

FUNDAMENTAL UNSOLVED PROBLEMS IN PHYSICS AND ASTROPHYSICS

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Abstract

There is given a list and discussion of what are arguably the top 20 unsolved problems in physics and astrophysics today. The list ranges from particle physics to cosmology. Possible resolutions are noted, but without judgement. Perhaps the most remarkable aspect of the discussed problems is that they are closely interrelated. This opens the prospect that a solution to one or a few may lead to a significantly better understanding of modern physics.

1 Introduction

Problems in physics arise in different ways, of which the two main categories are technical and conceptual. An example in the former class is the solution of the N-body problem in Newtonian mechanics as applied, for example, to the solar system. Such problems can in principle be solved, given new techniques and/or computational methods. An example of a conceptual problem is Olbers' paradox, wherein apparently obvious assumptions about the electromagnetic spectrum and the cosmological density of sources leads to conflict with observation. These problems are often solved by a reformulation of the underlying assumptions. At the present time, physics and astrophysics appears to be plagued with a large number of problems of both types. However, one should be aware that science today is an intellectual industry which necessarily throws up more questions than in historical times; and problems offer the opportunity, given resolution, of breakthroughs into new areas with a general broadening of the scope of research.

In what follows, there is given a discussion of what are arguably the 20 most pressing unsolved problems in physics and astrophysics. The tone of the discussion, following from what was stated above, is not negative: formulating a problem succinctly is essential to a solution. Perhaps the most remarkable aspect of what follows is that many of the problems are interrelated, so the solution of one or a few opens the prospect of widespread advancement.

2 The Problems Today

History teaches that problems eventually get solved, either through painstaking study or through serendipity. 20 years from now, most of the following 20 problems will not be classified as such. There may be recalcitrant ones, but even these will eventually yield to new techniques and new concepts. (Olbers' paradox is probably the longest-running conundrum in astrophysics, but after its formulation in the 1820s it was solved definitively in the 1980s: see Wesson 1987 and references therein.) Having stated this, however, it would not be wise to be judgmental about the relative difficulty of the problems, and even less wise to favour particular paths to resolutions. The aim is to state the problems compactly and give, objectively, comments on possible routes whereby they might be solved. The material is organized, as far as its interdependence allows, in the order of particle physics to astrophysics.

2.1 Supersymmetry and Zero-Point Fields

Supersymmetry involves an extension of the standard model of particle physics (Griffiths 1987), wherein each boson with integral spin is matched to a fermion with half-integral spin. Thus, the particle which is presumed to mediate classical gravity (the graviton) is matched to a partner (the gravitino). This kind of symmetry is natural, insofar as it accounts for both bosonic and fermionic matter. But its motivation runs deeper. The four known interactions of physics can be described by fields which, however, have finite energies as the effective temperature goes to zero. These zero-point fields are calculated to have enormous intensities, which are not observed. Supersymmetry automatically leads to their cancellation. The best-studied zpf is that of electromagnetism (Section 2.2 below). In the gravitational sector, supersymmetry could lead to a resolution of the cosmological constant problem (Section 2.3). Supersymmetric gravity or supergravity is an extension of general relativity from 4 to 11 dimensions (see Section 2.14 for the question of the dimensionality of space). 11 is the minimum number of dimensions necessary to unify the forces in the standard model (ie., to contain the gauge groups of the strong $SU(3)$ and electroweak $SU(2) \times U(1)$ interactions). 11 is also the maximum number of dimensions consistent with a single graviton (and an upper limit of 2 on particle spin). These results, due principally to Witten and Nahm, are reviewed in the articles by Witten (1981) and Duff

(1996); and in the books by West (1986) and Green, Schwarz and Witten (1987). The preceding comments apply in the Kaluza-Klein context (Kaluza 1921; Klein 1926; Overduin and Wesson 1997a). In this, extra dimensions are added to spacetime to extend its physical consequences, beyond the 4D of special relativity as a theory of photons and the 4D of general relativity as a theory of gravitons.

This is also the idea behind supersymmetric strings or superstrings. Strings replace a point particle by an extended structure, and if supersymmetry is imposed then the zpf situation can be avoided. However, superstrings are naturally 10D. This leads to certain technical problems. These can be avoided, though most effectively by removing the distinction between 11D supergravity and 10D superstrings in favour of the more general concept of M-theory (for “Membrane”). As far as superstrings are concerned, the unique property of 10D is that any solution of curved 4D general relativity can be embedded in a flat 10D manifold.

We will return to supersymmetry and particles below, in a discussion of the nature of dark matter (Section 2.8). Here, we note two major questions about supersymmetry: Is it a valid theoretical concept? If so, why is it (apparently) badly broken in the real world?

2.2 The Electromagnetic Zero-Point Field

This, as mentioned in the preceding section, is better understood than other types of zpf. A 1D harmonic oscillator has states which can be raised or lowered in units of $\hbar\omega$ where \hbar is Planck’s constant divided by 2π and ω is the frequency. With momentum and position operators \hat{p} and \hat{q} , the Hamiltonian (energy) of the system is $\hat{H} = (\hat{p}^2 + \omega^2\hat{q}^2)/2$. The states have energy $E_n = (n + 1/2)\hbar\omega$. So if the kinetic energy of the system, or alternatively the temperature, goes to zero, there remains a zero-point energy per mode of $\hbar\omega/2$. When summed over frequencies, the energy density in this zpf is colossal.

This problem is in fact generic to phenomena described by waves in a space that has structure (De Witt 1975, 1989); and the implications for electromagnetism and gravity have been studied by a number of people (Puthoff 1989, Haisch, Rueda and Puthoff 1994; Rueda and Haisch 1998; Wesson 1999). The contradiction is basic, particularly for the electromagnetic case: if one believes in the harmonic oscillator with $n > 0$ as the basic “mech-

anism” of quantum mechanics, the electromagnetic zpf would be a major contributor to the intergalactic radiation field and the curvature of space-time (as calculated using general relativity). Neither thing is observed; and even if the zpf spectrum is cut off at a frequency that avoids these problems, the resulting field would conflict with data on the 3K microwave background (see Section 2.9). This is a major puzzle, since basic physical theory is in conflict with observational astrophysics.

There are two obvious, if generic, ways out: either the electromagnetic zpf does not gravitate; or its energy is cancelled by another field of negative energy density (see Sections 2.1 and 2.16). While vulnerable to modern astrophysical tests, it should be noted that the electromagnetic zpf has in a way already been probed by nearly a century of data on the hydrogen atom and other bound systems. This because while electrons in general radiate energy when they are accelerated or decelerated (bremstrahlung or braking radiation), they do not do so in the H atom. Something happens to particles in bound systems that prevents them radiating. This stops the otherwise inevitable decay of their orbits and stops their contribution to a universal zpf. While it would be imprudent to speculate about the ultimate resolution of this problem, it is probably true to say that research has a better chance of understanding the electromagnetic zpf than it does of understanding the nature of zpf’s associated with the other interactions.

2.3 The Cosmological Constant Problem

In Einstein’s 4D theory of general relativity, the cosmological constant Λ is introduced as a coupling to the metric tensor $g_{\alpha\beta}$ which defines an interval via $ds^2 = g_{\alpha\beta}dx^\alpha dx^\beta$ ($\alpha, \beta = 0, 1, 2, 3$ for ct, xyz). From $g_{\alpha\beta}$, one can define uniquely the Ricci tensor $R_{\alpha\beta}$ and the Ricci scalar R . Then the full field equations in conventional units are $R_{\alpha\beta} - Rg_{\alpha\beta}/2 + \Lambda g_{\alpha\beta} = (8\pi Gc^4) T_{\alpha\beta}$, where the energy-momentum tensor $T_{\alpha\beta}$ contains properties of matter such as the density ρ and pressure p . However, it is well known that one can move the $\Lambda g_{\alpha\beta}$ term to the other side of the field equations, where it defines a density and pressure for the vacuum via $\rho_v = \Lambda c^2/8\pi G$, $p_v = -\Lambda c^4/8\pi G$. The equation of state is $p_v = -\rho_v c^2$. This gravitational vacuum field is analogous to the zero-point fields of the other interactions, and herein lies the problem: astrophysical data shows $|\Lambda|$ to be small, whereas unified theories of the interactions predict a massive value.

Various resolutions to this have been proposed, as reviewed in the papers

by Weinberg (1989) and Ng (1992) and the book by Wesson (1999). One group of ideas, due to Hawking, is that quantum processes with their appropriate expectation values effectively force the mean or observed value of Λ to zero, perhaps in a space with a changeable topology (see Section 2.13). This is theoretically possible, but there is increasing evidence from QSO lensing and other astrophysical observations that while Λ may be small it is not zero. Another group of ideas to resolve the problem involves the reduction of a higher-dimensional Kaluza-Klein type space to a 4D one, which can yield an effective 4D Λ that is small. For example, in the so-called canonical frame of 5D relativity whose interval is $dS^2 = (\ell^2/L^2) g_{\alpha\beta}(x^\alpha, \ell) dx^\alpha dx^\beta - d\ell^2$, there is an extra coordinate $x^4 = \ell$ and a cosmological length L . When $\partial g_{\alpha\beta} \partial \ell = 0$ as in general relativity, the field equations of the latter theory are recovered as $R_{\alpha\beta} - Rg_{\alpha\beta}/2 = 3g_{\alpha\beta}L^2$ (Wesson 1999, p. 159). Thus $\Lambda = 3L^2$ and because L is large then Λ is small.

2.4 The Hierarachy Problem

There have been numerous approaches to calculating the observed spectrum of particle masses from theory, but they have not been successful. The usual result from grand-unified theories (see Section 2.5) is a tower of states with little resemblance to the masses seen in nature and accelerators. This hierarchy problem is particularly acute in Kaluza-Klein type theories (see Weinberg 1989 and Wesson 1999). The fact is that the mass of a particle becomes ill-defined on the smallest scales. One possibility is to use a 5D space with particle masses related not primarily to the extra or scalar potential but to the size of the extra coordinate. But while this works in the canonical frame mentioned in Section 2.3 above, it becomes ill-defined in other frames because 4D physics is not in general invariant under changes of 5D coordinates. The same comment applies to the latest version of brane theory (Youm 2000), which while elegant introduces extra forces into the 4D world which have not been observed.

2.5 Grand Unification

There are many types of grand unified theory. A simple example is straight Kaluza-Klein theory, which is a classical theory of gravity, electro-

magnetism and a scalar field, whose quantum modes (particles) are the spin-2 graviton, the spin-1 photon and the spin-0 scalaron. Extending this approach raises the appealing possibility of unifying all of the 4 known interactions of physics in one formalism (see Section 2.1). However, the coupling “constants” in these theories are energy or range-dependent (see Griffiths 1987 and also Section 2.11). And the energy at which unification occurs is unknown. It could be as large as the Planck mass, $(\hbar cG)^{1/2} = 2.2 \times 10^{-5}$ gm, but it could be orders of magnitude less. Ignorance of the grand-unification scale is a major hindrance to progress in this field.

2.6 Quantum Gravity

There is no generally accepted theory of this, but rather many competing ones. In recent years, most work has been done on the Euclidean approach, where the signature of the metric is changed from $(- + + +)$ to $(+ + + +)$ and a sum-over-paths is used to define an action (see Gibbons and Hawking 1993). However, in recent years there has been a move away from attempts to quantize the gravitational field as such, and in some modern versions of M-theory it is largely unconstrained (see Section 2.1). Thus, we do not know if there is a sensible theory of quantum gravity, or what role the Planck mass plays in extreme astrophysical situations and cosmology.

2.7 Neutrinos

This is another area of ignorance: we do not know how many types of neutrino there are and what their masses are. (For a review of neutrinos in physics and astrophysics, see Kim and Pevsner 1993.) There has, of course, been much discussion about the solar neutrino problem, which is an apparent mismatch between theory and observation for neutrinos which originate in the central regions of the Sun. However, our lack of understanding has arguably greater consequences for cosmology. If neutrinos are copious and massive, they can help bind the Milky Way, contribute significantly to the halos of other galaxies, and perhaps even provide the critical density necessary to make the universe spatially flat (ie., provide the matter necessary to obtain agreement with the $k = 0$, Einstein-de Sitter model of standard cosmology). A discussion of the nature of dark matter is deferred to Section 2.8, but it

can be mentioned here that most work has been done in the cosmological context on the model of Sciama. In this model, massive neutrinos with the critical density decay, producing the energy source for various astrophysical processes. Unfortunately, the photons produced in this model appear to be too numerous to match observations of the intergalactic radiation field at ultraviolet wavelengths (Overduin and Wesson 1992, 1997b). This problem is generic to models with massive neutrinos, about which we clearly need more information.

2.8 The Identity of Dark Matter

The fact that the dynamics of galaxies and clusters of galaxies do not match standard gravitational theory with the observed or luminous matter can in principle be explained in 2 different ways: we are using the wrong theory of gravity, or we are not seeing all the matter. The latter is the more common view (though see Section 2.18 below). However, there is no clear consensus about what the dark matter may be. It could be astrophysical in nature, such as massive compact objects or brown-dwarf stars. Or it could be particles, which can be classified as “hot” or “cold” depending on their kinetic energies. There has in recent years been considerable work done on constraining candidates predicted by particle physics using observations of cosmological background radiation in certain wavebands. The method, which was outlined above for neutrinos, consists basically in looking for the decay photons from unseen “dark” matter as compared to those from known sources such as stars and galaxies. This method is effective, and comes close to ruling out neutrinos, axions and the possibility that the ‘vacuum’ may have a finite energy density but be unstable (see Section 2.3 and Overduin and Wesson 1992, 1997 b,c). It does, however, leave open the possibility that the dark matter may be supersymmetric weakly interacting massive particles, such as gravitinos or neutralinos. Supersymmetry was discussed in Section 2.1, and there is clearly a direct link between that concept and the identity of the dark matter which should be vigorously investigated.

2.9 The Microwave Background Horizon Problem

This arises because the microwave background is believed to have been produced in the fireball that followed the big bang, but the field today is too

uniform in temperature to be compatible with standard cosmological models based on general relativity (Misner, Thorne and Wheeler, 1973; Kramer et al. 1980; Mann and Wesson 1991; Will 1993). Put another way, causal contact is defined in general relativity by the concept of the horizon (Rindler 1977); and photons we see now in the microwave background with the same temperature should have been outside each other's horizons and so out of causal contact in the early universe. Of course, this problem can be avoided by altering the model for the early universe. The appropriate modification is to have a phase of rapid, perhaps exponential, expansion at early times. This idea - inflation - now has a big literature. But the energy source has not been identified. One possibility is that the cosmological "constant" actually decays with time, producing a vacuum that was unstable early on (see Sections 2.3 and 2.8). Another possibility is that inflation was powered by the collapse of other dimensions of space which are now microscopic (see Sections 2.1 and 2.14). However, while much has been written about the horizon problem for the photons of the microwave background, this problem is only part of a larger one to do with causality.

2.10 Particle Properties and Causality

Causality as defined in general relativity involves photons moving on null geodesics within a region of space defined in size by the (particle) horizon. Photons within our horizon can be expected to have the same energy or temperature, as discussed in the preceding Section. But how do particles in general "know" to have the same properties, such as mass, charge and spin? And if there was causal disconnection early on, why do we now observe that particles in (say) widely separate QSOs have the same properties?

A conceptual way to answer these questions is to invoke the Strong Equivalence Principle in a form wherein it is taken to mean that the properties of particles are the same everywhere in an (unbounded) universe, even if there are portions of the latter which were out of causal contact with each other in the past. However, most workers would prefer a more concrete and testable mechanism to explain this form of communication, especially since astrophysical data show a remarkable degree of uniformity of properties in the universe (Tubbs and Wolfe 1980). One mechanism, often attributed to J.A. Wheeler, is that instead of there being of the order of 10^{80} electrons

(say) inside the visible universe, there is in fact only one. By dint of being able to move at apparently superluminal speeds by virtue of moving through a multiply-connected universe, this one particle could manifest itself as many. Another, and less speculative mechanism, involves modifications to the usual laws of causality in 4D by virtue of the influence of extra Kaluza-Klein type dimensions (Davidson and Owen 1986; Wesson 1999). This idea might work, since the size of the horizon depends on the dimensionality, but needs careful investigation.

2.11 Fundamental Constants

Following on from the comments of the preceding Section, it is useful to recall that there have been numerous attempts to explain the universality and nature of the basic parameters which appear in the equations of physics (like G the Newtonian gravitational constant, h the Planck unit, and e the charge on the electron). There have also been numerous attempts to see if they could be variable, particularly in regard to the age of the universe. The latter attempts have, with a certain small number of questionable measurements, failed. Further, there is no generally accepted explanation for the sizes of the dimensionless numbers formable from the constants, though the numerology of Eddington and the anthropic principle due to Carter are possibilities (see Wesson 1992, 1999 for reviews). It is certainly the case that one can view the so-called fundamental constants as merely parameters that transpose the physical dimensions of other quantities into forms handleable by geometry. Thus $(c^2 G \rho)^{1/2} = [L]$ converts the density of a fluid to a length, while $hmc = [L]$ does the same for the rest mass of a particle. However, while this enables physical quantities to be related to the geometrical ones of field theories like general relativity, most workers would be more comfortable if there was some systematic rationale for the fundamental constants.

2.12 Are There Problems with the Big Bang?

This may sound like a somewhat provocative question, but it is one being asked by an increasing number of workers.

It is worth recalling that in most branches of physics, a singularity or place of non-integrability of the equations is discarded as being due to a breakdown

of the model. But in 4D general relativity, the big-bang singularity can be quantified via theorems due to Carter, Hawking, Ellis and Penrose, and has previously been taken as a real starting event for the universe. This puts general relativity in a different conceptual class from other theories of physics. Uncomfortable with this, several workers such as Ellis, Cooperstock, Israelit and Rosen have recently constructed 4D cosmological models which have no initial singularity but are in tolerable agreement with observations. That models are possible which start from empty Minkowski space but evolve into reasonable matter-filled cosmologies has been known for some time (Bonnor 1960; Wesson 1985a). It is also possible that the big bang, if it ever occurred, was the signature of a quantum tunneling event (Vilenkin 1982). The same argument can be applied to higher-dimensional Kaluza-Klein cosmologies. Indeed, in 5D there exist models which are flat and empty, but whose 4D subspaces are curved and have matter with properties in excellent agreement with observations (Wesson 1999). These considerations make it justifiable to ask if there really was a big bang.

2.13 The Topology of Space

Einstein's field equations, and others like them, are second order partial differential equations that in nature are local. A full solution normally requires the assumption of boundary conditions, which in cosmology are in most cases unknown. One could argue, with Einstein and Wheeler, that the universe should therefore have no boundary. For example, in a $k = +1$ standard cosmology, the space has the shape of a sphere, so light can travel around it (Misner, Thorne and Wheeler 1973). This can be tested astrophysically, for example by looking for multiple images of the same galaxy. A similar argument applies to connectivity. Parts of one space may in principle be connected to the same space or another by wormholes; and it is possible to construct cosmological models where the universe consists of juxtaposed cells, a periodicity which can be looked for using astronomical data (Hayward and Twamley 1990). This is in 4D. In $N \geq 5D$, the possibilities are even more extensive, and there was mentioned in the preceding Section the case of a flat 5D space that can contain curved 4D spaces.

There is hardly any information on the topology, and connectivity, of space.

2.14 The Dimensionality of the World

This also is unknown. Above, there has been discussion of 5D Kaluza-Klein theory, 10D superstrings and 11D supergravity. But there is nothing sacrosanct about dimensionality, either from the historical perspective or the mathematical one. Minkowski added time to the 3 dimensions of ordinary space by the simple but powerful device of inventing $x^0 = ct$. The next simplest extension involves a coordinate $x^4 = \ell$ which via the scalar field of Kaluza-Klein theory can be related to mass. From the mathematical side, lower-dimensional Riemannian spaces suffer from certain algebraic pathologies that make them unsuitable to use in physics. For example, for $N = 3$ the Riemann-Christoffel tensor can be expressed in terms of the Ricci tensor, so the field equations for the latter result in rather trivial physics from the former (Weinberg 1972, p. 144). The choice of the dimensionality depends on how we wish to describe the physics. Thus the 4D Schwarzschild solution can be embedded in a flat space with $N \geq 6$; and as mentioned in Section 2.1, any 4D Einstein solution can be embedded in a flat space with $N \geq 10$. This raises the question of whether there is any unique choice for the dimensionality of the world. As long as physics progresses, the answer may be No.

2.15 Mach's Principle

The idea that the mass of a particle locally may be dependent on the distribution of matter globally has a long tradition. Formulated by Mach and admired by Einstein, it is a perennial subject of investigation. Machian theories of gravity have been developed by Hoyle and Narlikar, Liu, Mashhoon, Wesson and others. Reviews of the principle and related questions like the nature of mass, may be found in the books by Rindler (1977), Barbour and Pfister (1995), Wesson (1999) and Jammer (2000). It is certainly possible to construct such theories in both $N = 4$ and $N \geq 5$ that are in reasonable agreement with observations. For example, the $N = 5$ Kaluza-Klein extension of $N = 4$ Einstein theory is Machian in nature, but agrees with all the classical tests of relativity in the solar system (Kalligas, Wesson and Everitt 1995). The question that awaits an answer is not so much if such theories can be constructed as whether or not they are needed.

2.16 Negative Mass

It should be appreciated at the outset that antimatter particles exist and move downwards in the Earth's gravitational field, while negative-matter particles are hypothetical and would move upwards. Nevertheless, there are symmetries in some of the equations of physics which in principle allow of negative mass. (An example is the relation $E^2 = m^2 + p^2$ between the energy, mass and 3-momentum of a particle.) Investigations have been carried out by Bondi (1957), Bonnor (1989), Wesson (1999) and others. These authors find no reason in principle why negative mass should not exist. Such might help explain the problems with zero-point fields outlined in Sections 1.1 and 1.2. However, while objects with negative mass would move away from sources made of ordinary matter, it is puzzling why there is no evidence of such objects in the universe.

2.17 The Origin of Galaxies and Other Structure

There are two commonly-discussed theories of galaxy formation, neither of which works very well.

In the gravitational instability picture, small statistical perturbations in the early universe grow through gravity in an expanding fluid. However, the growth rate is too slow to produce galaxies as observed in a reasonable time. This problem can be overcome in principle by assuming the presence of larger-than-random seed perturbations. These could have been a pre-Galactic generation of stars (population III), black holes, defects from an early phase when a scalar field was important, or quantum fluctuations.

In the adiabatic or pancake picture, galaxies form from the anisotropic collapse of large clouds of gas with masses of the order of clusters or super-clusters. However, this should have led to the formation of spirals with disks aligned preferentially, for which there is some but not convincing evidence (Wesson 1982). This problem could be overcome in principle by a strong relaxation (randomizing) process early on, but this is poorly understood, and in any case this theory merely pushes the origin of structure backwards in time.

Both of the standard theories of galaxy formation clearly contain ad hoc elements, as do theories of the origin of larger-scale structure.

2.18 The Origin of the Spins of Galaxies

It is instructive to discuss this separately than the issues outlined in the preceding Section. This because the problem is more readily quantifiable and rests on well-understood principles of gravity and the conservation of angular momentum.

Consider an aspherical galaxy which has recently formed (by whatever process) and is a member of an expanding ensemble of similar objects. The gravitational quadrupole moment of the subject galaxy is acted upon by the others in the ensemble, exerting a torque which can be calculated using standard techniques. This torque imparts a spin to the subject galaxy. However, the torque is effectively cut off after a while because the other objects in the ensemble recede. The result is a net angular momentum.

This is a neat mechanism, and operates naturally within the gravitational instability picture. (A similar calculation can be done for galaxies which form inside clusters, when the torque is effectively cut off by the collapse of the protogalaxy: see Wesson 1985b.) The mechanism was originally proposed by Hoyle and has been worked on by numerous people. However, there is a consensus that for the Milky Way at least, the theoretical angular momentum is almost an order of magnitude smaller than that observed. This could be due to shortcomings in the astrophysical parameters of the model; but it could also be due to some more basic reason involving the laws of dynamics in the early universe.

In the latter regard, it should be mentioned that the rotation curve of the Milky Way provides a good way to test gravitational theory. While the flatness of the curve is frequently attributed to a halo of dark matter (Section 2.8), it could be due to a modification of the law of gravity (e.g., Milgrom 1983). The spins of galaxies, while problematical in origin, provide a good data set for testing fundamental physics.

2.19 The Angular Momentum/Mass Relation

Objects other than galaxies have spins, and it has been known for a long time that when the angular momenta J are plotted against the masses M in a log/log plot, the result is a straight line with a slope close to 2 (for

a review see Wesson 1981). This holds for asteroids, planets, stars and galaxies. There have been many mechanisms proposed to account for this, but none has gained widespread acceptance. That is, there is a relation which numerically reads $GM^2/Jc \simeq 1/300$, but no explanation.

2.20 Life and the Fermi-Hart Paradox

Fermi is reported to have mused over lunch that there could not be intelligent life forms elsewhere than Earth because they would have colonized space and already be here. Conversely, the presence of life on the Earth implies its presence elsewhere. This problem, though it originated with Fermi, has been worked on by many people, most notably Hart (see Wesson 1990 for a review). It is really a question about the density of life in the universe.

There are numerous possible resolutions of what has become known as the Fermi-Hart paradox. Consider two examples at somewhat opposite ends of the scientific spectrum. The cosmic zoo hypothesis says life is abundant in the universe, but shuns humankind as not being advanced enough either psychologically or technologically to warrant contact. The cosmic horizon hypothesis says life is sparse in the universe, but that the nearest civilization is beyond the particle horizon, and so out of contact.

The Fermi-Hart paradox may turn out to be like Olbers' paradox mentioned in Section 1. That is, a problem whose origin lies in faulty premises.

(Editor's Note: For possible evidence relevant to the extraterrestrial visitation question see the recent books "The UFO Enigma: New Review of the Physical Evidence" by Peter Sturrock and "Close Encounters of the Fifth Kind" by Richard Haines. Also the 3-part "Report on a Survey of the Membership of the American Astronomical Society Concerning the UFO Problem," Peter Sturrock, *J. Scientific Exploration*, 1994, vol. 8, pp. 1–46; vol. 8, pp. 153–196; vol. 8, pp. 309–346. [B. Haisch])

3 Conclusion

The preceding list of 20 major problems in physics and astrophysics is not intended to be exhaustive. It does, however, cover most of the trouble-

some issues of the present day.

In conclusion, and on a positive note, it should be recalled that science is an inherently logical activity. Problems and paradoxes do not really lie in the science, but in the way humans formulate it. Realizing this, progress will be made given new ways to think.

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