oplus,e^-}$ has a direct connection with strict equivalence of inertial and gravitational mass. This is consistent with our interpretation of the term $\dot{\eta}_{\oplus,\gamma}$ (which describes a spin-orbital nonequivalence effect) as a deviation from strict equivalence, which, of course, is the central premise of our entire theory. The first connection of $_N\dot{\xi}_{\oplus,e^-}$ with strict equivalence follows from the fact that ephemeris time (Heilings' Einstein dynamic time) is that experimental time that defines the motion of the Earth's mass about the Sun, subject to the requirement that the gravitational attractive force between the masses of the Sun and the Earth is exactly balanced by the inertial mass force that quantifies the Earth's attempt to escape from the solar system. This gravitational-inertial mass equality underlies our designation of the term N in $_N\dot{\xi}_{\oplus,e^-}$.

On the other hand, atomic time is ultimately traceable to the vibrational motion of the electron (designated as e^- in $_N\dot{\xi}_{\oplus,e^-}$). The motion of the electron creates virtual *gravitationally unbound* photons. This *unbound* radiation must also obey strict equivalence between inertial and gravitational mass, since our theory requires that only gravitationally-bound mass violates strict equivalence. It follows, therefore, that the term $_N\dot{\xi}_{\oplus,e^-}$ arises from the fact that the nucleon's mass participating in the Earth's orbital motion of the Sun and the gravitationally *unbound* radiation related to the electronic nature of the Earth's atoms, both are obeying essentially strict equivalence between inertial and gravitational mass.

It should be noted that the substitution of Eq. (3) for the empirical α in Eq. (2) introduces an expression containing both macroscopic and microscopic quantities. The latter is particularly relevant since the non-Newtonian expression in Eq. (2) describes the gravitational potential energy over the entire range of r values. This requires that atomic time factors encountered at short range and ephemeris time factors dominant at long range be properly combined over the entire range of r values. Furthermore, the entire basis of ephemeris time, namely, the Earth's orbital period about the Sun, is a key component of the Earth-light aberration effect inherent in $\dot{\eta}_{\oplus,\gamma}$ Eq. (4).

The specific connection between Fischbach's hypercharge coupling f^2 and our gravitational binding nonequivalence is detailed by our substitution of the ratio [1 rad $\dot{\eta}_{\oplus,\gamma}/2\ \pi\ \dot{\xi}_{\oplus,e^-}$] for α in the Fischbach relationship, Eq. (8)

$$f^2/G_0\ m_p^2 \cong \alpha/(1 + \alpha) \qquad (8)$$

where m_p is the mass of a nucleon, thereby yielding Eq. (9).

$$\left[f^2\left(\frac{1 \text{ A.U.}}{c}\ \dot{\xi}_{\oplus,e^-}\ 2\pi\right) \omega_{\oplus,\text{orbit}} \frac{1+\alpha}{(1-e_\oplus^2)^{1/2}}\right] + \left[G_0 m_p^2 f_{g_\oplus}\left(\frac{m_i - m_G}{m_G}\right) \hat{\mathbf{u}}_n \cdot \vec{\boldsymbol{\omega}}_{\ominus,\text{spin}}\right] \cong 0 \qquad (9)$$

We note a complete symmetry between the bracketed terms in Eq. (9). For example, the product of Fischbach's hypercharge coupling f^2 and $\dot{\xi}_{\ominus,e^-}$, times the minimum time required to send a signal to our local center of gravitational mass, the Sun, (1 AU/c), is analogous to $[G_0 m_p^2 f_{g_\oplus} (m_i - m_G)/m_G]$ in the other bracket of Eq. (9). Further, both brackets involve either a spin or orbital angular velocity. Eq. (9) clearly suggests that the hypercharge coupling f^2 originates in gravitational binding nonequivalence $f_{g_\oplus} (m_i - m_G)/m_G$.

An additional argument for use of our terrestrial frame, nonequivalence description of α in both Eqq. (2) and (8), lies in the discrepancy noted between Fischbach's higher (by a factor of 16.4) estimate of the magnitude of the hypercharge $f^2 = (4.6 \pm 0.6) \times$

$10^{-42} \times e^2$ based solely upon fitting the Eötvös data, and another set of coupling values [$f^2 = (2.8 \pm 1.5) \times 10^{-43}\, e^2$] obtained by fitting Eq. (2). He attributes the discrepancy between the two estimates to hypercharge distribution effects. However, it should be noted that the time term $\dot{\xi}_{\oplus,e^-}$, which is a multiple of f^2—see Eq. (9)—is 21.8 times larger than the $\dot{\eta}_{\oplus,\gamma}$ term which contains the nonequivalence effect of our reference frame. Fischbach's graphical analysis of the Eötvös results, using the term [$f^2/G_0\, m_p^2\, a$], with a an empirical numeric, could implicitly involve [$f^2\, \dot{\xi}_{\oplus,e^-}/\dot{\eta}_{\oplus,\gamma} = f^2_{\text{Eötvös}}$]. This would have the effect of increasing the Eötvös hypercharge coupling estimates by a factor of 21.8, an increase comparable to the factor 16.4 encountered by Fischbach.

On the basis of the preceding arguments, we propose to substitute our nonequivalence time relationship in Eq. (3), [*Eq. (3) retains the invariance with planetary reference point that the quantum* $\alpha = e^2 / \hbar c$ *possesses*], for the empirical α term into Eq. (2), thereby leading to Eq. (10).

$$V(r) = -\frac{m_1 \times m_2}{r_{12}} G_\infty \left[1 + \frac{1 \text{ rad}\ \dot{\eta}_{\oplus,\gamma}}{2\pi\ \dot{\xi}_{\oplus,e^-}} \exp\left(\frac{-r/c}{\lambda/c}\right)\right] \quad (10)$$

This implies that hyperphotons generated by nonequivalence in gravitational binding, and described by the term $\dot{\eta}_{\oplus,\gamma}$, mediate the gravitational process quantified by $\Delta V(r)$. Further, it suggests that terms such as the angular spin of the Earth, $\omega_{\oplus,\text{spin}}$, and its orbital counterpart, $\omega_{\oplus,\text{orbit}}$, that are inherent in $\dot{\eta}_{\oplus,\gamma}$, also are playing a role in this process. In addition, the aforementioned time term, $\dot{\xi}_{\oplus,e^-}$, is also involved.

S. Weinberg has shown that hyperphoton coupling is exponentially dependent on the range λ (1964). Gravitational complementary field arguments based strictly on nonequivalence permit us to estimate the size of λ (Soldano 1985). McCrea's gravitational binding argument requires that the Earth's Schwarzschild radius $2L_\oplus$ be the gravitational component of the range λ. We propose that $R_{\oplus c,\text{barycenter}}$, the distance between the center of mass of the Earth and the barycenter of the Earth-Moon system, be the inertial component of λ. Combining these inertial and gravitational lengths, that is, $\lambda = (2\, L_\oplus\, R_{\oplus c,\text{barycenter}})^{1/2}$, one obtains a value for $\lambda = 203.34$ meters, since $R_{\oplus c,\text{barycenter}} = 0.7325\, R_\oplus$ (Soldano 1985). The resultant gravitational complementary field length defines a range well within the empirical estimate of that required by both Stacey's and Fischbach's fits.

There exists independent confirmation of our description of both α and λ. The $\dot{\eta}_{\oplus,\gamma}$ term in the numerator of α not only contains a terrestrial gravitational binding nonequivalence term that requires the use of the Schwarzschild radius in defining the range λ (McCrea 1964), but it suggests that this nonequivalence term in α is affecting the Earth's spin $\omega_{\oplus,\text{spin}}$ in Eq. (4). Further, the presence in λ of the inertial term, $R_{\oplus c,\text{barycenter}}$, the distance from the Earth's center of mass to the Earth-lunar barycenter, implies that the orbital motion of the masses of both the Earth and the Moon is also involved. Further, the existence of the lunar-Earth orbital velocity (about the Sun) $v_{\oplus,\text{orbit}}$ in $\dot{\eta}_{\oplus,\gamma}$, as well as $\hat{\mathbf{u}}_{n,\text{orbit}}$, implies that the range λ involves all three bodies, Sun, Earth, and Moon. The 29.53-day synodic orbital period of the Moon describes a conjunction of these same three bodies. Significantly, the ratio of the time associated with the range, that is, $\lambda/c = 6.78 \times 10^{-7}$ second, when divided by the lunar synodic month ($P_c = 29.53$ days), is directly related to another very important time ratio. Specifically, it is precisely 0.563 of the fractional decrease in the spin rate of the Earth which, according to Allen, is 0.0015 sec/century (1976). It has long been known that the conventional tidal explanation can account for only slightly less than one half of the actual slowdown in universal time (UT1). Our description of both α and λ involves factors which suggest that it is gravitational binding nonequivalence that accounts for the remaining 56 percent of the decrease in the angular spin velocity of the Earth.

Our preliminary conclusions are that a nonequality in gravitational binding mass has the effect of introducing into Newton's universal law of gravitation an additional term that represents a detailed compendium of information on our terrestrial reference frame. From a field standpoint, a variation in G is expected to follow from the fact that the four forces: strong, electromagnetic, weak, and gravitation, are considered to be different aspects of a single force (which, from our point of view, is the nonequality in gravitational binding and a related difference between ephemeris and atomic time). The existence of such a unification force leads to a deviation in the value of G from that required by Newtonian mechanics. To further elucidate this point, we now examine the role of time in Newtonian mechanics and its relevance to α [bracketed expression in Eq. (10)].

Role of Time

A fundamental difficulty with the universal law lies in the fact that Newton treated time as an absolute concept; that is, the implicit assumption that one can determine unambiguously the simultaneity of two events. This, however, would require that two observers be in instantaneous communication. Synchronization of the two clocks needed to measure simultaneity requires that the signal transmission time in one direction be measurable. To devise such an experiment requires the introduction of a new experimental idea for its verification, or a new concept such as mass nonequivalence in gravitational binding. To show how this is achieved requires that we briefly analyze the concept of time itself.

There are only two fundamental time relations in a relativistic universe (Capek 1961): (1) successive causal connections; and (2) contemporary causal independence or acausality. What we sometimes call *spatial distance*, that is, r_{12} in Eq. (10), is really measured by the duration of the corresponding causal links. For instance, if the Sun is closer to us than Neptune, it is so because the Sun is only 8 light minutes away, while Neptune is 4 light hours away. The time r/c in Eq. (10) represents a *causal time connection*.

The second feature is the time interval of *causal independence or acausality*. The length of this interval measures the degree of indeterminacy concerning the simultaneity of spatially separated events. For the Sun-Earth, this interval is 16 minutes. It is always double the duration of the corresponding causal time link. In a theory based on nonequivalence in gravitational binding, however, additional intervals of causal independence or acausality are required. This should not be a cause for concern, since our previous work and our present construct for λ, Eq. (10a), demonstrate that time acausalities arising from mass nonequivalence in gravitational binding can be treated mathematically in a causal fashion, leading to solutions to fundamental problems in physics (Soldano 1985). Precedence for the use of time acausalities already exists in the Heisenberg uncertainty principle. There, uncertainties are used to obtain, for example, the half-life of a decaying species.

Operationally, the time acausalities required by gravitational binding mass nonequivalence involve taking the geometric average of a gravitational time acausality such as that given by the Earth's Schwarzschild length, that is, $[2L_\oplus/c]$ and an inertial time acausality, that is, $[a_L/c]$, where a_L is the separation distance of an orbiting satellite from the Earth's center of mass.

In the specific application of this approach to the calculation of the range λ in Eqq. (9) and (10), we used the geometric average of a time acausality associated with the Earth's gravitational Schwarzschild radius $[2\ L_\oplus/c]$ and an inertial time acausality defined by $(R_{\oplus c,\mathrm{barycenter}}/c)$, Eq. (10a).

$$\begin{aligned}\lambda/c &= [(2L_\oplus/c)\ (R_{\oplus c,\mathrm{barycenter}}/c)]^{1/2}\\ &= 203.34\ \text{meters}/c \end{aligned}\tag{10a}$$

The causal time, r/c, inherent in Eq. (10) is a measure of the minimum time required to send a one-way gravitational signal with velocity c from our terrestrial reference frame to the point under consideration. An expansion of the exponential in Eq. (10) shows that this time is associated with the time correction introduced by the fractional difference between ephemeris and atomic time; that is, $[2\ \pi\ \dot{\xi}_{\oplus,e^-}]$. There are several ways in which a difference between ephemeris and atomic time occurs (Heilings et al. 1983). One of them could arise from a time dependent variation in G due to a cosmic field (to be discussed later) that affects the form of the physical metric tensor. A second might be attributed to the existence of a cosmic field that affects atomic processes and not those that are macroscopic. In the present case, the cosmic field is manifested by the universal nonequivalence term $(m_i - m_G)/m_G$. It is clear because Eq. (2), with a variable G (which could arise from both a range dependency *and* a time dependency), would also require the existence of a difference between ephemeris and atomic time; that is, a nonzero $\dot{\xi}_{\oplus,e^-}$.

Electronic factors inherent in $\dot{\xi}_{\oplus,e^-}$ are playing a key role in defining the constant α, and are therefore helping to fix the magnitude of the range dependency of G. We shall now rewrite Eq. (10) by introducing the specific elements of both $\dot{\eta}_{\oplus,\gamma}$[Eq. (4)] and $\dot{\xi}_{\oplus,e^-}$ [Eq. (7)] into Eq. (10) in order to detail the nature of the terms that comprise α.

(It should be noted that in the interest of simplicity, we have dropped out the conversion factor of 2.06265 $\times\ 10^5$ arc seconds per radian.)

$$\begin{aligned} V(r) &= -G_\infty \frac{m_1\, m_2}{r_{12}} \\ &\times \left[1 + \left(\frac{f_{g_\oplus}\ [(m_i - m_G)/m_G]\ (\hat{\mathbf{u}}_n \cdot \overrightarrow{\boldsymbol{\omega}}_{\oplus,\mathrm{spin}})}{[v_{\oplus,\mathrm{orbit}}/c(1 - e_\oplus^2)^{1/2}]\ [(dt_{\mathrm{eph}} - dt_{\mathrm{at}})/dt_{\mathrm{at}}]\ \omega'}\right) \right. \\ &\qquad \left. \times \exp\left(\frac{-r/c}{[(2L_\oplus/c)\ (R_{\oplus c,\mathrm{barycenter}}/c)]^{1/2}}\right)\right] \end{aligned}\tag{11}$$

where $2\ \pi\ \dot{\xi}_{\oplus,e^-} = [(dt_{\mathrm{ephemeris}} - dt_{\mathrm{atomic}})/dt_{\mathrm{atomic}}] \times [2\ \pi/(t - t_0)]$ with t_0 any initial atomic time. The term $[\omega' = 2\ \pi/(t - t_0)]$ converts electronic or atomic time vibrational motion into a spin ω'. The range exponential in Eq. (11) increases the fractional difference between ephemeris and atomic time. The Lorentz invariant Doppler one term $(v_{\oplus,\mathrm{orbit}}/c)$, where $v_{\oplus,\mathrm{orbit}}$ is the basis of ephemeris time, represents a perturbation of ω'.

The remaining terms in Eq. (11) involve the specifics of spin-orbital perturbations. In the numerator, we have a nonequivalence perturbation of the unit vector normal to the ecliptic plane $\hat{\mathbf{u}}_{n,\mathrm{orbit}}$ (a monitor of the orbital motion of the Earth about the Sun) coupled to the Earth's spin $\omega_{\oplus,\mathrm{spin}}$. In the denominator we have a fractional time perturbation of the orbital velocity of the Earth about the Sun $v_{\oplus,\mathrm{orbit}}$, coupled to the "intrinsic spin" (ω') of the vibrating electron.

Thus, Eq. (11) suggests that α is due to two spin-orbital, time acausality perturbations. The terrestrial gravitational binding mass nonequivalence operating on ($\omega_{\oplus,\text{spin}}$) constitutes a spin-orbital perturbation of the basis of universal time. The spin-orbital perturbation in the denominator involves both atomic and ephemeris time. Thus we are led to conclude that the range dependent shift in the magnitude of G has its origin in the manner in which these three different time scales used in physics (ephemeris, atomic, and universal) implicitly enter into scientific description. Clearly, the entire correction term is based on a new, detailed delineation of the role of time in Newton's universal law, and therefore stands in sharp contrast with the Newtonian concept of absolute time.

Alternative Description of α in Eq. (11)

A fractional time difference represented by $\dot{\xi}_{\oplus,e^-}$ in Eq. (10) implies a time dependency of the gravitational constant G (Heilings et al. 1983). If we take cognizance of the fact that the two-way time acausality is twice the one-way causal time, we are led to conclude that the following relationship obtains, Eq. (12):

$$\dot{G}/G \cong \dot{G}_0/G_\infty = 2\,\dot{\xi}_{\oplus,e^-} = (0.218 \times 10^{-11})/\text{year} \qquad (12)$$

Significantly, Heilings et al. (1983) suggest that the upper limit for any time dependency in G is $\dot{G}/G \leqq (0.2 \pm 0.4) \times 10^{-11}$/year. Further, the remaining π in ω' [Eq. (11)] can be combined with the 2π in ($v_{\oplus,\text{orbit}} = 2\pi\, r_{\oplus-\odot}/P_{\oplus,\text{orbit}}$) thereby leading to an equivalent expression for the α used in Eq. (11) in the inner bracketed term, which enables one to calculate $\dot{G}_0/G_\infty$ for any planetary reference frame.

$$\frac{\dot{G}_0}{G_\infty} = -\frac{c_\gamma f_{g_\oplus}\,[(m_i - m_G)/m_G]\,(\hat{\mathbf{u}}_n \cdot \omega_{\oplus,\text{spin}})\,r^2_{\oplus-\odot}}{\langle \pi^2 r^3_{\oplus-\odot}\rangle\,(\alpha)\,[(P_{\oplus,\text{orbit}})^{-1} = \nu_\oplus]\,(1 - e^2_\oplus)^{-1/2}} \qquad (13)$$

The bracketed volume in the denominator of Eq. (13) represents a four-dimensional, Riemannian geometric elliptic volume, one consistent with the equivalence principle of general relativity. Further, the value of the mass inherent in the product of the denominator term where α is replaced by $\dot{G}_0/G_\infty$ is precisely that associated with the Earth's gravitational self-energy ($G\,M^2_\oplus/R_\oplus$) reduced by the ratio ($R_\oplus/r_{\oplus-\odot}$).

The latter ratio allows for the separation of the Earth from its local center of gravitational mass, the Sun.

The numerator of Eq. (13) now describes the details of a hyperphoton perturbation of the velocity of light c due to nonequivalence in gravitational binding. It should be noted that the nonequivalence term in the numerator $f_{g_\oplus}\,[(m_i - m_G)/m_G] = 2.3 \times 10^{-21}$ is not only comparable to the lower experimental limits for any charge asymmetry between the proton and the electron (Hughes 1969), but it is multiplied by the spin of the Earth. It was precisely a spin-dependent, charge asymmetry mechanism that Blackett (1947 and 1949) argued both should be a part of any explanation of the gravitational constant and should play a role in any unification scheme for the four forces.

Planetary Dependence of $\dot{G}_0/G_\infty$

On the basis of Eq. (13), there is reason to believe that changes in the time dependency of G, that is, $\dot{G}_0/G_\infty$, are also planetary dependent. This follows from the observation that since α in Eq. (13) is an invariant fixed by the quantum $e^2/\hbar c$, the wide variation in the planetary values for f_{g_i}, spin, spin axis orientation and location, ensures a broad variation in $\dot{G}_0/G_\infty$. Brantley (private communication) has found, based on Eq. (13), that $\dot{G}_0/G_\infty$ values for the nine planets, plotted in Figure 1 in their order relative to the Sun, vary in a smooth cyclic fashion that resembles two giant, gravitational, terrestrial and Jovian resonances, in spite of changes in $\dot{G}_0$ of over 10 orders of magnitude. These planetary variations in $\dot{G}_0/G_\infty$, stand in sharp contrast to the elements that comprise G_∞. The latter will be shown to lack any explicit time dependency, contrary to the theories proposed by Dirac et al. (1938).

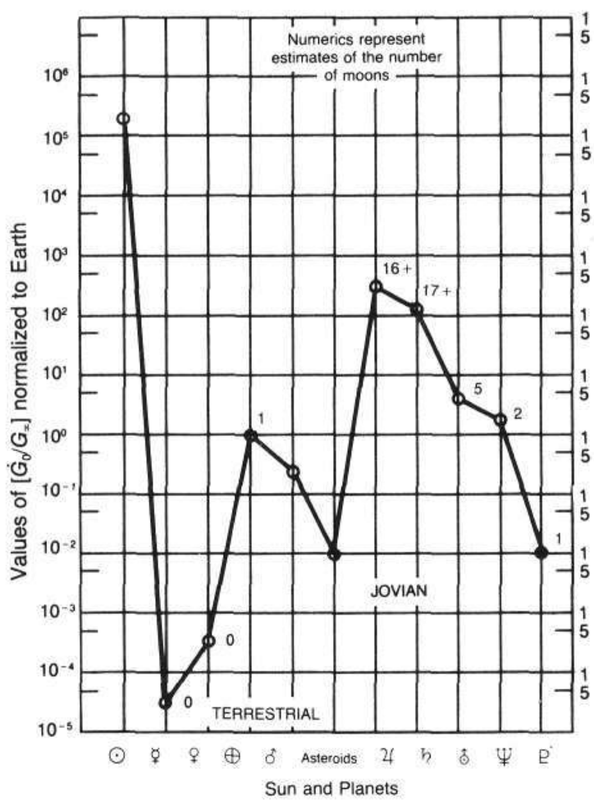


Figure 1. Planetary variations in $\dot{G}_0/G_\infty$. Based on Eq. 13, the $\dot{G}_0/G_\infty$ vary, in a smooth cylic fashion that resembles two giant gravitational terrestrial and Jovian resonances in spite of changes in $\dot{G}_0$ of over 10 orders of magnitude.

Derivation of G_∞

Eqq. (10) and (11) suggest that the size of the range dependency of Newton's gravitational constant G is fixed by a ratio of times whose magnitude is equal to that of the fine structure constant $\alpha = e^2/\hbar c$. Further, the range of these spin-orbit interactions is defined by a Yukawa-type range exponential. Significantly, the magnitude of the range λ is obtained by taking the geometric average of two lengths: the geometric averaging being a prerequisite of a model based on a general gravitational binding mass nonequality. Three elements—α, terms of the form $e^{(\ \ )^{1/2}}$, and nonequivalence—are shown to be required to explain range dependency. Therefore, in search of a description of Newton's G at $r = \infty$, that is, G_∞, it is reasonable to test the applicability of the functional form $[\alpha/e^{(\ \ )^{1/2}}]$. It is the value of G designated as $G_\infty = (6.734 \pm 0.002) \times 10^{-8}$ that is invariant as in Eq. (2). Specifically, if the second term in Eq. (11) accounts for the time component of a four-dimensional matrix, it is reasonable to test the applicability of the electrical variant of the fine structure constant, that is, $\alpha = e^2/\hbar c$, to account for each of the remaining three *spatial* dimensions of our four-dimensional space-time description of Newton's universal gravitational constant, Eq. (11).

In contrast with the *local* environmental range (λ) and time dependency ($\dot{G}_0$) of the minute component [second term, Eq. (11)] of Newton's constant, the invariant component G_∞ must be related to the *universe*. Sciama (1957) has suggested that G might represent an implicit estimate of the mass density of the universe. Significantly, he noted that the apparent local environmental independence of the electron may be masking an intimate link of the electron with the entire Machian universe. The presence of the fractional difference between ephemeris and electronic or atomic time, $(dt_{\text{eph}} - dt_{\text{at}})/dt_{\text{at}}$ in our time equivalent of the fine structure constant in Eq. (11), further suggests a role for the electron in the description of the invariant component of the Newtonian gravitational constant.

A premise, therefore, that we shall use in obtaining an estimate of G_∞ is that the electron is the vehicle by which the *invariant* inertial mass effects of the universe are manifested locally. *Specifically, it is the ratio of the time allotted to an electronic transition, T, relative to the lifetime, τ, of the excited state that essentially determines the order of magnitude of G_∞.* Obviously, even the minute local correction to Newton's gravitational constant in Eq. (11) is also related to the properties of charge. A key element in determining G_∞, therefore, involves an effect analogous to that encountered in the interaction of electrons with electromagnetic radiation. It has long been known (Born 1935) that the transition period T for an electronic transition relative to the atom's excited state lifetime τ is given by Eq. (14)

$$T/\tau \cong \alpha^3 \tag{14}$$

where $\alpha = e^2/\hbar c$. The weak coupling (α^3) between the excited atom and the ether makes it possible to distinguish atoms from the surrounding ether. Due to nonequivalence, a quantum coupling of $[e^2/\hbar c]$ to each of the three other coupling constants, expressed by the exponential $e^{(\ \ )^{1/2}}$, transforms the time ratio in Eq. (14) into one that exactly defines the size of G_∞. Field theorists have long expected a variation in G based on their belief that the hierarchy of four forces—gravitation, electromagnetism, weak and strong—are at some basic level, all elements of a new general interaction, which we have already claimed is the gravitational binding mass nonequality interaction. This means that gravitational binding nonequivalence should facilitate the coupling of $[e^2/\hbar c]$ to the other three forces. The probability that a charge coupling $(e^2/\hbar c) = (1/137.0360)$ could interact with the strong baryon coupling $(q^2/\hbar c) = 14.60$, thereby leading to a reduction of α in Eq. (14), is given by the exponential function $\exp[(e^2/\hbar c)\,(q^2/\hbar c)]^{1/2}$. We therefore propose to reduce the ratio given by Eq. (14) by a generalized charge "range" term involving "forbidden" coupling of the electromagnetic charge in $\alpha = e^2/\hbar c$, to the charges responsible for the remaining three forces, that is, the short range baryonic strong and weak, and the long range gravitational force. The resultant exponentials behave in a manner analogous to the f numerics encountered in quantum theory (Born 1935), which act as multiples of the lifetime of the excited state τ, Eq. (14).

For the baryonic strong force we will use the coupling constant $(q^2/\hbar c) = 14.60$ obtained from a study of meson-nucleon interactions (Kokkedee 1969). For the weak interaction we use the renormalized coupling constant, that is, $(G_F/\hbar c)\,(m_N c/\hbar)^2 = 1.01 \times 10^{-5}$, where G_F is the Fermi coupling constant and m_N, the mass of a nucleon. For the gravitational coupling of the baryon we use $[G\, m_N^2/\hbar c = 5.89 \times 10^{-39}]$. We therefore propose that due to nonequivalence in gravitational binding the Newtonian gravitational constant at $r = \infty$ should (except for gravitational mechanistic factors) be determined by Eq. (15).

$$G_\infty \stackrel{?}{=} \alpha^3 \Big/ \left[\exp\left(\frac{e^2}{\hbar c}\frac{q^2}{\hbar c}\right)^{1/2} \exp\left(\frac{e^2}{\hbar c}\frac{G_F m_N^2 c}{\hbar^3}\right)^{1/2} \exp\left(\frac{e^2}{\hbar c}\frac{G_\infty m_N^2}{\hbar c}\right)^{1/2}\right] = \frac{T}{\tau} \tag{15}$$

Equation (15) implies that at $r = \infty$, each exponential has reduced the fine structure constant by the participation of the electromagnetic force in a forbidden coupling with each of the three remaining forces. The resultant *leakage* of the strong and weak, short range force gives rise to the long range, attractive force associated with electromagnetism and gravitation. The magnitude of every term (except q) in Eq. (15) is known to a high degree of accuracy. Clearly, the value of G_∞ calculated by Eq. (15) will be influenced by the magnitude of the baryonic charge q used in Eq. (15). Using $q^2/\hbar c = 14.60$ in Eq. (15), one obtains a value of G_∞ precisely $[4 \times 1.04089]$ times higher than the experimental estimate of $G_\infty = (6.734 \pm 0.002) \times 10^{-8}$.

We are well aware of the difficulty in establishing the magnitude of q, to the precision suggested by these numbers, by the use of standard perturbation techniques. However, recent developments in meson physics (Kokkedee 1969) suggest that the mesic estimate of $q^2/\hbar c = 14.60$ does in fact represent a high level of precision. This suggests that there must exist a precise reason for the disparity of $[4 \times 1.04089]$ between the value of G_∞ calculated by our expression in Eq. (15), and that obtained by experiment.

The Mechanism of Gravitation A Resolution of the Disparity

To this point we have not considered the mechanism of gravitational transmission. Like Samuel (1950), we believe that the transmission of gravitation leading to attraction is a two-step process, separable in *location* and *kind*.

The fact that Newton's law of gravitation describes an attraction between two masses separable in *location* introduces an element of acausality that is twice the distance separating their centers of mass. If the second term in Eqq. (10) and (11) represents the *causal* element of a gravitational interaction, which is represented by the term (r/c) in the exponential, then it is highly probable that the term describing G at $r = \infty$, G_∞, accounts for the *acausal* element of this force of attraction. We have already noted that, in describing an interaction between any two bodies separated in *location*, a fundamental time acausality must be accounted for, which is twice the time required to transmit a signal from one mass to the other. It follows therefore that a factor of $2r_{12}$ obtains for each mass, since each is the source of attraction and is itself attracted. The resultant product automatically introduces a factor of 4 in the denominator of the force equation, which has automatically been incorporated in the empirical Newtonian constant G_∞.

The second step results when a continuum stream of spherical gravitational waves of great penetration spreads out from one mass and encounters another. There an interaction, due to binding nonequivalence, takes place which causes the affected mass to act as a secondary source. Of course, each of two interacting masses acts as both a primary and secondary source, so that the resulting superposition, involving to reinforcement behind each mass, leads to a resultant attraction. This process, which will be shown to account for the remaining disparate factor of 1.043364, is describable in terms of a simple two-slit diffraction equation.

If we consider each mass as a diffraction slit, then the overall diffraction process for two masses is analogous to the problem of double-slit interference, Figure 2. The diffraction disturbances arriving at point P from S_1 and S_2 are different in amplitude for two reasons. First, the distances r_2 and r_1 are different and the amplitude generated by an expanding spherical distribution falls off with increasing distance from the source. When $r \gg d$ (that is, $r \rightarrow \infty$), where d is the distance between the two slits, the condition for maximum interference becomes

$$r_2 - r_1 = d \sin \theta_n = n \lambda \qquad (16)$$

where n is any integer. If we identify the slit separation d with Newton's r separation between the two centers of mass, it follows that the diffracted gravitational wavelengths are given by Eq. (17).

$$r/n = \lambda/\sin \theta_n \qquad (17)$$

Both electromagnetic and gravitational forces are proportional to r^2; a complete description of the diffraction processes, therefore, requires the geometric average of the diffracted wavelengths for each mass involved; that is, $[(r/n)^2 \, (r/n)^2]^{1/2}$. Since the description requires a summation involving integers ranging from $n = 1$ to $n = \infty$, the resultant total sum is

$$\left[\sum_{n=1}^{\infty} (r/n)^2 \, (r/n)^2\right]^{1/2}.$$

Since the same averaging holds for any value of r, we can abstract the values of r^2 from the above expression, thereby obtaining Eq. (18)

$$\left[\sum_{n=1}^{\infty} (1/n^4)\right]^{1/2} = 1.043364 \qquad (18)$$

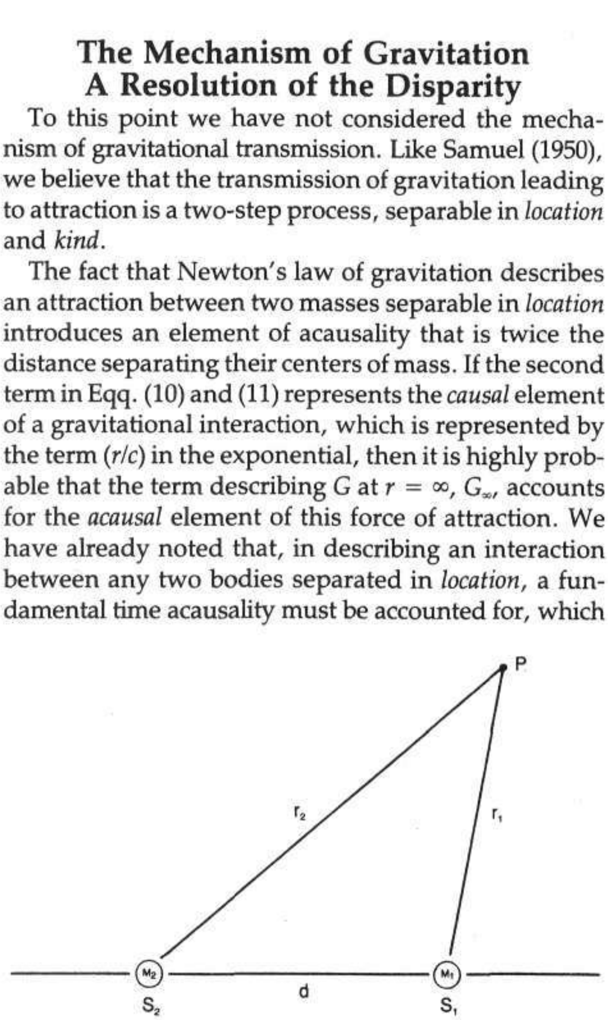


Figure 2. Double slit interference. The diffraction disturbances arriving at point P from Si1 and S_2 are different in amplitude because the distances r_2 and r_1 are different and the amplitude generated by an expanding spherical distribution falls off with increasing distance from the source.

which gives the remaining missing factor of 1.043364 required by Eq. (15). Thus the complete description of G_∞ is given by Eq. (19).

$$G_\infty = \alpha^3 \bigg/ \left[4\left(\sum_{n=1}^{\infty} \frac{1}{n^4}\right)^{1/2} \exp\left(\frac{e^2}{\hbar c}\frac{q^2}{\hbar c}\right)^{1/2} \times \exp\left(\frac{e^2}{\hbar c}\frac{G_F m_N^2 c}{\hbar^3}\right)^{1/2} \exp\left(\frac{e^2}{\hbar c}\frac{G_\infty m_N^2}{\hbar c}\right)^{1/2} \right] \tag{19}$$

Significantly, the value of G_∞ obtained by Eq. (19) deviates from the experimental value of $G_\infty = (6.734 \pm 0.002) \times 10^{-8}$ by no more than 27 parts in over 100,000.

Planetary Dependence of the Range Term

In spite of the fact that α for the second term is an invariant, Eq. (11) suggests that different planetary reference frames should have slightly different contributions to Newton's gravitational constant. This follows from the fact that they certainly possess different Schwarzschild radii, thereby leading to different values for the range λ in Eq. (10a). Variations in λ will lead therefore to slightly different values of G on other planetary reference frames.

Planetary Dependence of the $\dot{G}_0$ Terms

Eqq. (12) and (13) and Figure 1 suggest that the planetary dependence of the range term is also time dependent. For example, the mass $[h\,(\dot{G}_0/G_\infty)/c^2]$ associated with the peak in Figure 1 represented by the Earth, that is, 0.51×10^{-66} gram, is considerably smaller than the upper limit for the graviton mass estimated by Davis et al. (1975) at 2×10^{-62} gram, and by Yamaguchi et al. (1965) at 5×10^{-62} gram. On the other hand, the graviton mass associated with $\dot{G}_{0,\odot}$ for the Sun ($\sim 10 \times 10^{-62}$ gram) is comparable to both of their estimates. It is conceivable that solar reference frame, gravitational resonance fluctuations in the mass of the graviton associated with $(\dot{G}_0/G_\infty)$ that accompanied the protoplanet stage, could have introduced the necessary instabilities in the accretion disk surrounding the proto-Sun that led to the present distribution of planetary masses, locations, spins, inclinations, and orbital motions. [See Eq. (13).] Clearly, Bode's law for planetary location would have been one aspect of this effect. It should be reiterated that these reference frame time dependencies in G_0 as applied to celestial bodies are affecting a very minor fraction of the Newtonian gravitational constant, that is, $\sim 1/137$.

Alternative Spin Interpretation of G_∞

The term G_∞ can now be reinterpreted in a highly compelling spin-two ($2\,\hbar$) graviton format. We simply rearrange Eq. (19) by converting one of the α terms into $(e^2/2\,\hbar c)$ by transposing the term $(2r_{12})^2$ into $2r_{12}^2$. The latter step implies that only one passive-active gravitational mass pair is now being considered in arriving at the term $2r_{12}^2$. Converting one of the α terms to $(e^2/2\hbar c)$ enables one to attribute the process of gravitational attraction to spin-two graviton exchange. Further, the decomposition of the graviton ($2\,\hbar \rightarrow \gamma + \gamma$) into two spin-one photons ($1\,\hbar$) would not only account for the α^2 term, but the process would also justify interpreting G_∞ as a measure of the reduced efficiency of graviton exchange resulting from graviton decay. Further, Rosen (1962) has already shown that a graviton cannot decay *directly* into two photons. It follows, therefore, that the two spin-*one* coupling transition terms in Eq. (19), that is, $\exp[(e^2/\hbar c)(q^2/\hbar c)]^{1/2}$ and $\exp[(e^2/1\hbar c)\,(G_F\, m_N^2/1\hbar c)]^{1/2}$ constitute a description of the nucleonic processes whereby the two spin-one photons are obtained following the decomposition of the graviton. The remaining exponential in Eq. (19) must now, however, be altered to read $\exp[(e^2/2\hbar c)\,(G_\infty m_N^2/2\hbar c)]^{1/2}$, since this transition strictly pertains to the spin-two graviton. This change is mathematically strictly symbolic, since the latter exponential is equivalent to e^0 to approximately one part in 10^{20}. This strictly gravitational transition, however, can now be interpreted as representing the decay of the spin-two graviton ($2\,\hbar$) by the baryon nonconserving process of $2\,\hbar + p^+ \rightarrow 2(p^+ + e^-) + p^+$, whereby a spin-two graviton is converted into two spin-one $(p^+ + e^-)$ terms (Brock, 1965).

Finally, the introduction of the spin-two graviton into the range term of Eq. (20) leads to the interpretation of that term as representing the decay of the graviton due to nonequivalence in gravitational binding.

A Gravitational Mechanism for the Formation of a Hyperphoton

In light of Eqq. (10), (11), and (15) we can write a complete force expression for Newton's universal law that illuminates the role of the spin-one ($1\,\hbar$) hyperphoton inherent in our expression for α. Special emphasis will be focused on its relationship to the electronic ratio T/τ in Eq. (15) that fixes the order of magnitude of G_∞. We simply rewrite the factor 2π in the term $2\pi\,\dot{\xi}_{\oplus,e^-}$ in Eq. (10) as the ratio of Planck's constant h divided by the unit of angular momentum, $1\,\hbar$, for a spin-one hyperphoton. The above enables one to rewrite the scalar expression for the force of gravity, referenced to the Earth, so as to include a quantum role for our classical expression for α.

$$F = -\frac{m_{1,G}\, m_{2,G}}{(2r_{12})^2 \left(\sum_{n=1}^{\infty} n^{-4}\right)^{1/2}} \frac{T_{e_1^- \to e_2^- + \gamma}}{\tau}$$
$$\times \left[1 + \frac{(1\hbar)\, c f_{g_\oplus} \left[(m_i - m_G)/m_G\right] (\hat{\mathbf{u}}_{n_\oplus} \cdot \omega_\oplus)}{v_\oplus/(1 - e_\oplus^2)^{1/2}\, h\, {}_N\dot{\xi}_{\oplus,e^-}} \times \exp\left(\frac{-r}{(2L_\oplus\, R_{\oplus,\mathrm{barycenter}})^{1/2}}\right)\right] \tag{20}$$

We have explicitly represented the electron transition time T in Eq. (15) as $T_{e_1^- \to e_2^- + \gamma}$ in order to show that any electronic transition that accompanies a change in the electron's potential energy will result in the emission of a photon. The resulting spin-one hyperphoton ($1\ \hbar$) in Eq. (20) undergoes a terrestrial spin-orbit gravitational binding mass perturbation due to mass nonequivalence, the range of this nonequivalence effect being fixed by $(2L_\oplus R_{\oplus c,\mathrm{barycenter}})^{1/2}$.

Our expression for the range suggests that the hyperphoton is not only linked to the Schwarzschild radius, but it is also perturbed by the orbital motion of the Earth's satellite, the Moon.

The lifetime of the excited state, τ, in the denominator of Eq. (20) determines the time interval over which the quantum orbital energy, $(h\ {}_N\dot{\xi}_{\oplus,e^-})\ v_\oplus$, operates. It should be noted that we have added a subscript N to the fractional time difference between ephemeris, or dynamic time (also called Einstein time by Heilings) and atomic or electronic time, which we have previously to this point in the paper designated as $\dot{\xi}_{\oplus,e^-}$, in order to reflect the nature of the nucleonic effects (m_N and q) inherent in our description of the ratio T/τ.

It is clear that if we substitute $\dot{G}_{0,\oplus}/G_\infty$ of Eq. (12) for $2\dot{\xi}_{\oplus,e^-}$ in Eq. (10), the resultant factor of π can now be represented as the ratio of Planck's constant h divided by the spin-two graviton ($2\hbar$). It follows, therefore, that one could rewrite Eq. (20) to reflect the role of the graviton in determining the planetary dependence of $\dot{G}$. Furthermore, the graviton could be related to the change in potential energy of the electron undergoing a transition, $T_{e_1^- \to e_2^- + \gamma}$. It should be noted that τ and T can have any value, the only restriction placed on their values by Eq. (15) is that the ratio T/τ be constant.

The significance of Eq. (20) and its graviton counterpart lies in the fact that it represents a detailed description of a quantum electronic transition. Present quantum mechanics avoids the entire problem by suggesting that such transitions take place instantaneously, that is, "an instantaneous reduction of a probability packet." Eq. (20), on the other hand, contains the necessary elements for a description of how a photon is actually emitted during a quantum transition. It lends credence to Schroedinger's belief that an instantaneous transition is nothing more than a temporary, theoretical quantum mechanical fiction.

Summary

In light of Eqq. (19) and (11), which reflect the fact that both the invariant and variable elements of G are defined by highly precise ratios of times (a precision ensured by α), we can draw several conclusions. Firstly, our derivation of G clearly reflects a deep interrelationship between electromagnetism and gravitation beyond the inverse-square-law form they share. Secondly, it requires that both forces be propagated by spherical waves expanding from a center and traveling with a finite velocity c. Critically, both forces originate in the electronic oscillations of matter. It is not surprising, therefore, to find the exponentials involving the coupling constants acting as multiples of the variable time term $[(dt_{\mathrm{eph}} - dt_{\mathrm{at}})/dt_{\mathrm{at}}]$. On the other hand, the range exponential in Eq. (11) reflects a positional dependence of the terrestrial reference frame.

It has been noted by Smith (1984) that no satisfactory quantum theory of gravity exists at the present time. He suggests that the present approach of ignoring gravitation in particle physics may well be occurring with a degree of peril. Eqq. (19) and (11) indicate that the four coupling constants, three of which are quantum in nature, are basic elements of the gravitational constant. Whereas the quantum chromodynamic strong theory suggests that the strong and electroweak charges may have comparable values at $r \cong 0$, Eqq. (11) and (19) imply that at $r = \infty$ the strong force couples to the other three forces only through the symmetry breaking intervention of the gravitational binding mass-nonequivalence interaction.

In spite of the *local* reference frame variations in G due to both range and time effects, it should be emphasized that the dominant component of G, that is, G_∞, in Eq. (19) appears to be a universal invariant, consistent with the voluminous experimental data collected since Newton's monumental discovery of Eq. (1). Our derivation of G_∞, however, suggests that the dominant Newtonian term [the first term in Eqq. (2), (11) and (19)] represents an *acausal* description of gravitational energy. This should be contrasted with our causal interpretation of r in the small exponential term of Eq. (2), and so forth. In all probability, it is the hitherto unrecognized acausal character of the dominant first term in Eq. (11) that had led to the troubling interpretation of Newton's universal law of gravitation, as representing instantaneous action at a distance across (apparently) empty space. On the other hand, it is also this very acausality that had led to its great power in scientific description.

Acknowledgement

I wish to express my deep appreciation to Drs. William H. Brantley and C. Stuart Patterson for their technical assistance and critical review of this work.

References

Allen, C.W. 1976. *Astrophysical Quantities,* 3rd Ed. New Jersey: Athlone Press, p.113.

Blackett, P.M. 1947. *Nature* **169**: 658 (May 17).

______. 1949. *Philosophical Magazine* Ser. 7 **40**(301): 125.

Bondi, H. 1961. *Cosmology.* Cambridge Monographs in Physics, p. 162.

Born, M. 1935. South Indian Science Association, Bangalore, 9 Nov. 1935, p. 544.

Brantley, W.H. 1986. Private communication.

Brock, M.C. 1965. *Nature* **207**: 1079 (Sept. 4, 1965).

Capek, M. 1961. *The Philosophical Impact of Contemporary Physics.* New York, London: D. van Nostrand Company, Inc., p. 214.

Davis, L., A.S. Goldhaber, and M.M. Nieto. 1975. *Phys. Rev. Lett.* **35**(21): 1402.

Dirac, P.A.M. 1938. *Proc. Royal Soc. A.* **165**: 199.

Fischbach, E. et al. 1986. *Phys. Rev. Lett.* **56**(1): 3 (Jan. 6).

French, A. 1971. *Vibrations and Waves.* MIT Introductory Physics Series. New York: W.W. Norton & Company, Inc., p. 280.

Gibbons, G.W. and B.F. Whiting. 1981. *Nature* **291**: 636.

Heilings, R.W. et al. 1983. *Phys. Rev. Lett.* **51**(18): 1609.

Holding, S.C. and G.J. Tuck. 1984. *Nature* **307**: 714.

Hughes, V.W. 1969. In *Gravitation and Relativity.* Chiu and Hoffman, Eds. New York: Benjamin, p. 259.

Kokkedee, J.J. 1969. *The Quark Model.* Frontiers in Physics Ser. No. 32. New York: Benjamin, p.72.

Long, D.R. 1974. *Nature* **260**: 417.

______. 1980. *Nuovo Cimento* **55B**: 252.

McCrea, W.H. 1964. *Nature* **201**: 589.

Rosen, G. 1962. *Phys. Rev.* **128**: 449.

Samuel, H.L. 1950. *Essay in Physics.* New York: Harcourt Brace, p. 90.

Sciama, D. 1957. *Sci. Am.* **196**: 99.

Smith, C.H. 1984. *Nature* **312**(5995): 588.

Soldano, B.A. 1985. *IJFE* 3(3): 5.

Stacey, F.D. and G.J. Tuck. 1981. *Nature* **292**: 230.

United Press International news release by Jan Ziegler, Jan. 13, 1986.

Weinberg, S. 1964. *Phys. Rev. Lett.* **13**(15): **495** (October 12).

Yamaguchi, Y. and K. Hieda. 1965. *Progress in Theoretical Physics,* Supplement 262.

Toward the New Biophysics

by James W. Frazer, Ph.D.
M.D.Anderson Hospital and Tumor Institute
6723 Bertner Ave., Box 17
Room AG. 302
Houston, Tex. 77030

Editor's Note

This is a summary of a presentation by Dr. Frazer at a panel on lasing and biophysics sponsored by the Fusion Energy Foundation at the Lasers '85 conference in Las Vegas, Nev., Dec. 5, 1985. Other speakers on the FEF panel included Dr. F.-A. Popp, who is also featured in this issue; Dr. Philip Callahan of the U.S. Department of Agriculture in Gainesville, Fla.; and Dr. Jonathan Tennenbaum, director of the FEF in Europe.

Those of us who have used plastic electric tape in photographic darkrooms have noticed that when the tape is quickly pulled loose from its spool, light is given off, sufficient, in fact, to fog the film of the unwary. Some may have noticed that a stretched rubber band held against the forehead feels warm when it is allowed to relax. Both of these trivial events indicate a photon exchange not usually accounted for in polymer chemistry or physics: in the case of the tape, ultraviolet-visible photons; in the case of the rubber band, infrared.

Although these events seem removed from biological significance, their relationship becomes less tentative when one remembers the experiments described by Albert Szent-Gyorgyi in his second book on bioenergetics where the proboscis muscle of a marine worm could be made to contract, after "doping" with iodine and tryptophan when white light illuminated it, relaxing again in the dark with no nerve intervention. Szent-Gyorgyi was expounding a hypothesis involving charge transfer complexes as important in biosystems at nearly the same time the Pullmans were exploring redox potentials as a concomitant of carcinogenic and anticarcinogenic drugs. Neither hypothesis was completely true, nor completely false, but had historical value in focusing attention on photon transfer in biosystems.

While all this was going on, the attention of the biochemical world was slightly schizoid; one personality was tracking the epoch-making events in nucleotide encodements and their relationship to gene phenotype expressions, while the other personality was tracking the emerging events in oxidative phosphoryllation. The myriad methodological impacts both pursuits developed have formed the still-developing structure of today's molecular and supramolecular biochemistry.

Oxidative phosphoryllation and the mechanisms by which electron displacement could result in the formation of a high energy phosphate bond is still not a completely solved problem, although it is intimately related to proton transfer. It again has historical and tutorial importance, because investigation of the phenomena associated with it taught, firmly and unequivocably, the necessity for maintenance of precisely defined molecular architecture, without which the system not only failed to form ATP, but would hydrolyze it in large quantities. Another lesson, somewhat bitterly learned, was that low molecular weight factors did not carry energy from one site to another, but that there was energy transfer and "focusing" within a single protein that resulted in bond orbital changes in attached phosphate allowing coupling to appropriately oriented ADP. Note the precision of the geometric requirement for such a step.

At one time, when cells were seriously thought to be "bags of enzymes," the precision requirement would have led to unacceptability of hypotheses requiring such molecular level precision. Schneider and Hogeboom's isolation of relatively intact cellular organelles, including mitochondria, together with rapid development of technique and instrumentation for electron microscopy, have served to convince even the most recalcitrant of the reality of molecular-level architecture of all cells so far observed, though this architecture is varied in a seemingly endless number of ways.

One of the early indications of the importance of architecture came about from low angle and X-ray diffraction patterns of frog muscle obtained by Astbury and co-workers prior to World War II. Much more recently this was extended to "X-ray cinema" by Akoev and co-workers at the Institute for Biological Physics, Puschino, USSR where diffraction patterns related to myosin chain cross-linking were obtained at 0.1 millisecond intervals during muscle twitches.

The evidence for architectural significance of cells and their function now ranges from repositories for acidifying and hydrolyzing enzymes called liposomes, to the rough endoplasmic reticulum known to be protein synthesis factories, to the Golgi apparatus now beginning to be appreciated as the place of application of glycosidic groups to proteins destined to become part of the cell surface membrane, or to be secreted as one of several types of hormone. The glycosidic groups are becoming recognized as conferring very specific structures which are immunologically active, a property recognized in the phenotypic expression of blood groups, major histocompatibility loci, and the active portion of cell recognition molecules. These are the types of groups that form the low-density lipoprotein-cholesterol complex, bind it, and transfer it to lyposomes where the cholesterol is removed and most of it then incorporates in cell membranes.

The immune "system" itself, whose complete range is becoming evident though many of its mechanisms still remain unknown, is evidence for cell-cell recognition, cell activation of another cell (T helper effects on macrophages), activation of very specific forms of protein and glycoprotein synthesis, and release by stimulating antigens or cells with antigens on their surface. A cellular "social" biochemical behavior is becoming recognized.

These are only a few of the many examples of evidence for a very specific topological distribution of major cell recognition and activation systems located in a microscopic milieu 1-200 Å thick, but entering the cell interior for translocation to a large number of very specific internal locations.

Such a systematic maintenance of such a highly defined structure in the face of thermal bombardment at body temperatures (to be understood as not only collision bombardment but also interaction at 8-10 μ wavelengths at least) bespeaks a constant influx of energy in structure maintenance and liberation of that energy when the structure is deformed or broken. We know from our "adhesive tape" experiment that disruption of highly adhesive bonds can result in the emission of visible light, and we know that the energy exchanges resulting from metabolic oxidations are in the range of 305 to at least 700 μM radiation from the observations of spectral changes of the enzymes involved. We are also aware of the highly structured environment of these enzyme systems.

We were not well aware, until the work of Dr. Fritz-Albert Popp became known, that cellular architecture also conferred some rather unusual optical properties—among them a coherence path length on the order of meters. Popp's measurements have shown that emission of light from cellular systems can propagate through many cell depths (otherwise they would not have been detected) *in a coherent fashion;* that is, constant phase velocity relationships and at wavelengths bespeaking quantum energies far above kT.

Popp has already shown that ethidium bromide, a compound known to disrupt the tertiary structure of DNA and perhaps other sugar polymers is capable of increasing the number of photons released from his cellular systems. He has also shown that active tumor cells release more quanta than normal quiescent cells, a finding made interesting by the Warburg phenomenon in some tumors resulting in increased oxygen uptake, thus a putative higher metabolic throughput and a somewhat "disorganized" cell type.

Propagation of light quanta over such long coherent distances immediately makes one wonder about cell processes that might be synchronized by such processes. While we know the absorption coefficients for members of most of the molecular components of cellular systems, the qualification of coherency imposes sobering thoughts of molecular states at the time of photon transfer.

We have been looking at cellular organization from the viewpoint of magnetic resonance analysis—protons, 31P and 13C. The magnetic coupling in close-packed systems of normal cells usually has profound effects on the spectra obtained with 1H proton resonance, producing broad, ill-defined peaks any of which is a "sum spectrum" of a wide distribution of magnetic states of individual protons. One might expect that components in the loosely arranged glycosidic linkages on the cell surface would give relatively unperturbed spectra in comparison to molecules known to be part of lipid bilayers or other organized cellular systems. We have detected some of these, but find they strongly interact with solvent water as do other cell components. Although such a finding is not entirely unexpected, it does indicate that Popp's coherency path length imposes also some rather special consideration of the structure of water that might allow such a phenomenon.

Our proton magnetic resonance (PMR) data indicate a high degree of interaction between cell water and some of the glycosidic components, but little measurable interaction with considerable portions of protein and lipid spectra. In a clone with high metastatic potential, it has been shown that there is a fairly dramatic change in the types of glycoprotein formed, found at the cell surface and released to the medium. Prior observations of the "shedding" of cell surface glycoproteins show that there is considerable variation in this phenomena among tumor types, but in the clones we have examined, this "shedding" of a specific glycoprotein seems associated with metastatic potential and growth rate. Unfortunately, we have not yet compared rates of photon emission in these clones.

It is always easy to ask questions for which there is no present answer, but consider a mobile molecule with localized charge groups vibrating in all of its modes and emitting, as a result of charge relative motion, a variety of electromagnetic fields—photons, if you will. This molecule approaches another which is part of a relatively fixed structure on a surface membrane. The evidence indicates highly specific molecular "binding," in only a few of the many possible steric configurations. Would the fields induce preferred molecular orientations?

Information for Contributors

Manuscripts should be sent to David Cherry at the Fusion Energy Foundation, P.O. Box 17149, Washington, D.C. 20041-0149.

Manuscripts should be submitted in triplicate (with three sets of illustrations, of which one is an original.) They should be typewritten on one side of letter (quarto) paper and double spaced with at least 25mm (1 inch) margins. All pages must be numbered in sequence beginning with the title page.

TITLE PAGE of the manuscript should contain the complete article title; names and affiliations of all authors; name, address, telephone number, and cable or Telex number for all correspondence.

ABSTRACT of no more than 200 words should summarize the work and major conclusions.

TEXT should define all abbreviations at first mention. American measuring units should be accompanied by metric translation. In general, the meter/kilogram/second/ampere system of units should be used. Letters of permission should be submitted with any material that has been previously published.

FOOTNOTES should appear at the bottom of the respective page and must be numbered consecutively.

REFERENCES should be referred to in the text by the author's name and the date of the work. The references should also be listed alphabetically on a separate page. The references should include for articles: author, year of publication, title, periodical name, volume no., and pages; for books: author, year of publication, title, place of publication, and publisher's name.

TABLES, FIGURES, and ILLUSTRATIONS must be prepared each on a separate page, numbered in order of appearance, and have a title and descriptive legend. Photographs should be glossy black and white prints.

ACKNOWLEDGMENTS. Illustrations from other publications must be acknowledged. Include the following when applicable: author(s), title of journal or book, publisher and place of publication (if book), volume number, page(s), month and year of publication. The author is responsible for obtaining the publisher's permission to reprint.

REPRINT order forms will be sent to the author with proofs of the article.

Clarification of Some High Turbulence Results Obtained by the MAN New Technology Group

by Winston Bostick

Editor's Note. *This commentary by fusion scientist Winston Bostick accompanies a report on the technological potential of high turbulence processes done by the New Technology Group of MAN (Maschinenfabrik Augsburg/Nürnberg). Bostick visited the MAN group in Munich in 1985.*

Background

During the last five years, the MAN New Technology group in Munich has pursued research on plasma-focus-type devices with various experimental techniques and with a three-dimensional magnetohydrodynamics computer-simulation code. Some of the experimental results and theoretical inferences proceeding from this group are indeed startling and go considerably beyond the current state of the art as developed by the other workers in the field. Some milestones in understanding the plasma focus achieved by these other workers are as follows:

- Under many, but not all, circumstances the current in the plasma-focus current sheath is carried by paired, well organized, Beltrami-like, quasi-force-free, minimum-free-energy vortex filaments, ~1 millimeter in diameter.

- One phase in the operation of a plasma focus, or a vacuum spark, can be described as the electromagnetic ram, whereby the conduction current in the column of the vortex filaments (when the column is ~5 mm in diameter) is suddenly interrupted by the stimulated chopping of all the filaments by the explosive rupture of one of the filaments. The gap where the chopping occurs becomes magnetically insulated by the B_θ of the displacement current, which suddenly takes the place of the displacement current. This magnetically insulated "capacitor" is charged on a picosecond (ps) time scale to about 15 megavolts (MV). Electron and ion beams are accelerated at the geometric center where $B_\theta \rightarrow 0$. The capacitor discharges rapidly with beams as the displacement current decreases to zero and reverses sign. This process repeats itself many times on a cycle time of about 25 ps. The ion energy spectrum is of the form $dN \sim E^{-2.7}\, dE$ from 1 MeV $< E <$ 15 MeV. Sites of these intense ion and electron beam generation are sites of intense deuterium and soft X-ray emission and reaction-neutron and proton emission. Electron densities at these sites can approach $10^{21}/\text{cm}^3$. Magnetic field intensities can become 200 M gauss. In large plasma focus devices there occurs a multiplicity of the sites extended both in time and space.

- Magnetic field reconnection along pairs of filaments locally accelerates electrons and ions.

- The electrons in the electron beams travel in vortex structures of $\sim 3\mu$ in diameter with $\sim 10^{11}$ electrons per structure. $\beta \rightarrow .5$ to .7. These organized structures gather together into larger organized structures. These electron vortex structures collectively accelerate ions to energies of a few MeV.

- Ions coming out of the intense X-ray sites frequently come in clusters of many ions, but a small net e/m ratio.

- Oscar Buneman and Anthony Peratt with a 3-D, particle-in-cell, fully electromagnetic code, SPIASH, have simulated the formation of Beltrami-like Birkeland filaments to carry currents in laboratory and cosmic plasmas. They have successfully simulated the formation of barred-spiral galaxies, and the creation (by electron synchrotron effects) of the cosmic microwave background radiation corresponding to a blackbody at ~2.7° K.

The MAN Results

The MAN group is composed of Axel Hayd, Ph.D., who has a solid-state background involved with all phases of experiments; Peter Meinke, Ph.D., an engineer concerned with overall organization and objectives of the group; Martin Maurer, Ph.D., a theoretician involved principally with computer simulation; Wilhelm Satzger, Ph.D., who has an astrophysical background; Karl Köller, an elementary onta (particle) experimentalist connected with the University of Munich; and H.J. Kaeppeler, a professor at the University of Stuttgart, Institute for Plasma Research, and closely connected with the plasma focus group there. Kaeppeler has worked closely with the MAN group in developing the computer code.

A more detailed account of the MAN computer simulation with the 3-D algebraic computer code REDUCE for cylindrical geometry is given in Appendix A. The following is a brief summary of the 3-D code work.

For the $m = 0$ interchange instability, which they assume to be operative in the later stages of the Stuttgart POSEIDON plasma focus (280kJ, ~60kV, ~2.1MA), a one-fluid 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 $\approx 2 \times 10^{11}$, the magnetic fields to 5,100 tesla (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 the group at the Stevens Institute of Technology 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) was developed to handle the cases of strong electric fields and high currents in magneto-plasmas. Micro-effects are treated analytically, while macroscopic flows are handled by the REDUCE/Fortran hybrid code. Microturbulence is considered in the quasi-linear approximation, while the hybrid code permits a 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 $(\mathbf{r},t)$ space to (k,w) space. Due to the fact that the back-transformation from (k,w) space to $(\mathbf{r},t)$ space is carried out analytically, the problems connected with steep gradients do not arise. The calculation procedure is demonstrated for the simple case of Burger's equation.

The solutions to these magneto-fluid equations lead to a hierarchy of degrees of turbulence which are differentiated by their range of Reynolds number:

Common turbulence ≡ c-turb: $2 \times 10^3 \leqslant \mathrm{Re} \leqslant 10^6$
High turbulence ≡ h-turb: $10^6 \leqslant \mathrm{Re} \leqslant 10^9$
Extremely high turbulence ≡ e-turb: $10^9 \leqslant \mathrm{Re} \leqslant 10^{12}$
Ultra high turbulence ≡ u-turb: $10^{12} \leqslant \mathrm{Re}$

These classifications differentiate four ranges of turbulence separated from their nearest neighbors always by a critical value of Re ≡ Re_c. The MAN experimenters state that the results of their experiments suggest that the world of elementary onta would appear as a sort of "eigenvibrations of turbulence" at the critical transition from $h \rightarrow e$ turbulence, with $\mathrm{Re}_c = 10^9$.

Their electrodes were of the typical Mather geometry with positive center electrode (Figure 1) and a pointed negative center electrode. They operated with their storage capacitor in the range of 50 to 100 kV "in order to have Re reach values $\geqslant 10^9$."

One set of diagnostics involved coincident recording of high-energy onta proceeding from the plasma focus, by coincident scintillators which triggered spark chamber photographs of onta passing through 8 feet of iron. Data on these highly penetrating onta were accumulated over periods of several weeks of operation. Background counts due to cosmic radiation were carefully assessed. Results in detail of these experi-

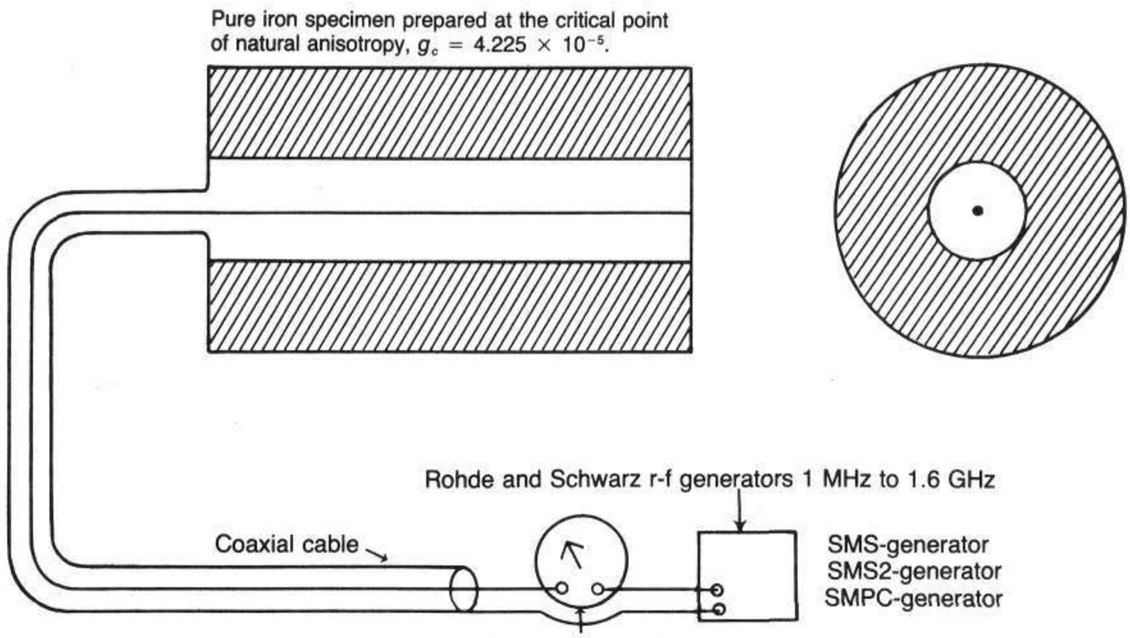


Figure 1. Positive center electrode. This is the typical Mather geometry.

ments were not presented to this author. The experimenters did show some typical tracks from their spark chambers and declared that such tracks were far above the cosmic ray background. They declare that there is unequivocal evidence of penetrating, high-energy onta coming from the plasma focus; that these coincidences and spark chamber tracks are not produced by n,γ reactions or by cosmic rays. However, this author wishes to see detailed data and conclusions from these experiments. The plasma focus was operated at repetition frequencies as high as 1,000 Hz.

The MAN group has stated that the experiments with scintillators and spark chambers were planned by Karl Köller, their elementary onta experimentalist, and constructed and carried out by the MAN electronics group, composed primarily of electronic engineers and technicians.

The second diagnostic tool used in the investigation of the production of elementary onta by the high turbulence of their plasma focus is a piece of pure iron of the shape indicated in Figure 1. The use of this diagnostic tool involves a second system at a critical point of turbulence; namely the $h \rightarrow e$ turbulent spin waves, otherwise known as magnons, within the Weiss ferromagnetic domains of this particular piece of iron. The usual linear dimension of a Weiss domain is 0.2×10^{-4} cm. The MAN group states that with these domains of h-turbulent magnons, a new detector concept becomes possible. They claim to have produced experimentally h-turbulent conditions of magnons that are coupled in a coherent way over about 5×10^8 Weiss domains. They call such a coherent, quasi-stable conglomeration of 5×10^8 Weiss domains a *soliton*. Such a soliton system can be used as "a microscope of quantum turbulence" *if* the soliton system is first driven to the $h \rightarrow e$ critical point of turbulence. To prepare a specimen of iron for such a high critical state of turbulence it is necessary to pump sufficient vorticity into the magnon clouds in order to attain the desired Re numbers. The stored vorticity which can be ultimately attained is a function of the natural anisotropy g. If a sample of iron is chosen which is at the critical point of natural anisotropy $g = g_c = 4.225 \times 10^{-5}$, that sample will permit a maximum of storage of vorticity in the magnon clouds.

The choice of the piece of iron most closely at the condition of $g = g_c = 4.225 \times 10^{-5}$, is made by neutron scattering measurements at the reactor at DESY (German electron synchrotron lab in Hamburg). The MAN group states that fortunately, by this process, they chose such a sample which worked very well. With such an iron specimen in place, as in Figure 1, the high vorticity of the magnon clouds is achieved by running through a hysteresis about 10^{10} times with the r-f generator. They state that the iron specimen remains in this highly-pumped, magnon vorticity state for a few hours, during which time the experiments with the plasma focus can proceed.

The MAN group states that the iron sample will now radiate an r-f signal which is a unique function of the Re. The r-f generator can also be used as a spectrum analyser and they plot Re as a function of frequency for their iron detector in Figure 2. They should describe how they have determined Re in producing such a plot. They operate the experiment at Re $= 5 \times 10^8$, $\nu = 26.9$ MHz at R on Figure 2, which is not far away from the critical point c.

Some Questions

The work of the MAN group will be received with much greater interest and credibility by the scientific community if the following gaps in their information can be supplied:

- Provide data from the coincident work with scintillators and spark chambers. What were the identifications of the high-energy elementary onta that penetrated the 8 feet of iron? Protons, τ mesons, ϕ ions, μ ions? Were neutrinos counted? If so, how?
- How did the investigators calibrate the iron detector to get the empirical "law" $\Delta f \sim \log m$? (The author presumes that this m is the rest mass.) Where did they find the 30 different onta of different m (m_0) to perform this calibration?
- How did the workers generate the curve of Figure 2 for their piece of iron?
- Can they draw and quantify the diagrams necessary to explain the detector, such as those shown in Figure 3?

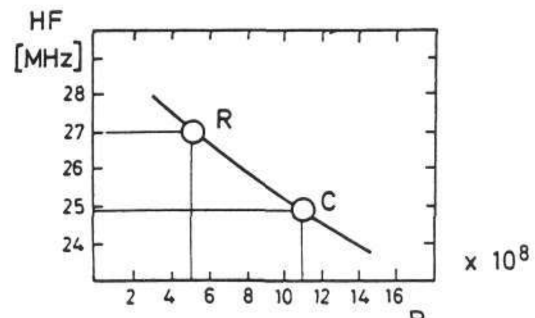


Figure 2. How was the curve generated?

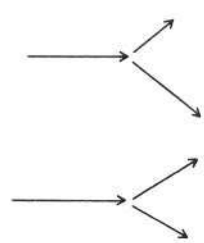


Figure 3. Diagrams of this kind are needed to explain the detector. Above, energy of turbulent packet $= E_{-\tau} + E_{+\tau} = mc_{-\tau}^2 + mc_{+\tau}^2$. Below, $mc_\tau^2 - m'c_\tau^2 = \hbar w_{\text{soliton}}\, n$ (where n is the number of atoms in the soliton).

Technological Potential of High Turbulence Processes

by Axel Hayd and Peter Meinke

Translated from the German by John Chambless.

Since 1978, a team of scientists at MAN Neue Technologie (The New Technology Group of the Augsburg/Nuremberg Engineering Works) has investigated the physics of high- and super-turbulent processes, working partly in close cooperation with the universities of Stuttgart and Munich. In 1981-1982, the West German Ministry for Technology sponsored a study of the technological potential of high turbulence processes (Hayd and Meinke 1983).

Self-Organization and Phase Changes of High Turbulence Processes

In recent years, "chaotic motions and strange attractors" have gained increasing importance. On the other hand, a new theory of "order out of chaos" has been developed, synergetics (J. Prigogine, H. Haken), in which an analysis of the ability of "self-organization" shown by many systems is given, understanding under self-organization the character of many systems to produce determinate processes, macroscopic patterns of behavior, and order as well as structure out of apparently chaotic microprocesses.

In liquids, gases, and plasmas, cooperative patterns of movement are often coupled with the formation of conditions of turbulent flow which take on the role of "organizer." Under determinate conditions, sharply delimited areas (forms) come into existence which are set off from the rest of the environment by specific features such as, for example, temperature, density, pressure, and degree of turbulence. Some typical geometries of such basic forms (normals) are shown in Figure 1, but other forms are also possible.

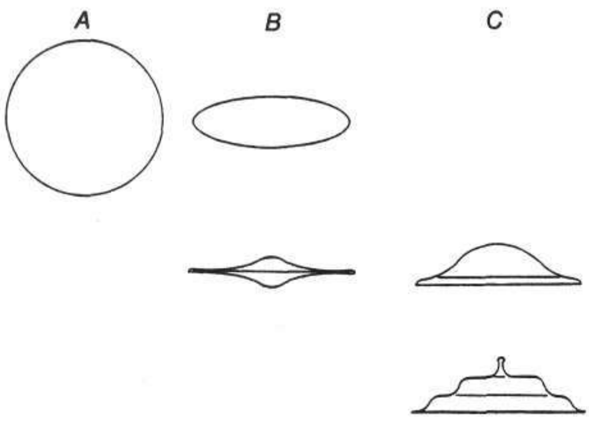


Figure 1. Basic forms (normals) of macroscopic behavior patterns in high-turbulence processes.

If the Reynolds number is chosen as the progressive parameter, then phase changes in turbulence can be defined in which ordering parameters such as length of correlation, magnetization, and stochasticity change their values in the manner of quantum jumps. The theoretical investigations undertaken revealed various "phase bands" for each of which a different spectral law was valid. On this basis, the following division was proposed:

Laminar flow $0 < \mathrm{Re} < 2.2 \times 10^3$
c-turbulence: $\mathrm{Re}_c = 2.2 \times 10^3 < \mathrm{Re} < 1.7 \times 10^6$
h-turbulence: $\mathrm{Re}_h = 1.7 \times 10^6 < \mathrm{Re} < 1.4 \times 10^9$
e-turbulence: $\mathrm{Re}_e = 1.4 \times 10^9 < \mathrm{Re} < 1.2 \times 10^{12}$
u-turbulence: $\mathrm{Re}_u = 1.2 \times 10^{12} < \mathrm{Re} < 9.6 \times 10^{14}$

In the following, we will consider in more detail two such stable, self-organized forms in plasma (see Figure 2): Both forms are rotationally symmetrical relative to the z-axis and exhibit alternatively rotational and translational movements. The plasma is more turbulent inside the forms than outside by orders of magnitude, and phase changes occur at the boundaries of the turbulence. The forms are more dense than the surrounding plasma and have higher temperatures (and radiation) than the environment. The pressure in the forms is substantially higher than in the surrounding plasma. If the forms meet certain dimensional conditions, they can propagate at high velocities without shock waves.

Development of Methods of Calculation

For the solution of systems of nonlinear partial differential equations for turbulent media, a REDUCE/FORTRAN hybrid code was developed. An "initiating disturbance" is made, the "disturbance" developed in a series of partial disturbances, and a wave formula introduced for these partial disturbances (Hayd et al. 1982).

A dispersion relation in ω,k-space was then derived, which provides information on the stable and unstable ranges of the system.

Since field strengths as functions of space and time are of interest, these must be retransformed from ω,k-space into r,t-space. The difficulties introduced by steep

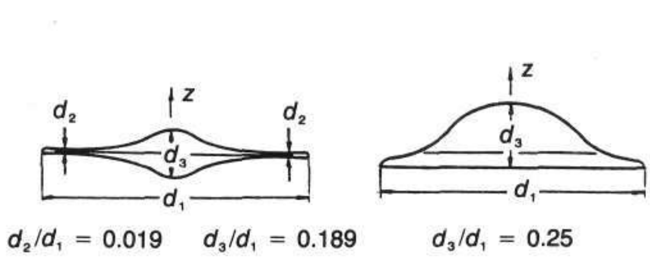


Figure 2. Asymptotically stable pulsing forms. (At point of maximum rotation around the z-axis.)

gradients in numerical procedures can be avoided if the retransformation is carried out in r,t-space analytically by means of partial integration using REDUCE. Finally, the actual initial values can be introduced, the solution carried out with FORTRAN, and then represented graphically.

Self Enclosure of Highly Dense Plasmas Relevant to Fusion

One result of the work shows the enclosure time of a highly dense turbulent plasma as follows:

$$n\tau \approx 4.5 \times 10^8 \times Re^{3/4} \text{ [s/m}^3\text{]}.$$

Of all plasma production machines built so far, the plasma focus attains the highest Reynolds numbers. Previously, with equipment in the 20-30 kJ range, Reynolds numbers of 10^{11} were occasionally found. The plasma in a medium-sized plasma focus machine is already in the e-turbulence condition with temperatures between 0.5 and 1 keV. Even Reynolds numbers of 10^{16} are not unthinkable given present knowledge of plasma focus equipment. The plasma focus is also interesting, therefore, as a component of a fusion reactor.

The fusion processes occur in plasma focus in the pinch phase as well as in later phases, although it was earlier believed that neutron production took place only after $m = 0$ instability was reached during the later phases. With equipment such as POSEIDON with a pinch flow over 600 kA, various exchange instabilities occur, from which it is assumed that they are connected with the fusion reactions. Exchange instabilities of the $m \geqslant 2$ type are the cause of filament formation, which will play a crucial role in the next generation of focus generators. These filaments were investigated theoretically, especially in relation to neutron production, which indicated there will be advantages in higher charging voltage for future large plasma focus machines with pinch flows I_p over 1 MA since the exponent n in the scaling of neutron yield $Y \sim I_p^n$ increases with charging voltage. As an example, a high-voltage focus design furnished with a 1:1 D-T mixture that theoretically reaches the breakeven point:

Charge voltage 1.8 MV
Pinch flow 6 MA
Pinch length 745 mm
Plasma radius 42.5
Internal electrode 160 mm Ø
External electrode 560 mm Ø
Pinch period 1.74 μs
Temperature 600 eV
Number of filaments 12

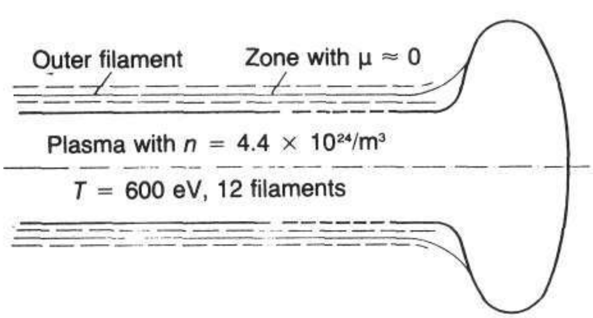


Figure 3. Mushroom-like pinch formation in a breakeven focus.

According to calculations with REDUCE/FORTRAN, at approximately $I_0 > 1$ MA, $U_0 > 300$ kV, mushroom-type instead of umbrella-type pinch configurations arise that are stabilized by flow return filaments (outer filaments) in Figure 3.

A New Method for Production of High Energy Particles

The research showed that high-turbulence plasmas with Reynolds numbers over 10^{12} deviate sharply from the Maxwellian velocity (energy) distribution.

Within such a plasma P_h, regions P_e arose which were smaller by orders of magnitude (Figure 4) and which initially consisted only of electrons; other elementary particles were added later through inelastic impact. Experimental results lead us to expect that high-energy particles will be released from P_e. It is striking that the transverse impulse P_T of the Centauro events agrees approximately with the experimental results (P_T in the laboratory $\approx$ 1.7 GeV with a total energy of 1.3×10^6) in (Figure 5).

A continuation of this work could lead to a practical high-turbulence laser for particles of rest mass $\neq 0$.

Extension of the Turbulence Concept to Quasi-particles

Many quasi-particles exceeding a minimum density can be conceived, like atoms or molecules, as a continuum relative to a flow description.

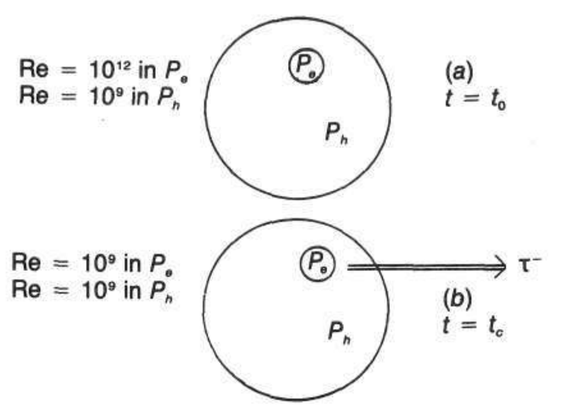


Figure 4. Negatively charged plasma as part of a turbulence packet.

In the associated Reynolds number, the dissipative portion is determined not only through the viscosity, however, but also through general scattering processes. High turbulence processes of phonons and magnons have proved to be of particular interest—phonons, because of their general lawfulness with respect to tribological processes; and magnons, because of their large effective cross section for the weak interactions, that experimental results show can be increased through high turbulence by a factor of 10^9 to 10^{10}. Especially large correlation lengths were reached with phase changes of *h*-turbulence to the *e*-turbulence ($Re_e = 1.4 \times 10^9$) of the magnons.

Theoretical investigations have shown that, at a critical intrinsic anisotropy $g_i = g_c = 4.225 \times 10^{-5}$, the transfer of turbulence heat took place more slowly by a factor of 10^5 to 10^6 than with other g_i values.

With such a high turbulence "magnon detector," laboratory experiments for the generation of high-energy particles in 1981 determined the masses of a series of elementary particles (Meinke, Koller, Hayd, 1981). The derived values of the rest masses of W^- (82.7 GeV) and Z_o (93.0 GeV) have since been rather precisely confirmed at CERN (1983) with the values of $W^- = 81 \pm 2$ GeV and $Z_o = 95 \pm 2$ GeV. For the gluon (102.3 MeV) as well as the neutrino (15 ± 7 eV) and the antineutrino (3.9 ± 0.4 eV), results of such control measurements by conventional procedure are still lacking. No *t*-quarks were observed in the described experiments, but ⅓-charged leptons were. Considering that this type of experimentation took place on only two or three laboratory tables, we can see its great promise for high-energy physics.

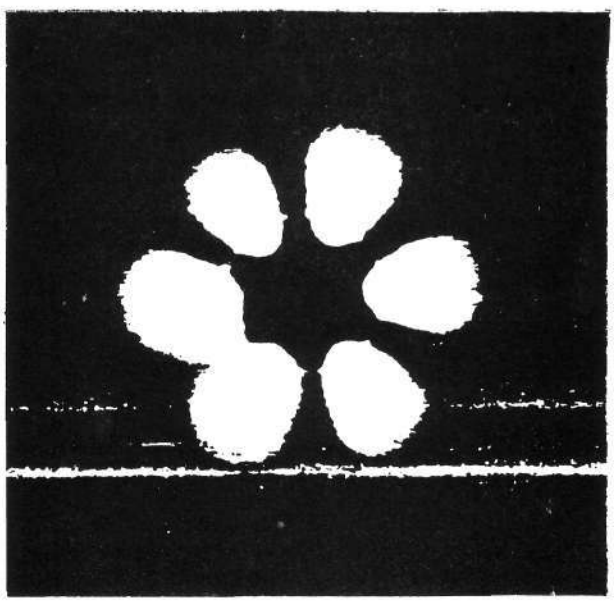


Figure 5. Centauro event produced in the laboratory.

References

Hayd, A., H.J. Kaeppeler, M. Maurer, and P. Meinke. 1982. *Die Berechnung von Turbulenzerscheinung in der Plasmadynamik mit Hilfe von REDUCE (MAN-Bericht 1982).*

Hayd, A. and P. Meinke. 1983. *Abschätzung des Technologiepotentials hochturbulenter Prozesses (MAN-Bericht 1983).* Hannover: Technische Informationsbibliothek.

Meinke, P., K. Koller, and A. Hayd. 1981. "New Experiments with Turbulence at a Critical Point have given the following Experimental Masses." Telex No. 349 to CERN: 02/23/1981.

A Critique of E. Fischbach's 'Reanalysis of the Eötvös Experiment'

by William H. Brantley

E. Fischbach et al. [*Phys. Rev. Lett.* **36** (1):3 (1986)] have reanalyzed the data of the original experiments by R. v. Eötvös et al., which compared the accelerations to Earth of various materials, and concluded that the Eötvös-Pekar-Fekata (EPF) data are dependent on the materials used. This is contrary to the original interpretation of a null result, so often cited as confirmatory experimental evidence for the celebrated equivalence principle of general relativity. Fischbach et al. conclude that their new results support the existence of a *fifth force* in the hierarchy of physics forces, which is of intermediate range and coupled to baryon number or hypercharge.

This paper is very stimulating, but its most striking feature is that there is no mention whatever of the obvious possibility that the nonnull result of the Eötvös reanalysis is due to a failing of the equivalence principle.

In a 1961 article about the Eötvös experiment, R.H. Dicke writes:

> The dates of these experiments (1889 and 1908) have led some physicists to believe that Eötvös' work had a decisive influence on Albert Einstein as he was formulating his general theory of relativity between 1908 and 1915. The fact is, as Einstein wrote in 1934, he "had no serious doubts about [the constancy of gravitational acceleration] even without knowing the results of the admirable experiments of Eötvös, which—if my memory is right—I only came to know later." Nevertheless, it is entirely accurate to say that if the results of the Eötvös experiments had been anything but negative, every physicist would have heard the astonishing news within days and the whole foundation on which the general theory of relativity rests would have vanished before the theory had been conceived.

W. Rindler writing about general relativity, after a long passage on "An elementary consequence of the principle of equivalence is the bending of light in a gravitational field," adds, "Note that all this depends on the equality of inertial and gravitational mass, which is therefore a *sine qua non* of Einstein's general relativity."

Fischbach et al. report that "although the Eötvös experiment has been universally interpreted as having given null results, we find in fact that this is not the case." Their reanalysis of the original Eötvös results suggests that the more massive an object is, the slower it will fall near the surface of the Earth. Yet they mention nowhere in their paper the inevitable question this raises concerning the validity of the famous principle of equivalence, nor do they even hint that "the whole foundation on which the general theory of relativity rests would [have] vanished. . . ." The reanalysis of Fischbach et al. has clearly brought into question the principle of equivalence.

It would seem necessary to address this question, but instead a fifth force, dependent on hypercharge, is proposed. Granted that the major question raised is being ignored, the suggestion of a fifth force seems at first to have some plausibility, because of recent work on the geophysical measurements of G. Their introduction indicates that their reanalysis of the Eötvös experimental data was motivated, in part, by recent geophysical determinations of Newton's gravitational constant G, which yield values consistently higher than the laboratory value. Thus, their reanalysis is based on the assumption that these differences are real, and tends to confirm that assumption. But this raises a serious question, not mentioned in their paper, that, were there different G values, then the validity of the field equations of general relativity, which are based on a constant G, are brought into question. Thus, the increasingly well-established variation in the universal gravitational constant lends further experimental evidence against general relativity which, according to Dirac, requires an invariant Newtonian gravitational constant.

The work of Y. Fujii, D. Long, F. Stacey, W. Gibbons, and others in recent years led to the investigation of a non-Newtonian (Yukawa-form) gravitational potential energy expression which is added to the original Newtonian potential; that is,

$$V(r) = -G_\infty m_1 m_2/r \, [1 + \alpha e^{-r/\lambda}]$$

where G_∞ is the Newtonian constant at $r = \infty$. The critical information, provided by a private communication from Stacey, is the value of the constants α and λ necessary for this equation to be consistent with the geophysical data on G. They suggest that if this added term represents a real force, then according to their [to-be-published] general analysis, such a force would be manifested, at present sensitivity levels, in only three places: (1) the $K^0 - \overline{K^0}$ system at high laboratory energies, a system well known for its anomalous results; (2) the comparison of satellite and terrestrial determinations of the local gravitational acceleration g; and (3) the original Eötvös experiment. The Eötvös experiment was chosen because it was done with the Earth as a reference frame, in contrast to subsequent refinements in which the Sun is the reference frame. Thus, only the original Eötvös experiment would be sensitive to the intermediate range force implied by the Yukawa-type potential. They conclude that there is evidence in the Eötvös-Pekar-Fekata data for such a potential.

The anomalous effects in the $K^0 - \overline{K^0}$ system, and the negative value of α led them to account for the added potential by a massive hypercharge field with hyperphoton exchange giving a potential having the same form as that suggested by geophysical measurements. This leads to a relationship for the difference between the accelerations of two objects falling near the Earth, expressed as a function of baryon number of the group-paired test materials used by Eötvös-Pekar-Fekata.

An interesting aspect of the reanalysis is that the original experiment was so accurately done, it was amenable to reanalysis using modern handbook data, careful consideration being given to the chemical composition of the materials used to arrive at a theoretical result. The calculated ratios of baryon number to mass are then compared directly to the experimental results of Eötvös-Pekar-Fekata. The acceleration differences measured by Eötvös-Pekar-Fekata are linearly related to the corresponding theoretical differences for each set of material used. A linear regression yields a slope from which the square of hypercharge times their range-related integrating factor is determined. This quantity, when compared with the corresponding value obtained from the geophysical data, is found to differ by a factor of only about 17.

From a to-be-published analysis, Fischbach et al. conclude that the specific values of α and λ calculated by Stacey are not only consistent with the geophysical data and their reanalysis of the Eötvös data, but they claim that these values also account qualitatively and quantitatively for the kaon data as well. They proposed additional tests for a short-range force of repulsive nature by: (1) repeating the Eötvös experiment, (2) time-of-flight comparisons of falling masses, (3) comparison of the difference between the locally measured value of g and that implied by satellite data, and (4) direct search for hyperphotons.

Contrary to their stated "universal" interpretation of the Eötvös experiment giving null results (and thus confirming equivalence), B.A. Soldano, in a series of more than 40 abstracts published in the *Bulletin of the American Physical Society*, going back as far as 1960, has explored the application to many different physics areas of the effect of a subtle violation of equivalence between inertial mass and the binding fraction of gravitational mass. Interestingly, the very experimental areas that Fischbach et al. suggest be searched for effects of a fifth force, are among many of the problems in which the consequences of nonequivalence have been examined by Soldano. For the case of $K - \Delta CP$, he finds that the ΔCP nonconserving parameter η_{+-}, arises from nonequivalence in gravitational binding of our solar local center of gravitational mass. Further, he finds that the hitherto unexplained degradation of the orbit of NASA's Lageos satellite is due to gravitational binding nonequivalence of the Earth. To mention another abstract based on nonequivalence, he calculates the limits of validity of nine different experiments testing general relativity. He finds that the present experimental limits of general relativity tests tend to confirm the nonequivalence limits rather than the zero limit predictions of general relativity.

It would seem that the proposal of a fifth force by Fischbach et al. is not only unnecessary, but that the real conclusion they could have drawn from their results—namely, that there exists a limitation on the equivalence principle—is a glaring omission and one that ignores a growing body of evidence supporting the idea of a nonequivalence $[(m_i - m_G)/m_G = 5.05 \times 10^{-12}]$ between inertial mass and the gravitational binding component mass.

The work of Soldano sheds a new light on the concept of mass, and suggests that the above fractional mass difference is universal and pervades in subtle ways our physical description of all areas of science, from astronomy to subatomic particle physics. It is remarkable that such a minute and specific difference in mass makes such a vast difference in our understanding of physical phenomena, and the question presents itself whether there is further quantitative division of mass still remaining?

A.A. Michelson said, "The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote. . . . Our future discoveries must be looked for in the sixth place of decimals." But if we think his statement too extreme, we can still be charitably disposed toward him, for that was 1894, and we are well aware of his legacy to us of extremely accurate measurement. And the last part of his statement may well contain a germ of truth, if we but make in it the replacement "12th place of decimals."

In closing, several things deserve comment. One is the extraordinary skill exhibited by Eötvös and his coworkers in their experiment begun almost 100 years ago. We can be thankful to Fischbach et al. for calling our attention back to this singular experiment by their own innovative reanalysis. And we should be grateful that the occasional coworker in the scientific endeavor has the insight to see the flaw in the underpinning of the foundation of physics, and have ready in the wings a new physics to try, a nonequivalence physics.

I am reminded of what we teach our students, and do well to relearn ourselves from time to time, and it was said so well by Richard Feynman that I quote him: "The principle of science, the definition, almost, is the following: *The test of all knowledge is experiment.* Experiment is the sole judge of scientific 'truth.'" How clearly, now, we see that experiments done with extraordinary care and accuracy can have major impact on science 100 years later, when scientific and technological advance lead to reanalysis.

There is a strong belief in the physics community that the equivalence principle is correct, even in the face of this reanalysis of the Eötvös experiment and a plethora of very different experimental limits for some aspects of the equivalence principle. It is apparent that this broad range of limits, and many other questions facing physics today, can be explained by nonequivalence between inertial mass and the gravitational binding component of mass. Thus, we must guard against building such a solid front against nonequivalence that we fail to carefully consider it, and then find ourselves in a position somewhat similar to the Aristotelians of Galileo's day, of whom Galileo wrote: "My dear Kepler, what would you say of the learned here, who, replete with the pertinacity of the asp, have steadfastly refused to cast a glance through the telescope? What shall we make of all this? Shall we laugh, or shall we cry?"

New Experimental Results Surprise Quantum Theory

by Carol White

A group of scientists at the Institute for the Study of Heavy Ions at Darmstadt University in West Germany have observed that, contrary to theoretical predictions, positron-electron pairs are created in nuclei with high atomic numbers, in the Z range from 180 to 188.

The interest in their results, however, does not occur in the confirmation of the deviation from the "theoretical" predictions that pair production would occur where the atomic number was a reciprocal of the fine structure constant, $Z = 137$. This deviation had already been predicted. Rather, the interest lies in the occurrence of a quantized positron kinetic energy peak at 300 keV.

The results were covered extensively in the November 1985 *Physics Today*.[1] However, author Bertram Schwarzschild fails to note their most remarkable feature: The Darmstadt results lend substance to the contention of nuclear physicist Erich Bagge that the traditionally accepted symmetries in positron-electron emission do not exist and, therefore, there is no need to posit the existence of the neutrino.

The highest known nuclear charge does not have a Z as high as 137; however, the experimenters at Darmstadt were able to simulate a "supercritical" nucleus with a Z above 173 by colliding uranium nuclei, or other similarly high atoms. Walter Greiner at Goethe University, Frankfurt-on-Main, West Germany, led the group of experimenters who achieved these results, and in the Soviet Union Yakov Zel'dovich proposed a similar idea.

For theoretical reasons to do with the bound state of the electron, it might have been predicted that production of positron-electron pairs would occur only at atomic number $Z = 137$, (the integer closest to the reciprocal of the fine structure constant), producing a pair from a vacancy in the lowest-lying electron orbital level in the electron shell.

However, it has been generally assumed, from a so-called realistic experimental point of view, that in fact this would occur not at 137 but at $Z = 173$ or greater. This has to do with the actual finitude of nuclei, and the particles that make it up, which in quantum physics are treated as point particles rather than as having a finite volume.

Prior to the work at Darmstadt, this positron-electron emission was never verified experimentally. Eight years ago, Greiner and his colleagues produced heavy nuclei by colliding heavy ions with each other. For example, thorium hitting tantalum produced a fused nucleus as high as $Z = 163$. Since 1981, the group at Darmstadt has been producing heavy nuclei in a still higher range, as high as $Z = 188$, and they have hopes of reaching higher ranges still.

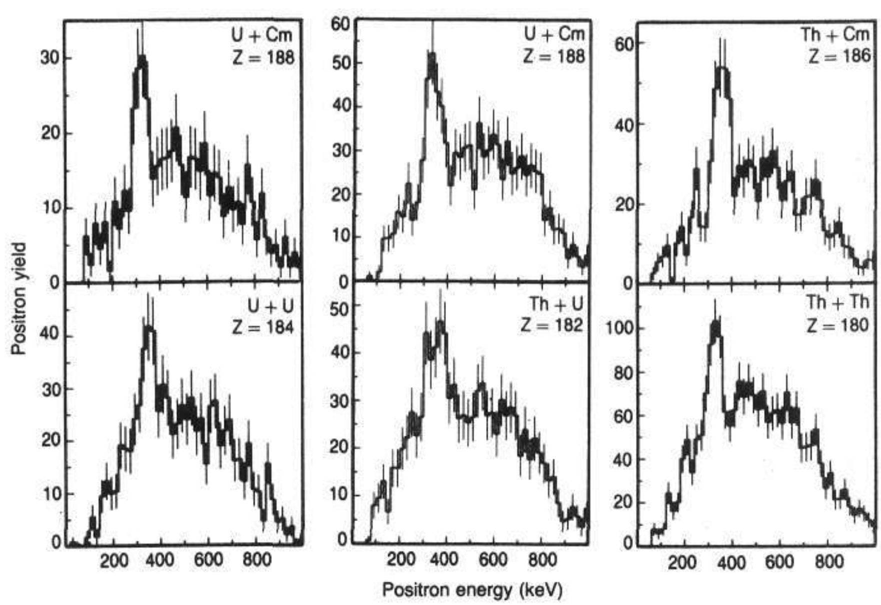
Quantum electrodynamic predictions say that peak production of positron-electron pairs should be very sensitively correlated to Z. The surprise in the Darmstadt result is that this pair production has occurred over a broad range of Z, while the energy of the positron-electron pair remained very constant at about 300 keV irrespective of the colliding energies as well as of the Z.

In the case of heavy nuclei, which have a high charge, there is a very strong electrostatic field at the lowest lying level. With normal elements, the chemical bonding at the valence shell is in the range of 8 to 10 eV, whereas with heavy nuclei the charge is in the range of 1 million eV. (The shell, of course, will be much closer to the nucleus because of the extremely high charge of the nucleus.) It is from this high field that the paired particles are produced. The energy required to produce an electron ($E = mc^2$) will be approximately 511,003 eV, and both a positron and an electron are created at $2 \times 511{,}003$ eV.

Conventional Wisdom?

Like the fifth force people, conventional wisdom is already looking for the decay of a previously unknown *boson* to account for these findings. And this new boson should be, in their view, only about three times the mass of the electron. Others are looking to quark theory for an explanation.

Results such as these point to the need for major revision in quantum theory. One place to look is the crucial experiment conducted by Erich Bagge that showed that the production of a positron-electron pair



Quantized positron kinetic energy peak. Contrary to theoretical predictions, positron-electron pairs are created in nuclei with high atomic numbers in the Z range from 180 to 188. The quantized positron kinetic energy peak occurs at 300 keV. Shown are experimental results for the Darmstadt experiments.

Source: Institute for the Study of Heavy Ions, Darmstadt University, West Germany from a gamma ray had an energy spectrum in effect opposite in distribution to that predicted by the Bethe-Heitler theory.[2]

Bagge conducted this experiment as a crucial demonstration that the theory behind the Bethe-Heitler prediction was incorrect, in particular because it depended upon the posited existence of the neutrino to prevent violation of energy conservation laws. Bagge's own theory accounts for the apparent loss of energy, by denying the existence of a vacuum and substituting instead a fundamental "negative energy" state, in which the positron normally exists and from which it must be torn away.

Notes

1. "Puzzling Positron Peaks Appear in Heavy Ion Collisions at GSI," by Bertram Schwarzschild, *Physics Today* (Nov. 1985), p. 17.
2. See the accompanying note by Bagge and also his article "Why Neutrinos Don't Exist: What Really Happens in Pair Production and Beta Decay," in *Fusion* (Nov.-Dec. 1985), p. 29.

Low-Energy Positrons in Pair Creation

by Erich H. Bagge

In the November 1985 issue of *Physics Today*,[1] Bertram Schwarzschild reports on "puzzling positron peaks appearing in heavy ion collisions at the Society for Heavy Ion Research at Darmstadt in West Germany (GSI)." There is also a discussion of experiments to explain the intensity peaks of positron energies between 300 and 400 keV.

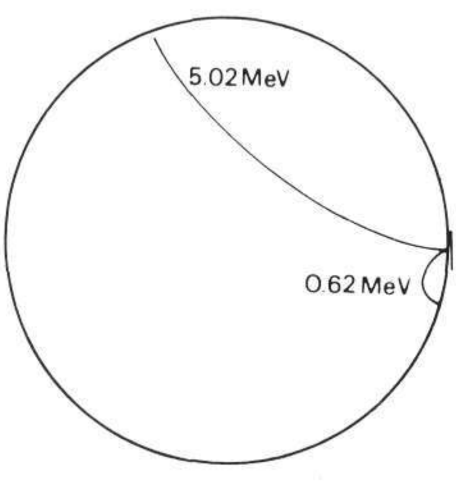
Erich R. Bagge, Ahmed Abu El-Ela, and Soad Hassan have reported in several places,[2] on measurements of pair creation of positrons and electrons that were triggered by gamma quanta of 6.14 MeV at their passage at nuclei of gold atoms ($Z = 79$). It was also established that the positrons predominantly receive low kinetic energies, generally around 270 keV.

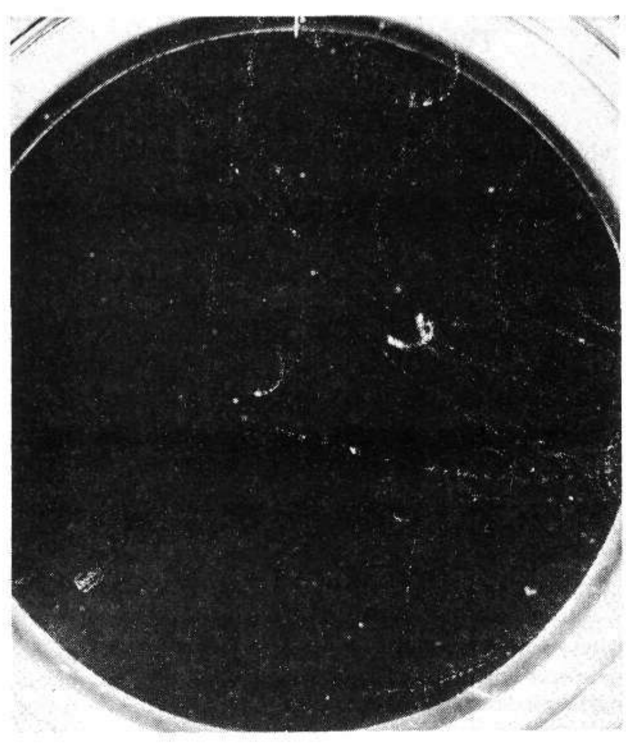
There is a great probability that both the GSI measurements and those done by our group at the University of Kiel are based on the same effect. If one conceives of the impact of a uranium nucleus ($Z = 92$) of 6 MeV energy per nucleon on another uranium nucleus of the same type at rest as being a pair-producing process, as if the Fourier-analysed Coulomb fields of the 92 impacting protons would be fields of light quanta, then these trigger electron-positron pairs in the Coulomb field of the nucleus at rest. In these pairs—in accordance with our observations and their consequent interpretations—mainly positrons are created, densely compacted at the surface of the Dirac Sea; that is, with practically zero energy. These positrons are then discharged through the Coulomb field of the uranium nucleus at rest.

Since the positrons must be looked at as wave packets of minimal extension h/mc, they can, by means of this discharge process, gain the energy:

$$E^{+}_{\text{kin}} = \frac{Ze^2}{\hbar c} mc^2 = 92/137\ mc^2 = 343.2\ \text{keV}.$$

This is just about the energy found at GSI in the maximum intensity peaks, during six experiments using various actinic impact partners. The results of the ex-





Trajectories of an electron-positron pair. In this photograph of one of Bagge's experiments in a Wilson cloud chamber, the electron exits upward, with energy of 5.02 MeV, while the positron exits downward with energy of 0.62 MeV. According to the Bethe-Heitler theory, the two energies were supposed to be nearly equal.
Courtesy of Erich Bagge

periments our group conducted at Kiel show the same interpretation in the case of the gold nucleus, with somewhat smaller average energies:

$$E^{+}_{\text{kin}}\,(\text{Kiel}) = E^{+}_{\text{kin}}\,(\text{GSI}) \cdot 79/92$$
$$= 294.7 \text{ keV}.$$

Notes

1. "Puzzling Positron Peaks Appear in Heavy Ion Collisions at GSI," by Bertram Schwarzschild, *Physics Today*, (Nov. 1985), p. 17.
2. Erich R. Bagge, *Fusion* (German-language edition), (Dec. 1985), p. 11; and *IJFE*, (Jan. 1985), p. 53; Ahmed Abu El-Ela, Soad Hassan, Erich R. Bagge, *Atomkernenergie/Kerntechnik*, **47** (109), 1985; **45** (208), 1984; *Fusion*, (Nov.-Dec. 1985), p. 29.

New Directions for Quantum Physics

by Dr. Robert J. Moon

At the same time that high-energy physicists are continuing the search for the evanescent quark and elaborating its theoretical attributes, recent experimental work suggests that a return to the line of thought indicated by de Broglie and Schrödinger nearly 60 years ago would be more fruitful. Rather than looking at the "fundamental" particle-of-the-day as the primary building unit, such an approach demands recognition that there are coherent systems of structures in which "particles" may exist.

The demonstrated stability of the proton (with a lifetime of more than 10^{22} years) leads to the reasonable conclusion that the magnitude of the force needed to sunder a proton to observe a quark, would be enormous. Such a force would indeed have to counter the force of space itself. In other words, the proton is a singularity that exists within, and depends upon, the geometry of the whole of space, and all of its particles.

Furthermore, as elaborated here, the fundamental particle in the universe (as observed at present), is an old and familiar friend—the electron. Every formula, including that for the quark, in the final analysis, depends upon a measure of the amount of charge. Such a measure is, in effect, nothing else but a count of the electrons; that is, an addition of geometrical singularities. Of course, these are balanced by repulsive force between positive charges, but this does not alter the point.

The recent award of the Nobel Prize to Klaus von Klitzing, for demonstrating the quantization of the Hall resistance, suggests both a series of further experiments and new possibilities for merging the empirical findings of quantum physics with a more "classical" geometrical approach to their interpretation.

Klitzing (1980) established the Hall resistance for the quantum number $n = 1$ to be 25,812.815 ohms, which yields the highest principal plateau for the Hall resistance as a function of the magnetic flux density; and for other plateaus which occurred for lower values of the magnetic flux density, and lower Hall impedances for $n = 2, 3, 4$, and 5. The plateaus become less distinct for $n > 5$. This experiment provides a highly accurate means of measuring the fine structure constant, because of the accuracy with which h/e^2 can be determined.

Klitzing found the value of the Hall resistance in a very thin strip of semiconducting material using current control electrodes to keep the number of current carriers at a low value. He worked at temperatures near absolute zero tó reduce the thermal agitation of nuclei in the semiconductor. As a result, he determined the value of h/e^2 more precisely than was previously possible. In 1969, publication of the Josephson effect (Parker et al. 1969; Josephson 1965) allowed a major improvement in the accuracy of measurement of the fundamental constants, giving the value of the Josephson Frequency-Voltage Ratio $= 2e/h = 4.835976(12) \times 10^{14}$ Hz V^{-1} (2.4 ppm).

From a slightly different perspective, this suggests the reinterpretation of the fine structure constant itself—in the case of the Hall impedance in a two-dimensional semiconductor—as the ratio between the largest resistive or active component of the impedance with a sharply defined reactive component, h/e^2, to that of the reactive impedance of free space, $\mu_0 c$. The fine structure constant involves—along with the velocity of light, the electronic charge, and Planck's constant—a value, μ_0, representing the permeability of free space. The product of μ_0 and c is the impedance of free space, equal to 376.7303 ohms. This ratio, of the impedance of free space to the greatest Hall impedance with a sharp reactive component (the fundamental Hall impedance), is $\mu_0 c/(h/e^2)$, and at $n = 1$, is equal to 2α, where α is the fine structure constant. Such an interpretation immediately raises the question of the actual geometry of free space.

What of the difference between *free* space and the *limited* space in the extremely thin semiconductor used to demonstrate the quantized Hall resistance near absolute zero (that is, the behavior of the electron in a plane)? Why does "the electron" behave differently in the plane and in free space? The quotation marks are there to hint at the solution. Is the electron properly considered as an individual?

The geometry of close packing in a plane provides a plausible model for the quantized Hall resistance (sharply defined quantized reactive components of the Hall impedance). This model utilizes the cyclotron frequencies of the electron to provide the geometric metric for circulation of the electrons in the plane as follows: Since the strength of the magnetic induction and the velocity of the electron determine the radius $r = m_e v/Be$ of circulation of the electrons, this model and the cube, matching vertices to the centers of faces. The octahedron has a symmetry, but does not fit such that every face of the icosahedron has a vertex in it. This is more than likely due to the closeness of the protons to one another. Forty-six positions are easily filled; a second such dodecahedronal configuration can be attached to the first, sharing one pentagonal face. This means that the two dodecahedrons together have only 86 positions available (5 vertices being shared). This is the nucleus of radon. The 87th position violates the exclusion principle, and hence a singularity occurs in the form of an instability. This opens the configuration sufficiently to allow the addition of five more protons connected to the pentagonal face where the singularity occurs. The two dodecadedrons will now be annexed at only one vertex—a position of maximum instability.

This model is currently being developed in a computer simulation and shall be elaborated in future issues of the IJFE. Applications to the process of nuclear fission, particularly in the case of element 92, uranium, will be developed.

References

B.D. Josephson. 1965. *Advan. Phys.* **14**: 419.

K.v. Klitzing, G. Dorda, and M. Pepper. 1980. *Phys. Rev. Lett.* **45**: 494.

W.D. Parker et al. 1969. *Phys. Rev.* **177**: 639.

Bertram Schwarzschild. 1985. *Phys. Today* **38**: 17-20 (Dec.).

Is the Universe Really Expanding?

by Jim Everett

Based on: "Is the Universe Really Expanding?" by Paul A. LaViolette, Astrophys. J., **301**: *544-553 (Feb. 15, 1986).*

Since Fred Hoyle and company in effect conceded defeat after the discovery of microwave background radiation, no one in the astronomy establishment has fought for an alternative to the Big Bang scenario of cosmic creation. Although a number of astronomers may be uncomfortable with the creation ex nihilo hypothesis, Big Bang proponents have had an impressive string of observation-to-theory successes. The list includes the helium to hydrogen ratio, the universal background radiation, and the expansion of the universe. In the swelling chorus of acceptance, it is sometimes hard for a single dissenting voice to be heard.

Paul LaViolette has revived the "tired light" hypothesis, first proposed by Zwicky in 1929, as an alternative explanation to the observed red shift of galaxies. LaViolette, in earlier published work, noted that a photon of light loses energy at the rate of 5-7 percent per 109 light years. Realizing that the Doppler shift explanation is the foundation of the Big Bang, he proposes in this paper to compare the tired light model to the Big Bang model in four crucial areas.

> It is concluded that the tired light model makes a better fit on all four data sets. The expanding universe hypothesis may be considered plausible only if it is modified to include specific assumptions regarding the evolution of galaxy cluster size, galaxy radio lobe size, galaxy luminosity, and galaxy number density. . . . But the required assumptions are numerous. Consequently the tired light model is preferred on the basis of its simplicity. Presently available observational data, therefore, appear to favor a cosmology in which the universe is conceived of as being stationary, Euclidean, and slowly evolving, and in which photons lose a small fraction of their total energy for every distance increment they cover on their journey through space. (p. 552)

Like the Bondi-Gold-Hoyle theory of 1948, LaViolette sees matter as being created continuously throughout space, each new particle serving as a nucleation site for further particle creation. Particle creation sites would come into being only rarely and grow slowly initially, but the growth would increase exponentially. The universe would then be much older than in the Big Bang scenario, but galaxies would not be infinitely old.

The LaViolette hypothesis shares, however, important fundamental features with the Big Bang model. Creation ex nihilo is simply distributed throughout the universe in space and time, rather than localized in an initial event. In the Big Bang, the universe begins to die a heat death from the very moment of creation. With LaViolette, the universe is also entropic, but with a new twist. What happens to the energy lost by traveling light? He believes that energy is not a conserved quantity, but that it disappears from the universe.

Filaments of Galaxy Clusters

by Jim Everett

Based on: "A Possible 300 Megaparsec Filament of Clusters of Galaxies in Perseus-Pegasus," by David J. Batuski and Jack O. Burns, Astrophys. J., **299**: *5-14 (Dec. 1, 1985).*

Cosmologists have had precious few observational constraints to incorporate into their cosmic creation theories. That is beginning to change now, at least in the area of large-scale distribution of matter in the universe. With the help of new automated spectral techniques, the measurement of redshifts of thousands of galaxies is adding a third dimension to galaxy distribution maps.

The early Shane-Wirtanen two-dimensional map of galaxies showed intriguing suggestions of large-scale filamentary structure, but one could not be certain that the filaments were not the result of chance projections of galaxies on the map. The Batuski and Burns study is the latest of several over the last few years to support the reality of filamentary structures.

Their three dimensional map plots the largest structure yet detected in the universe, an apparent filament of galaxies and galaxy clusters stretching over one billion light years long through the constellations Perseus to Pisces. Surrounding the filaments are huge voids.

Another recent survey led by Margaret Geller of the Center for Astrophysics suggests that galaxies may lie on the surface of "bubbles," thin regions that bound large voids. In this view, filaments may be only apparent, that is, bubble surfaces seen edge on.

Filamentary structures this large pose problems for the most widely accepted theories of galaxy formation. The isothermal model of globular, cluster-size, density fluctuations that coalesce into gradually larger structures over time cannot build structures this large. The adiabatic, or "hot particle" model, where all but large-scale fluctuations are damped out, requires either new particles or particles with as yet undetected properties.

Gamma Rays From Cygnus X-3
by Jim Everett

Based on: "Detection of 10^{15} eV Gamma Rays From Cygnus X-3," by T. Kifune, Astrophys. J. **301**: *230-234 (Feb. 1, 1986).*

High energy gamma rays ($> 10^{12}$ eV) are an important component of cosmic rays striking Earth, but their source has remained mysterious. Over the last decade attention has focused on the strong X-ray emitter Cygnus X-3. Gamma rays with energies less than 1,015 eV were detected starting in 1976. The signature of Cygnus X-3 radiation is the 4.8-hour periodicity of the presumed binary star system. In 1983, Samorski and Stamm were the first to report 10^{15} eV gamma rays of 4.8-hour periodicity coming from the direction of Cygnus X-3. This observation was confirmed shortly afterward in England, India, and elsewhere. But the need for further observations is great. Each of the groups has detected only a handful of unambiguous events and the generation mechanism of PeV gamma rays is unclear.

The latest Cygnus X-3 gamma-ray detection comes from the Institute for Cosmic Ray Research in Tokyo. They deployed an array of scintillators to record extensive air showers (EAS) sparked by high-energy, gamma-ray interactions in the atmosphere. The scintillators are tied to a "trigger" that is used to isolate and record only high energy EAS. Gamma-ray-induced EAS are muon poor. The Tokyo group recorded 18 such muon-poor events in the period 1981-1984. Their data suggest a peak near 0.6 phase, which is also the X-ray peak.

The Tokyo results differ somewhat from previous efforts, and these differences point to the outstanding problems concerning Cygnus X-3. Their 0.6 phase is different from the 0.3 phase of Samorski and Stamm and others, which is the X-ray minimum. The difference may be due to the sensitivity of the "trigger", but it may point to a double peak in intensity. If this is the case, the gamma-ray source may be a pulsar beam passing twice through the atmosphere of a companion star. Gamma rays would be produced by inverse Compton scattering as electrons or, more likely, protons entered the companion star's atmosphere.

Also unusual was the Tokyo report of a lower than expected deficit in muons detected in the EAS, compared to Samorski and Stamm. Their higher figure is uncharacteristic of gamma-ray interactions as currently understood, prompting some to suggest that the Cygnus X-3 radiation was not gamma rays at all, but an unknown, long-lived neutral particle. (Charged particles would be deflected somewhat and thus not show the observed 4.8-hour periodicity.) The Tokyo finding is more in line with theoretical predictions, supporting the gamma-ray hypothesis.

Abstracts

The following selection, prepared by Wolfgang Lillge, M.D., is a history and present status report of basic virology research, with special emphasis on retroviruses. The AIDS pandemic (whose causal agent is linked to a retrovirus called variously HTLV-III, LAV, ARC) has made it mandatory to massively push ahead with this research. Beyond this immediate concern, studies of retroviruses may eventually provide fresh knowledge about natural evolution, including the evolution of man.

Retroviruses

"The DNA Provirus Hypothesis"
by H.M. Temin
***Science*, Vol. 192, pp. 1075-1080**
(June 11, 1976)

In this paper (delivered as a lecture in Stockholm, Sweden, on Dec. 12, 1975 when he received the Nobel Prize in Physiology or Medicine) Temin, for the first time, officially contradicted the "central dogma of molecular biology" formulated in the late 1950s. This dogma stated that genetic information would only be transferred from DNA to RNA to protein. Using the Rous sarcoma virus (RSV), Temin demonstrated that retroviruses in fact undergo a life cycle, starting with the viral RNA single strand that is transcribed into DNA by an enzyme called reverse transcriptase. A second strand of DNA is synthesized, and a double-stranded closed circular viral DNA appears, which eventually is integrated into the genome. As early as 1964, Temin called this integrated piece of viral genetic material a "provirus", which acts as a template for the synthesis of progeny RSV RNA.

In the 1960s, Temin had demonstrated that these viral genes mutated at a high rate; that mutation in a viral gene present in an infected cell often led to a change in the morphology of that infected cell; that two different viruses infecting one cell were stably inherited; and that the intracellular viral genomes were probably located at only one or two sites in the cell genome.

Based on observations of the phylogenetic distribution of endogenous virus-related nucleotide sequences in chickens and other animals, in 1970, Temin arrived at a "protovirus hypothesis"; that is, that RNA-directed DNA polymerase (reverse transcriptase) activity exists in normal animals; that it plays a role in normal cellular processes like differentiation; that RNA tumor viruses evolved from this activity; and that cancer arises from variational events in the functioning of this activity.

"On the Origin of RNA Tumor Viruses"
by H.M. Temin
***Annual Review of Genetics*,**
Vol. 8, pp. 155-177 (1974)

In this paper, Temin further elaborates his ideas about the generation of RNA viruses from normal genomes. He states that proviruses and potential proviruses (protoviruses) acted as agents of the expansion and alteration of cellular nucleic acid sequences seen in evolutionary times, as might have happened in gene duplications and in the differentiation of an organism. This protovirus mechanism has the advantage that it can involve any length of DNA (from part of a gene to many genes), that no deletion of the original DNA is required, and that the duplicated DNA can be inserted anywhere in the cell genome.

Protoviruses, according to Temin, have undergone independent but parallel evolution in different organisms, and the closer to an active provirus this system became, the more efficient it was regarding its primary cellular functions.

"Viruses, Polymerases, and Cancer"
by David Baltimore
***Science*, Vol. 192, pp. 632-636 (May 14, 1976)**

The author, Professor of Microbiology at MIT (who received the Nobel Prize for Physiology or Medicine 1975 together with Temin and Dulbecco), states in his Nobel lecture that one of the major breakthroughs in uncovering the role of RNA viruses was the discovery that these viruses themselves carry an RNA polymerase (an enzyme that copies the viral RNA into multiple messenger RNAs). Subsequently, it was discovered that RNA tumor viruses carry a DNA wrapped up inside. This kind of virus is now known as retrovirus and the enzyme as reverse transcriptase.

Baltimore discusses the question of why retroviruses are the only viruses found to induce cancer. He thinks that the integrated DNA sequence provides the necessary stability to the virus-cell interaction so that a viral gene product can permanently change the growth properties of an infected cell.

Moreover, the transformation of cells by retroviruses is highly selective so that only a limited range of cell types are transformed by a given virus. Baltimore concludes: "If we assume that all transforming genes of viruses are like those of Rous sarcoma virus, genes that are not necessary to the growth of the virus, then we can postulate that each type of transforming virus makes a specific type of transforming protein."

"Multiple Divergent Copies of Endogenous C-Type Virogenes in Mammalian Cells"
by R.E. Beneviste and G.F. Todaro
***Nature* Vol. 252, pp. 170-173 (1974)**

The authors report that all individual animals of a species (as well as all tissues of each animal) contain, in the chromosomal DNA, nucleic acid sequences that can code for the production of complete C-type viral particles. They postulate that these sequences (C-type virogenes) are transmitted from parent to progeny with the other cellular genes.

"Evolution of C-Type Viral Genes: Evidence for an Asian Origin of Man"
by R.E. Beneviste and G.J. Todaro
***Nature* Vol. 261 (May 13, 1976)**

On the basis of the evidence of the previous paper, the authors discovered that Old World monkeys and apes, including man, possess as a normal component of their cellular DNA, gene sequences (virogenes) related to the RNA of a virus isolated in baboons. Those Old World monkeys and apes that have evolved in Africa can be distinguished from those that have evolved in Asia, comparing the viral gene sequences and the other cellular gene sequences. By these criteria, the authors conclude, only the gorilla and chimpanzee seem to be of African origin, while gibbon, orangutan, and man are identified as Asian. Therefore, there is reason to believe that man's evolution has occurred outside Africa, despite man's close morphological and anatomical resemblance to the African apes and despite most of the recent paleontological discoveries that would indicate an African origin of our species.

"Sequence of Retrovirus Provirus Resembles That of Bacterial Transposable Elements"
by K. Shimotohno, S. Mizutani, and H.M. Temin
***Nature* Vol. 285 (June 19, 1980)**

With recombinant DNA techniques for cloning eukaryotic genes and with rapid DNA sequencing, the authors succeeded in isolating several infectious proviruses of spleen necrosis virus and their surrounding cellular sequences including the cell-virus junctions. The structure found resembles that of bacterial transposable elements and is consistent with Temin's original protovirus hypothesis that retroviruses have evolved from the normal cell genome involved in regular transfer of genetic information in and between cells. Transposable elements (transposons) are bits of DNA that only occasionally move about their parent genomes; however, when they do move, they sometimes travel as free DNA circles before integrating back into the chromosomal DNA in a new location.

"Viruses and Cells: A History of Give and Take?"
by A. Scott
***New Scientist* Vol. 109, pp. 42-47**
(Jan. 16, 1986)

In this review article, the author presents the current knowledge about retroviral replication and its implication for evolution. He describes viruses as "roving bits of nucleic acid [that] were apparently once cellular genes that have escaped to infectious freedom."

The article includes a report of work by K. Saigo at Kyushu University in Japan, who has found a transposon that contains genes very similar to the three main genes found in all retroviruses, including the one that encodes the crucial reverse transcriptase enzyme. Apparently, Saigo also found transposons that became wrapped up in some kind of outer coat, forming structures very similar to viruses. Thus, it seems that there is a much closer relationship between retroviruses and transposable elements than has been previously thought. The basic hypothesis is that transposons may sometimes generate viruses, while viruses may occasionally regress back into transposons.

The author discusses also the role of "viroids", pieces of naked infectious RNA that can do great damage to plants, but are only speculated to cause cancer in animals. It turns out that viroids are structurally related to "introns," which are noncoding sections of RNA spliced out of precursor RNAs when the mature RNA of a gene is formed. It is suggested that these introns actually gave rise to viroids after mutational or other transformation and set free and multiplied out of control. In that way, introns may even have evolved into proper viruses.

D. Zimmern of Cambridge University, the author reports, discovered that introns may be replicated soon after their release, and then be released to the neighboring cells, in a way that "informs" them about which genes are active in their own cell.

A debate has started in the virology community, the author reports, about whether viruses might in fact have contributed greatly to evolution by being able to transfer genes between organisms and cells or to alter the genomes of cells simply by integrating into sensitive sites. Species jumps in natural evolution, otherwise not explainable by "random mutation" or "selection", could be traced to the input of viral genetic parts into the host genome.

"The Terminal Nucleotides of Retrovirus DNA Are Required for Integration But Not for Virus Production"
by A.T. Panganiban and H.M. Temin
***Nature* Vol. 306, pp. 155-160**
(Nov. 10, 1983)

Nucleotide sequence analysis of the termini of retrovirus DNA has revealed that there are characteristic differences between unintegrated and integrated strands of virus DNA respecting changes in the Long Terminal Repeat (LTR) of the viral DNA and the end parts of the cellular DNA. The two authors report that deletion of specific nucleotides at either end of the LTR of the avian retrovirus, spleen necrosis virus, results in replication-competent, but integration-defective virus. They draw two conclusions: A clearly defined portion of the terminal part of virus DNA is required for integration, but integration of retrovirus DNA is not required for retrovirus gene expression.

Unintegrated viral DNA contains all sequences required for expression of the retrovirus genes, and this form can serve as a suitable template for transcription, however at a lower rate of virus production.

"Retrovirus Vectors for Gene Transfer"
by H.M. Temin
To be published in *Gene Transfer* Ed. R. Kucherlapati. New York: Plenum Press

In addition to discussing the use of retroviruses as vectors for gene transfer, the author provides current information about retroviral activities. He lists three different biological systems where reverse transcriptase has been used to synthesize DNA that is integrated into chromosomal DNA:

(1). Highly oncogenic retroviruses, that contain viral oncogenes either substituted for or added to the retrovirus genome. They don't contain transcriptional control elements or other control sequences. It seems all of these sequences are lost during evolution of highly oncogenic retroviruses from their original status as proto-oncogenes.

(2). Retrotransposons. In the genome of any eukaryotic cell there is generally a considerable amount of cellular movable genetic elements that use reverse transcriptase for transposition that are called transposons or now retrotransposons because of their sequence similarity with retroviruses. The difference from retroviruses is that they do not make infectious particles and often don't have the *env* gene coding for the envelope protein. Temin estimates the number of copies of retrotransposons in the mammalian genome to be 1,500 per haploid genome in mouse and man; that is, 1.5 percent of these genomes.

(3). Retrotranscripts. These are sequences with characteristics resembling reverse transcription as well as transposition, and they have been called retrotranscripts to differentiate them from retrotransposons. The mammalian genome, according to Temin, contains at least 500,000 copies of retrotranscripts per haploid genome in mouse and man, which amounts to nearly 10 percent of these genomes.

"Circles with Two Tandem LTRs Are Precursors to Integrated Retrovirus DNA"
by A.T. Panganiban and H.M. Temin
***Cell* Vol. 36, pp. 673-679 (March 1984)**

When a cell is infected by retroviruses, this leads to the synthesis of three different forms of virus DNA. The authors determined that only circular DNA with two tandem Long Terminal Repeats (LTR) will serve as precursors to the provirus.

"Evidence for Two Forms of Reverse Transcriptase in Human Placenta of a Patient with Breast Cancer"
by A. Vogel and P. Chandra
***Biochem. J.* Vol 197, pp. 553-563 (September 1, 1981)**

The two researchers at the University of Frankfurt, West Germany, purified two different polymerases with properties of viral RNA-directed DNA polymerase in the placenta of a patient with breast cancer. The two enzymes are distinguished by their specificity to transcribe two different RNA-DNA hybrids, and have other differences in biochemical properties. They note that after the discovery of reverse transcriptase in human leukemic cells by Gallo in 1980 as the first evidence for the expression of retroviral information in human malignancy, their own laboratory purified reverse transcriptase from different human tumor tissues and showed that these enzymes are biochemically similar to reverse transcriptase from the known retroviruses, but distinct from their respective cellular DNA polymerases.

"The Location of V-src in a Retrovirus Vector Determines Whether the Virus is Toxic or Transforming"
by W.G. Tarpley and H.M. Temin
Molecular and Cellular Biology
Vol. 4, No. 12, pp. 2653-2660 (December 1984)

This work investigates the insertion of oncogenes (like the avian sarcoma virus v-src gene) at different sites in the virus genome and concludes that the location of an oncogene in the viral genome is an important factor regulating the level of its expression and whether or not this expression is toxic or transforming to cells. Inserting the v-src gene near the 5′ end of the viral genome resulted in a vector with an acute toxic effect on chicken and dog cells, while the presence of the same gene near the 3′ end of the viral genome led to malignant transformation of such cells.

HTLV-III/LAV

"Complete Nucleotide Sequence of the AIDS Virus, HTLV-III"
by R.C. Gallo et al.
***Nature* Vol. 313, pp. 277-283 (January 24, 1985)**
"Nucleotide Sequence and Expression of an AIDS-Associated Retrovirus (ARV-2)"
by R. Sanchez-Pescador et al.
***Science* Vol. 227, pp. 484-492 (February 1, 1985)**
"Sequence for the Lymphadenopathy-Associated Virus (LAV)"
by L. Montagnier et al.
***Cell* Vol. 37 (January 1985)**

These three original papers report on the molecular characterization of the virus that is believed to cause AIDS. The differences in sequence reflect the high mutagenicity of key parts of the virus genome, the main reason researchers do not expect any early development of an AIDS vaccine.

"Human T-Lymphotrophic Retroviruses"
by F. Wong-Staal and R.C. Gallo
***Nature* Vol. 317, pp. 395-403 (Oct. 3, 1985)**

This is a very comprehensive review article discussing the key aspects of human retroviruses, including HTLV-III/LAV, the putative agent caus ing acquired immune deficiency syndrome. The authors note that HTLV-III constitutes a continuous spectrum from closely related viruses to more divergent viruses. LAV, the original isolate of the Pasteur group, and ARV (aids-related virus), an isolate obtained more recently, both fit within this spectrum. However, they warn, the most divergent part of the genome lies in the portion of the *env* gene that codes for the major exterior glycoprotein. There are clearly "hot spots" of mutation in this area, which might correspond to epitopes that drift with immunoselection. On the other hand, there are also regions of strong stability, one of which interacts with the cellular receptor.

The authors also address the problem of false-positive and false-negative AIDS antibody tests. They state clearly that seropositivity almost certainly means also virus positivity; that is, "a properly performed positive result means a person is infected, and until proven otherwise the individual must be considered infectious." However, false negative tests, where an AIDS-virus carrier is seronegative for antibodies, is a much more grave problem given the fact that there may be many more such cases than so far suspected that are infectious without knowing it.

AIDS, Papers from Science 1982-1985
Ruth Kulstad, ed.
Washington D.C.: American Association for the Advancement of Science (1986)

This contains all the papers dealing with AIDS that appeared in *Science* in the period between 1982 and 1985. It is a useful encyclopedia since many of the original research papers on the topic first appeared in *Science*.

"Approaches to AIDS Therapy"
by D. Klatzmann
and L. Montagnier
***Nature* Vol. 319, pp. 10-11**
(Jan. 2, 1986)

The authors discuss therapeutic approaches to AIDS in the context of the sensational treatment of AIDS patients with the tumor drug cyclosporin A, an immunosuppressant, by a group of French physicians. The question posed by such an approach is whether AIDS can be considered a virus-induced autoimmune disease. There are at least two reasons why AIDS is not the result of the direct destructive effects on lymphocytes.

The first is that the AIDS virus will only replicate and have cytopathic effects on activated T4 lymphocytes. Infected, but resting T4 cells, do not show viral replication or expression of viral antigen on the cell's surface. A second reason is that apparently only a small portion (5-10 percent) of T4 cells is infected by the virus, and in AIDS patients normally less than 1 in 10,000 lymphocytes are found to replicate HTLV-III/LAV virus at a given time. Thus, there must be other processes involved that account for the impairment of T4 cell number and function.

The authors discuss the possibility of an immunosuppressive protein produced by the AIDS virus, as in the case of the human T-cell leukemia viruses I and II. So far, only a "soluble factor" has been suggested to be present in sera of an AIDS patient that can suppress *in vitro* T-cell functions. But also a specific autoimmune mechanism is not excluded by the authors. They think it is possible that not only HTLV-III/LAV virions themselves can bind to T4 molecules, but also free virus proteins released from HTLV-III/LAV producing lymphocytes. If that is the case, noninfected lymphocytes become highly immunogenic because of the surface-bound T4 molecules (proteins) leading to a classical cellular and antibody mediated cytotoxicity. This whole destructive process may be enhanced by the repeated stimulation of the immune system by other antigens or alloantigens.

Therapeutic approaches must therefore concentrate on three fields identified by the authors:

(1) Destruction or inhibition of viral particles and infected cells. Trials with several different drugs did not yield lasting improvements in the patients' conditions.

(2) Stimulation of the immune system. Drugs such as interleukin-2 and interferon have been tried on a restrictive basis because there is a high risk of actually accelerating progression of the disease when the virus replicates in stimulated lymphocytes faster than before.

(3) Immunosuppressive approach. This type of treatment would be directed to control virus replication in a first step and then to make the immune system "tolerate" noninfected cells coated with virus proteins.

The authors suggest extreme caution with this last approach, and they quote reports in the literature about fulminant pneumocystis carinii pneumonia in patients after being treated with immunosuppressive drugs before it was known that they were AIDS-infected.

"The *Trans*-activator Gene of HTLV-III Is Essential for Virus Replication"
by F. Wong-Staal et al.
***Nature* Vol. 320, pp. 367-371 (March 27, 1986)**

This paper represents the specific basic work to uncover all the genetic properties of the HTLV-III/LAV retrovirus implicated as the causal agent of AIDS. The authors report the identification of a sixth open reading frame in addition to the five previously known in the genome (*gag, pol, sor, env,* and 3′*orf*). The expression of this new gene, *tat*-III, is reported to be an absolute requirement for virus expression. The observation that *tat*-III is critical for virus replication may have relevance for the treatment of AIDS patients since a specific inhibition of this gene's activity could represent a novel and effective therapeutic approach.

"Acquired Immune Deficiency Syndrome in Florida—A Review"
by C.L. MacLeod, G. Scott, and M. Whiteside
***Journal of the Florida Medical Association* Vol. 71, pp. 112-171 (September 1984)**

For the first time the suggestion is made that AIDS may have a much broader Caribbean and tropical base than believed so far. It is also stated that "environmental factors" may contribute to the epidemiology of AIDS in the tropics.

Physics

These abstracts were prepared by Charles B. Stevens.

"Determination of the Conservation and Balance of Magnetic Helicity Between Source and Spheromak in the CTX Experiment"
by Chris W. Barnes et al.
Los Alamos National Laboratory Preprint LA-UR-85-2993, submitted to *The Physics of Fluids*

This paper reviews the experimental evidence for conservation of magnetic helicity for time scales which are short, compared to resistive diffusion time in the CTX spheromak. Helicity is generated electrostatically in the CTX by currents drawn from electrodes. The plasma ring then flows into a conducting flux conserver during which a closed spheromak configuration is generated and sustained. The initial helicity generated by the electrodes, and that maintained by the equilibrium spheromak, are measured within $\pm$ 16 percent. Thus, the transfer efficiency of magnetic energy from the electrodes to the spheromak is determined. The increment of energy, lost while conserving helicity in the formation process and sustainment of the spheromak, is controllable. This lost energy has been measured as ranging from 1.8 to 10 times the magnetic energy content of the CTX spheromak. Sustainment to classical resistive decay times with electrostatic helicity injection has been explored.

"Polarization of the Radiation Scattered As a Result of Interaction of Laser Photons with Relativistic Electrons"
by V.A. Musrashova et al.
P.N. Lebedev Physics Institute, Moscow
***Sov. Phys. JETP*, Vol. 61, No. 2, pp. 196-198 (Feb. 1985)**

Both theory and experiment are reviewed with regard to orthogonal geometry for scattering between electron and photon beams and the polarization of the resulting radiation. It is concluded that generation of a polarized gamma-ray beam should be possible in orthogonal geometry.

"On the Role of the Periodical Structures Induced by Powerful Laser Irradiation of Metallic Surfaces in the Energy Coupling Process"
by I. Ursu and I.N. Mihailescu
Central Institute of Physics, Bucharest, Romania
***Physica*, Vol. 132C, pp. 395-402 (1985)**

Development of periodical structures (PS) has been demonstrated recently. PS parameters appear to be determined by wavelength, polarization, and angle of incidence of the laser light. PS appear to facilitate and enhance energy transfer from the laser beam to the metal surface. This paper shows that surface electromagnetic waves, which develop on the surface of metallic targets together with PS, are generated by high-power laser irradiation. These waves increase the energy transfer to the metallic structure. In this way, phenomena previously thought to be anomalous, or only accounted for in terms of defects and impurities, can now be more directly explained.

"Fluid Dynamics, A LASL Monograph"
by Francis H. Harlow and Anthony A. Amsden
LA-4700, UC-34

This report develops the equations of basic physical fluid dynamics and some techniques for obtaining solutions in specific problems. Areas covered include a simplified discussion of molecular dynamics as related to fluid flows, rarefactions and shocks, compressible-flow solutions, incompressible-flow solutions and numerical methods for high-speed computers. The monograph provides the formal background for methods currently incapable of solving the Riemann problem of the isentropic expansion of a gas through a vacuum and its interaction with a wall.

"Energy Deficits in Pair Creation by Gamma Rays"
by Ahmed Abu El-Ela et al.
***Atomkernergie-Kerntechnik,* Vol. 47, No. 2, pp. 109-114 (1985)**

Observations of pair production by 6.14, 6.91, 7.11 and 8.87 MeV gamma rays in a Wilson cloud chamber show that the energy spectra of generated positrons and electrons disagree strongly with those predicted by quantum electrodynamics in its usual form. While this theory predicts that the spectra should be exactly the same for both electrons and positrons, the experimentally reported spectra show that the electrons receive most of the energy.

"Vortices in a Finite-Beta Plasma"
by V.N. Ivanov and A.B. Mikhailovskii
I.V. Kurchatov Institute of Atomic Energy, Moscow
***Sov. J. Plasma Phys.*, Vol. 11, No. 4, pp. 278-281 (April 1985)**

The theoretical possibility of the existence of solitary vortices in nonuniform, magnetized plasmas with finite beta is explored. This paper extends the work on Larichev-Reznik plasma solitary vortices, originally developed on the model of solitary vortices of Rossby waves in rotating fluids, to finite beta plasmas. Examination of the inertial branches of low-frequency, long waves demonstrates that such vortices can arise from them.

"Temporally and Spatially Resolved X-Ray Emission from a Collapsing-Gas-Shell Z-Pinch Plasma"
by L.A. Jones and D.R. Kania
Los Alamos National Laboratory
***Phys. Rev. Lett.*, Vol. 55, No. 19, pp. 1993-1996 (Nov. 4, 1985)**

This paper reviews experiments and attempts to model collapsing-gas-shell z-pinches in which X-ray emission "hot" spots have been observed. The work represents an extension over previous experiments in that better temporal and spatial resolution with an X-ray streak camera has been obtained. As a result, observation of a "wink" in X-ray emission was observed from these hot spots. The 1 keV and greater X-ray emission turns on for a few nanoseconds, turns off for a nanosecond, and turns back on for a few nanoseconds. Runaway electrons are presented as the cause of the hot spots, and their interaction with plasma ions is suggested as the source of the "wink." The alternative of thermal emission resulting from plasma compression, expansion, and recompression was rejected as the collapse velocity would be physically unreasonable and the X-ray emission would have been orders of magnitude too great.

"A Kinked Z-Pinch as the Helicity Source for Spheromak Generation and Sustainment"
by T.R. Jarboe et al.
Los Alamos National Laboratory
***Comments Plasma Phys. Controlled Fusion,* Vol. 9, No. 4, pp. 161-168 (1985)**

This paper reports that a conventional z-pinch, operated in an unstable mode, is under development as a substitute for both coaxial electrode methods of spheromak generation and the magnetic helicity injection for their sustainment. A "kinked" z-pinch provides the alternative for spheromak formation and helicity injection. The potential advantages are: 1) The z-pinch source connects more smoothly to the helical state of the entrance region for spheromak formation, avoiding field configurations with higher values of gamma, such as those seen in the axisymmetric ones of a coaxial source. (Gamma is the ratio of the current to the magnetic field in force-free configurations.) 2) The z-pinch electrodes are more readily accessible for cooling. 3) Development of a fully inductive approach can be seen by utilizing a stabilized toroidal z-pinch in place of a linear z-pinch. Injection of two toroidal z-pinches could be also considered.

"X-Ray Generation in ICF Target"
by T. Yabe and C. Yamanaka
Osaka University
***Comments Plasma Phys. Controlled Fusion,* Vol. 9, No. 4, pp. 169-181 (1985)**

X-ray generation is a key question in inertial confinement fusion. They can be utilized for diagnostics or for driving isentropic compressions. Although many papers have covered the X-ray spectrum generated by medium-Z laser plasmas, there are few on high-Z laser plasmas at high densities typical for inertial confinement conditions under nonlocal thermodynamic equilibrium. This paper analyzes the soft and hard X-ray spectrum from such high-Z laser plasmas by the average ion model and the Hartree-Fock-Slater (HFS) model. Both radiation generation and transport are investigated. Relativistic effects are included in the HFS model and the *M* shell line spectra for laser produced Au plasmas identified. These line spectra result from multiple inner-shell ionization.

"Spin Polarization of Photoions Produced During Ionization of Unpolarized Atoms"
by V.D. Ovsyannikov
Voronezh State University
***Sov. Phys. JETP,* Vol. 61, No. 4, pp. 687-691 (April 1985)**

When nonoriented atoms are photoionized by circularly polarized radiation, the resulting polarization of electrons and nuclei may lead to a preferential orientation of the electron shell spin of the atomic residue. Therefore, the magnetization of positive ions and electrons are similar in nature and magnitude. The polarization of photoelectrons has been investigated previously. Besides practical applications, such as generation of polarized electrons, this phenomenon is utilized to investigate fundamental atomic processes. By combining the anisotropy in the angular distribution of the photoelectrons with the polarization, it can be determined how correlation and relativistic effects determine the internal structure of atoms. This paper explores the theory for polarization of photo-produced paramagnetic ions.

"Laser Source of Polarized Protons and H^--Ions"
by A.N. Zelenskii, et al.
Institute of Nuclear Research, USSR
***JETP Lett.,* Vol. 42, No. 1 (July 10, 1985)**

This paper reports on experiments of a new process for producing a source of polarized protons through the capture of polarized electrons by protons. Polarization takes place when optically oriented sodium atoms in a strong magnetic field capture protons. 65 ± 3 percent polarization has been measured in charge exchange in a 15 kG field. Design of a polarized proton and H^--ions source for accelerators is presented.

"Dense Z-Pinch as a Fusion Power System"
by J.D. Sethian and A.E. Robson
Naval Research Laboratory
***Fusion Technology*, Vol. 8, pp. 1613-1615 (July 1985)**

This papers analyzes the prospects for developing a compact and simple fusion reactor based on a linear, dense z-pinch. A 200-micron diameter vortex of heavy water is formed in a 2-meter diameter pressure vessel. A z-pinch is generated along the axis of this vortex. Thus, the heavy water acts as the electrical insulator, heat transfer fluid, and a continuously replaceable first wall. It is argued that advances in pulsed power technology permit more than 500 kilojoules to be delivered to a pinch in less than 100 nanoseconds. According to studies by Hagenson et al. at Los Alamos, a 10-centimeter pinch, 200 microns in diameter, with a 1.4 megampere current could be sustained for 2 microseconds, resulting in a 4.4-megajoule fusion output for a small 140-kilojoule electrical energy input. For the power reactor, a pinch is generated 120 times per second with a 17-megawatt electrical input and a 500-megawatt thermal fusion output. Experiments to demonstrate a 330-kiloampere pinch formed in quartz capillaries of diameters between 200 to 1,600 microns and filled with deuterium at pressures ranging from 80 mm of Hg to 20 atmospheres are underway.

"Climatic Consequences of Nuclear War: Working Group #1" by Joseph B. Knox
Lawrence Livermore National Laboratory
UCRL-93760 Preprint for publication in *The Proceedings of the International Seminar on Nuclear War 5th Session*
Erice, Italy, Aug. 19-24, 1985

This paper reviews the general questions involved in analyzing the long-term climatic consequences of nuclear war and the prospects for inducing a "nuclear winter" in particular.

"Climatic Consequences of Nuclear War: New Findings, 1985"
by Joseph B. Knox
Lawrence Livermore National Laboratory
UCRL-93768 Preprint for publication in *The Proceedings of the International Seminar on Nuclear War 5th Session*
Erice, Italy, August 19-24, 1985

This paper reviews the history of analyzing the long-term climatic consequences of nuclear war and the hypothesis of a nuclear winter. Sensitivities of computer models and simulations are explored, and new results are presented. It is found that current projections are much more moderate than those presented in 1984.

"Solitons in Optical Fibers and the Soliton Laser"
by L.F. Mollenauer
AT&T Bell Laboratories
***Phil. Trans. R. Soc. Lond. A*, Vol. 315, pp. 437-450 (1985)**

This paper reviews the experiments and theory for both fundamental and higher-order solitons in optical fibers. While readily generated in single-mode fibers, the soliton has proven to be quite stable. Proposed applications are reported. Among these are the creation of a soliton laser in which pulse characteristics are determined by a length of single-mode fiber configured in a feedback loop. The first version of this soliton laser has been developed on the basis of a color-center laser with reduced pulse lengths of .13 picoseconds. Compression in a second, external fiber has led to pulse lengths less than 50 femtoseconds. Further reductions in pulse length by as much as 2 are expected in near future.

"Experimental Demonstration of Soliton Propagation in Long Fibers: Loss Compensated by Raman Gain"
by L.F. Mollenauer
AT&T Bell Laboratories
***Optics Lett.*, Vol. 10, pp. 229-231 (May 1985)**

Given sufficient peak power and correct pulse shape ($sech^2$ intensity envelope), laser pulses propagate through single-mode optical fibers as solitons, in which the index nonlinearity exactly cancels dispersive broadening. In the limit of zero loss, the pulse width and shape can be maintained over long spans of fiber. By simultaneously maintaining a continuous, counterpropagating laser beam at an appropriate (shorter) wavelength, Raman gain can provide a means of transferring energy to the soliton pulses and therefore make up for losses over long distance propagation. This paper reports on experiments with a 10-kilometer length fiber that achieved distortionless propagation of 10 picosecond FWHM fundamental ($N = 1$) soliton pulses at a wavelength of 1.56 microns.

"Spontaneous Symmetry Breaking and Neutral Stability in the Noncanonical Hamiltonian Formalism"
by P.J. Morrison and S. Eliezer
Institute for Fusion Studies, The University of Texas at Austin
DOE/ET-53088-212 (IFSR #212) (Oct. 1985)

Spontaneous symmetry breaking has arisen primarily in the context of relativistic field theories. When the vacuum state of a system possesses less symmetry than its Lagrangian, spontaneous symmetry breaking occurs. Goldstone's theorem posits that corresponding to each broken continuous symmetry, there is a massless boson. In the case of nonrelativistic many body quantum systems such as superfluids, superconductors, and ferromagnets, spontaneous symmetry breaking is related to excitation branches that do not have an energy gap. Utilizing the noncanonical Hamiltonian formalism, this paper extends this treatment to fluids and plasmas. The particular examples of the nonlinear Alfven wave and Korteweg-de Vries soliton are developed.