PHYSICS WITH AN OPEN MIND

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Introduction

The relation of physics to parapsychology is complicated. Some physicists find the phenomena intriguing and at least vaguely plausible. A few physicists in this camp have gone so far as to perform parapsychological experiments of their own, often with groundbreaking results (Jahn & Dunne, 1988; Schmidt, 1974; Targ & Puthoff, 1974).[1] At the other extreme, a number of physicists—some quite eminent—contend that parapsychology is pseudoscience and that its subject matter is nonexistent. A full review of the literature, pro and con, would be an article or more likely a book in its own right. The scope of the current work is more modest; it is to consider what the current state of knowledge in physics actually has to say about the claims of parapsychology, with samples of the relevant literature used to illuminate commonly-used arguments.

Terminology and Taxonomy

Although this paper discusses parapsychology, the current sentence marks the only appearance of the word 'paranormal' in the text. It is increasingly clear that the phenomena examined by parapsychology, however rare or poorly understood, are among the normal capabilities of human beings (and perhaps of other living things). To use a misleading term that is widely seen as a pejorative synonym for 'supernatural' seems completely inappropriate. For referring to these phenomena as a general class, the terms 'psi' or 'psychic phenomena' will be used throughout.

However, the general topic of psi is a grab-bag of anomalous observations, not all of which necessarily operate in the same ways or even constitute the same phenomenon. Various attempts to organize categories of psychic phenomena have been made in the past. The

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[1] These citations are not intended to be an exhaustive bibliography even of the authors cited, but merely illustrate some early work by the respective authors.

utility of this has been arguable since phenomena can usually be found that either cross between categories or cannot reliably be classified as one or another. In order to consider psi from the perspective of a physicist, this paper will employ a taxonomy based on concerns relevant to physical theory; these categories should not be taken as fundamental or even necessarily appropriate to psi research as such.

The label 'ESP' will be used for all observed phenomena in which human beings apparently acquire causally accessible information by means other than their known senses. 'Causally accessible' means that it would be possible in principle for some signal of a type known to exist (e.g., radio) to convey the information from its source to the place and time at which the percipient acquired the information. This covers a broad range of experimentally distinct phenomena, including clairvoyance, telepathy and retrocognition as defined by Rhine, as well as some forms of remote viewing, dowsing, psychometry or 'object reading', Ganzfeld studies, veridical OBEs and NDEs, etc.

The label PK ('psychokinesis') will be used for all phenomena in which human beings appear to be altering the behavior of physical systems external to themselves. It is immediately obvious that this is a questionable term for the analysis of experiments: for example, is the now widely-known DMILS (Direct Mental Interaction with Living Systems) experimental paradigm a case of ESP by the study target, or of PK by the active agent? For purposes of physical analysis, however, such phenomena are conceptually quite different from ESP. It will be useful, moreover, to distinguish between micro-PK, in which only the statistical parameters of a distribution of unpredictable behaviors are altered, and macro-PK, in which bulk movements of objects of appreciable size, or measurable energy flows or emissions, are observed. Micro-PK phenomena include parapsychological RNG, dice, and perhaps DMILS experiments. The extensive recent research on 'intentional healing', especially 'distant intentional healing', must also be classed from a physical point of view as micro-PK with biological targets, even though they are generally being studied by scientists other than parapsychologists. The canonical example of macro-PK is, of course, the RSPK phenomenon formerly referred to as 'poltergeist' activity. Intentional healing case studies which fall completely outside the normal range of responses for the patient (e.g., spontaneous remission of a condition which is incurable without treatment) would also seem to fit the criteria for macro-PK, as would multiple well-

attested cases of mediumistic levitation, and the recently popular demonstrations of 'external qi gong' in China (Braude, 1997). [2]

The terms *retrocausation* or *retrocausal* will be used for observed phenomena regardless of other categories in which there seems to be a reversal of the usual order of cause and effect. This includes some forms of remote viewing, all forms of precognition, premonition, and presentiment, and PK experiments in which the target's behavior was established before the PK effort was made. The issue of causality is of sufficient physical importance to merit a separate category even when the phenomena within it do not seem to differ, except for the time delay, from other psi phenomena.

The Basic Problem of Physical Relevance

Contrary opinions of many physicists notwithstanding, current knowledge of physics places relatively few constraints on the possible nature or extent of psi phenomena. The primary reason for this is that the observations from which modern physical theories are constructed do not include observations relevant to psi hypotheses.

To see why this is important, consider the 'revolution' in physics that took place in the first quarter of the 20th century. Newtonian physics, which had been the unchallenged paradigm for over two centuries, was suddenly shown to be inaccurate in two distinct regimes: that of extremely small masses and energies, and that of velocities comparable to that of light. These two domains gave rise to two distinct generalizations from Newtonian mechanics: quantum mechanics in the domain of the small; special relativity in the domain of the fast-moving. Both of these theories give the same answers as Newtonian mechanics for bodies of humanly observable scales moving at moderate velocities.

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[2] The strongest evidence for modern, reproducible macro-PK experiments is apparently contained in a paper by Leping Zha which was presented at an IONS conference but seems never to have been formally published. The information "Zha, L (2001). 'Review of History, Findings, and Implications of Research on Exceptional Functions of the Human Body.' Presented at the Third IONS Conference on the Science of Spiritual Healing, Dec. 2001, Hawaii." is therefore relegated to this footnote rather than given as a regular citation. The existence of this paper is attested online at the URLs http://www.noetic.org/publications/research/main.cfm?page=frontiers_59.htm and http://www.ramcconnell.com/selfdeception.htm

As long as observations were limited to such bodies neither alternative could be discovered.

Similarly, since experiments in physics have not been designed to examine psi hypotheses, the current structure of physics describes the behavior of physical systems in the absence of appreciable psi effects. Theoretical physical arguments against psi are therefore extrapolations into an experimentally untested regime, and therefore can be expected in principle to be as unreliable as trying to compute the behavior of elementary particles from Newtonian premises.

Aside from the general lack of empirical support in the relevant areas, there are a number of additional considerations which undermine any attempt to criticize psi based on physical laws.

Built-In Bias of Instrumentation

Upon even brief reflection it begins to seem obvious that the equipment and experimental designs of physics will automatically be as hostile to psi effects as possible. Given the wide range of observed effects and the tendency toward erratic replication that are common knowledge in the parapsychological literature, it seems reasonable to suppose that different experimental designs and apparatus may be more or less psi-conducive. What, then, can be expected during the design and test phase of physics experiments, or of the equipment intended for use in such experiments? Since the designers are not considering possible psychic effects, equipment that responds with variant readings or other forms of erratic behavior in response to stray thoughts of experimenters or passersby will be interpreted as behaving erratically *for no detectable reason.* As anyone who has ever attempted to construct sensitive equipment will appreciate, such unpredictability cannot be tolerated; if the source of error cannot be found and controlled with a reasonable investment of effort, the current design will be discarded and a different one adopted. From a parapsychological perspective, modern equipment in the physical sciences is the end product of many generations of development which has unwittingly minimized its sensitivity to any kind of psi influence. At face value this would appear to be relevant only to PK experiments of various sorts, but various attempts to design instruments to detect psi influences must also be subject to this effect.

Self-Affirming Theories

Almost every controlled study of psi has been inspired by anecdotal reports of a similar or related phenomenon occurring spontaneously. Several categories of such phenomena are targeted by physical criticisms that share a common, and circular, structure. (Specific examples will be discussed elsewhere; this argument is given in general terms to avoid repeating it at each appearance.) The hostile physicist claims that the phenomenon is impossible because it conflicts with some feature of physical theory. Since the phenomenon is known to be impossible, the anecdotal evidence, no matter how extensive, and no matter how commonplace it may be in human experience, must be dismissed as due to selective observation, selective memory, and the generally poor ability of human beings to understand probabilistic phenomena. Confirmation in controlled experiments must be due to sloppy procedure or outright fraud. If, however, the theory on which the criticism is based should be challenged, the critic replies that the theory enjoys overwhelming empirical support and has no empirical counterexamples. Naturally not, since all potential counterexamples have already been dismissed on the grounds of their theoretical impossibility. This particular phenomenon extends and intensifies the problem created by the fact that physics experiments generally disregard psi; once this vicious circle becomes established, the everyday practice of physics does not merely ignore potential psi effects but actively dismisses them from serious consideration and disregards them even when they appear.

Physics Experiments May Provide Evidence of Psi

Some entire categories of physical experimentation seem to have the potential of providing support for psi even though the majority of physicists have not recognized them as such. The 1980s saw the emergence of two dramatic controversies in physics: the alleged discovery of 'cold fusion', and the possible existence of a fifth fundamental force suggested by re-analysis of old data from gravitational studies. The cold fusion controversy still drags on with some experimenters claiming significant progress; the 'fifth force' issue is widely regarded as settled. In both cases, especially in the early years, an overview of relevant publications seemed to show a remarkable correlation between the experimenters' attitude toward the phenomenon and their ability to produce it (or at least to report it) under laboratory conditions. To establish whether this apparent

correlation is real and statistically significant would require an immense meta-analytical investment which has not yet been made.

In summary, there are abundant *a priori* reasons for regarding physics-based arguments against psi as suspect. The following, more detailed discussion of several such criticisms should be taken with the caveat that it may be giving these arguments more credence than they deserve.

Erroneous Criticisms

Most physicists who have a positive interest in psi phenomena tend either to perform experiments or construct modest theoretical models. Their publications are therefore likely to be technical and evidence-laden. In contrast, physicists hostile to the field are generally more concerned with indicting the whole of it and are therefore prone to make sweeping philosophical statements in writings for a more general audience.

When, in contrast, a hostile physicist attempts to make specific criticisms of particular experiments or programs, the result often indicates that the physicist failed either to understand or to correctly analyze the experiments in question. To review all such cricitisms and evaluate the frequency with which they err would require an encyclopedia; therefore only two examples drawn from the author's personal experience will be offered to establish existence of this phenomenon.

The paired articles Freedman, Jeffers, Saeger, Binns and Black (2003) and Dobyns (2003) illustrate one instance of such a failed criticism. One of the authors of the first article (Jeffers, a physicist) contributed to it a methodological criticism of experiments at Princeton Engineering Anomalies Research (PEAR), of which their experiment was a partial replication. (Jeffers' identity as the source of this part of the paper can be concluded from his having raised the identical issue in prior correspondence with PEAR.) Sections 1 and 2, and Figure 1, of the commentary article provide a detailed demonstration that Jeffers' suggested 'improvement' of the methodology in fact weakens the experimental controls rather than strengthens them.

Stenger (1990) mentions what he sees as methodological vulnerabilities in the experiments reported by Jahn and Dunne (1988). The descriptions and illustrations of the equipment and protocol in the latter reference, however, immediately make it clear that the

experiments were fully protected against every source of artifactual interference proposed by Stenger.

The fact that physicists can make mistakes is fundamentally not very interesting, even if it should turn out that they are unusually prone to making such mistakes when trying to find flaws in a psi experiment with positive results. It seems more instructive at this point to turn to physicists' general criticisms of the subject, and consider whether they are as theoretically compelling as the authors seem to think.

The Argument from the Unity of Science

It is widely held that, even though we do not know all the details, there is some universal body of natural law that explains all phenomena in every branch of science. Explanations in one science can be grounded in knowledge from another science considered more fundamental. This concept is not unique to physicists; the underlying unity of scientific knowledge was been widely popularized by biologist E. O. Wilson (1998) under the name 'consilience'. As applied against psi, this argument roughly states that even though we don't know all the details of this universal 'theory of everything', we know enough to be sure that psi is innately incompatible with this framework.

Anderson (1990) calls science a 'seamless web' in the process of declaring PK experiments fundamentally wrongheaded; he argues that our ability to perform precise measurements at all proves the phenomenon can't exist. Weinberg (1992) goes so far as to declare: "... our discovery of the connected and convergent pattern of scientific explanations has done the very great service of teaching us that there is no room in nature for astrology or telekinesis or creationism or other superstitions." (In the preceding discussion Weinberg consistently uses 'telekinesis' to refer to psychokinesis.)

Despite its endorsement by two Nobel Laureates, the argument from the unity of science actually carries very little weight. The reality is that any comprehensive system of natural law must be essentially modular in structure, and profound changes can be made to portions of it without the slightest effect on the remainder.

This can be demonstrated immediately by the fact that physics itself does not comprise one framework for natural law, but two. Quantum mechanics, in its special-relativistic form of quantum field theory, has demonstrated enormous predictive power and has been confirmed to very high levels of precision. It has been rivaled in its success only by the power of general relativity in dealing with astronomical phenomena

involving large masses and intense gravitational fields. Unfortunately, these two very successful theories are fundamentally incompatible with each other. At least one of them must be fundamentally revised before we can have a genuine 'Theory of Everything' just in physics, let alone in science as a whole. (For the moment, the claims of string theory to this 'Theory of Everything' mantle can be ignored, since it has yet to make even one empirical prediction.) Yet somehow, this inconsistency at the core of physics fails to create similar fissures throughout the rest of science. To show an example from another perspective, physicists have not felt obliged to revise their theories in response to the geologists' development of plate tectonics in the 1960s, despite the fact that this constituted a profoundly revised understanding in a science which would seem on the face of it rather closely related to basic physical principles. Although it seems reasonable to assume that there is indeed a single universal system of natural laws, it also seems clear that the details of any particular branch of science can be revised without requiring wholesale revision of the whole of science.

The Argument from Historical Success

A closely related argument against psi is sometimes raised not from the presumed unity of scientific explanation per se, but from its history. Although the overarching framework of natural law that encompasses all observed phenomena is not known, it is contended that the current framework has enjoyed steady success in being extended to cover more and more phenomena. The preponderance of evidence therefore would seem to be that the continued extension of this paradigm will meet with continuing success, until it ultimately encompasses the whole of science and it will be directly seen that there is no room in it for phenomena such as psi.

This argument from historical success can easily be refuted by historical evidence. Long-term success of a scientific model cannot be extrapolated into an indefinite future. The Ptolemaic model of the solar system enjoyed uniform success and steady observational refinement for over a millennium; as late as 1450 a reasonable individual might have concluded that some refinement of an epicycle-based geocentric model would ultimately account for all astronomical observations to the limits of accuracy. Instead, the work of Copernicus, Kepler, Galileo, and Newton replaced that model within a time span that was quite short compared to its previous longevity. Newtonian dynamics in its turn was unchallenged for over two centuries until it was found necessary to

replace it in the first quarter of the twentieth century. Contrary to the expectation of historical stability, the history of science makes it quite clear that even the most fundamental concepts are subject to revision, and that revision may occur with very little warning.

Genuine Problems

Although general indictments of psi on principle can be seen to be vacuous, some of the observed features claimed for psi phenomena are difficult to reconcile with current physical theories. A review of these features will provide context for consideration of the extent to which current physical theories need revision to accommodate psi.

Distance Independence

For almost as long as ESP and PK phenomena have been subjected to serious investigation, they have appeared to be unaffected by intervening distance, at least over distances comparable to the Earth's diameter. Simple remote viewing studies achieved noteworthy hits over distances from kilometers to thousands of kilometers (Dunne & Bisaha, 1979; Dunne & Jahn, 2003; Puthoff & Targ, 1976). The US government 'Stargate' program, declassified in the mid-1990s, appears to have achieved impressively accurate remote viewing descriptions at intercontinental ranges (Puthoff, 1996; Targ, 1996). Systematic surveys of both remote perception and remote-REG (PK) data at PEAR could detect no evidence for distance dependence in the effect size (Dunne & Jahn, 1992; Dunne & Jahn, 2003). Although a high-profile ESP experiment conducted during the Apollo 14 mission attempted to extend this distance baseline, this single episode does not provide sufficient data for drawing firm conclusions about longer distances (Mitchell, 1974). More recently, the growing popularity of remote viewing has led to an explosion of almost hobby-like efforts to remote-view extraterrestrial targets, but the accuracy of such attempts is for obvious reasons hard to verify, and has produced such spectacular failures as the alleged presence of a large extraterrestrial spacecraft attached to, or perhaps comprising, Comet Hale-Bopp in 1997.

Although firm conclusions cannot be drawn for distance scales longer than about 12,000 km, the evidence is clear that psi effects (or at least ESP and micro-PK) are at most weakly attenuated by distances up to that scale and may be completely unaffected by them. They certainly do not show the $1/r^2$ distance dependence which is the longest-range

interaction for any known physical field, and which geometrical considerations suggest is the weakest distance dependence possible for any physical field effect.

This particular problem, however, does not seem to require any fundamental revision of physics, for numerous physical models of non-attenuating phenomena exist. Correlations produced by quantum entanglement, for example, retain the same statistical strength regardless of the distance intervening between particles. More prosaically, while the signal power of a broadcast message falls off as the squared distance to the transmitter, the informational content of the message does not; as long as the signal is strong enough to be distinguished from noise, its full content remains accessible at any distance. Since ESP and micro-PK both seem to be informational processes, the model of signal transmission seems adequate to explain their apparent distance-independence. It may be significant, in this light, that reports of macro-PK phenomena in general do not involve large distances between the phenomenon and its presumed originator.

Further consequences of these two analogical models for distance independence, entanglement and signal transmission, will be discussed later.

Energy Conservation

Apparent macro-PK incidents that have been captured on video, such as 1970s-vintage scenes of Nina Kulagina psychokinetically manipulating small objects or more recent Web-based presentations of qigong masters moving objects without touching them, tend to show the presumed originator apparently undergoing considerable physical strain while inducing modest motions in a target object of no great size. The visible effort of the video subject is more than adequate to explain the observed motion of the target object, although the means of connection are not obvious. Some reported macro-PK incidents, on the other hand, have apparently involved considerable energy input (e.g., levitating an entire human body or a massive table by a considerable distance) without concomitant signs of physical effort (Braude, 1997). If these incidents actually occurred, there is no obvious source for the energy that appeared as work on the object. It is, of course, possible to dispute the veracity of these large-scale macro-PK incidents, since regardless of the quality of attestations the accounts are decades old and the phenomena have never been reproduced under laboratory conditions. If, however, the evidence for the existence of these

phenomena is accepted, either macro-PK taps into a currently unknown energy source or the law of conservation of energy needs revision. Either of these possibilities requires a substantial change to current physical theories.[3]

Non-Detectable Energy

In certain genres of apparent psi manifestation, references to some form of energy unknown to, and currently undetectable by, standard scientific instruments are almost ubiquitous. Such unknown energy more or less defines the discipline of qigong; however, references to it in one form or another are almost inescapable in the field of intentional healing. As a reminder, from the perspective of a physicist intentional healing—distant or otherwise—appears to be a form of micro-PK with biological targets, even though the healers themselves do not use the terminology and the experimenters conducting the studies are generally not parapsychologists. Even a cursory examination of such phenomena makes it clear that this 'energy' is a perceived and experienced reality to the practitioners, for all that no currently known instrument can detect it (Goldner, 1999; Rand, 1998). It may, however, have detectable indirect effects in PK experiments (Jahn, Dunne, & Dobyns, 2006).

Other concerns with energy appear when macro-PK is considered. Even if we disregard cases where energy conservation seems to be violated, the less spectacular cases still leave the mystery of how exertion over here is conveyed into motion over there, without contact or any detectable medium. (If there were a detectable mechanism to transfer the force, the incident would not be classified as macro-PK!)

For micro-PK and ESP explanations there is a ready reconciliation that whatever practitioners are experiencing as 'energy' is their subjective perception of an informational phenomenon in which no physical energy difference is actually involved. This requires no revision of physics since there are currently any number of ways in

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[3] With regard to energy conservation it has been proposed that the 'cold areas' sometimes associated with RSPK reports are the source of the energy; thermal energy has been extracted from the environment and converted to kinetic energy to move the objects. I have seen this notion brought up innumerable times in casual discussion and correspondence but have failed to locate a single refereed publication containing the idea; I therefore cannot provide a normal citation. In any case, this possibility still requires some rewriting of physics, since it simply replaces a violation of the First Law of Thermodynamics with a violation of the Second.

which information can be encoded in the detailed structure of material objects while remaining completely invisible to all current instrumentation. This escape hatch is not available if macro-PK is to be taken seriously. There would appear to be two basic possibilities for a physical model of this 'energy' that is not detected by instruments; either potential energy is stored in some arrangement of known matter and fields that is unfamiliar to current physical models, or an additional field beyond the known ones must be posited. Both of these explanations would seem to require at least some new physics.

The 'new field' approach runs into a possible conflict with observational as well as theoretical physics. If the basic approach of quantum field theory is accepted, every fundamental field has a quantized excitation, which manifests as a particle. In general, collisions in particle accelerators will produce, at least briefly and with some measurable probability, every species of particle which the collision has sufficient energy to create. At the present time all particles that have appeared in such experiments fit comfortably into the so-called 'standard model' of quantum field theory. For an additional field to exist, either its excitations are so massive that they cannot be produced by any collision energy yet studied, or its coupling to other fields is so weak that even decades of experimentation have not been sufficient to produce a significant number of excitations, or some symmetry principle prevents its creation in the sorts of collisions examined.

Of course, physicists are fairly confident that at least one form of real substance has thus far eluded detection by one or more of the mechanisms just described. Astronomical observations seem to require that considerable amounts of 'dark matter' must be present in the universe, to explain the observed properties of galaxies and galactic clusters. Indeed, the total mass of this dark matter would seem to be perhaps four or five times the mass of the ordinary 'baryonic' matter from which stars and planets are made. Most models of dark matter require that some considerable quantities of it are present in the Solar System and presumably passing through Earth without interacting, or that it was created by physical processes early in the Big Bang, or both. Nevertheless, none of the minor zoo of potential dark matter candidate particles has ever been detected.[4]

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[4] This is not strictly true in that neutrinos are one of the dark matter candidates, and they have been detected abundantly enough that their existence is not in

Unfortunately, unlike the astronomers' dark matter, if a currently unknown sort of field is the source of psi effects, it interacts strongly enough with ordinary matter to be generated by biological entities and to affect bulk material objects. Problems with such a field will be discussed in more detail later.

The other alternative, that psi 'energy' might be stored or transmitted through manipulation of known fields or particles, suffers the drawback that the known behavior of these entities is not consistent with observed properties of psi. Using this as an explanation for psi therefore requires a specific rewriting of the laws governing, for example, electrodynamics. Although I present the reasons why it is not unreasonable to consider such a rewrite, it still constitutes a revision of known physics.

Retrocausation

Possibly the most difficult psi phenomenon for anyone, including physicists, to accept is the apparent retrieval of information from the future, or imposition of information on events already past. Even Stapp (1994), a physicist who accepted the evidence for psi and was writing an article to provide a theoretical model for it, flatly declared that "Such an influence of an observer backward in time on atomic events seems completely at odds with physical theory." The pervasive assumption in physics is that the past may determine or constrain the future, but the future cannot determine the past.

The trouble with retrocausation is that it appears to open the door to time paradoxes, in which a sequence of events becomes inconsistent with itself: it happens if and only if it does not happen. Obviously the potential for creating a physical instantiation of the Liar's Paradox is a matter of considerable concern. In the recent past the mere possibility of retrocausal effects was deemed sufficient grounds to reject a speculative phenomenon as nonphysical; for example, Benford, Book and Newcomb (1970) considered the mere possibility of a retrocausal

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dispute. However, neutrinos are a form of 'hot dark matter' since, even at the current level of cosmological expansion and cooling, the kinetic energy of primordial neutrinos would be large in comparison to their very small mass. The astronomical community is currently of the opinion that some form of 'cold dark matter' is required for models to succeed in representing the actual structure of galaxies and clusters, despite minority analyses to the contrary (Dobyns, 1988).

'tachyonic antitelephone' as an adequate disproof of the existence of tachyons. At the time this article was published the attitude of the physics community toward retrocausation was an archetypal instance of the "'Self-Affirming Theory' problem discussed above.

Since that time the attitude of the physics community has liberalized. A paper by Echeverria, Klinkhammer and Thorne (1991) presented a strong argument that retrocausal phenomena cannot, in fact, create time paradoxes. Although their analysis was based on the general-relativistic concept of traversable wormholes, it generalizes quite readily to other retrocausal phenomena. Their conclusion can briefly be summarized by saying that for any sequence of retrocausal events which is self-inconsistent, there must exist at least one family of closely related event sequences which are internally consistent and therefore possible.

Further liberalization of physicists' attitudes toward retrocausation is evident in an article by Hawking and Hertog (2006) invoking explicitly retrocausal models for cosmology, and in the convening of a 2006 AAAS symposium specifically to discuss retrocausal phenomena (Sheehan, 2006). Although the community as a whole may not have caught up with these developments, it seems safe to conclude that there are no physical reasons for rejecting retrocausation *a priori*.

Moreover, there are any number of physical models that suggest that retrocausal phenomena should occur. In electrodynamics, the study of radiative effects leads at first to the conclusion that any radiating body should generate both 'retarded waves', which radiate outward into the future, and 'advanced waves' which radiate into the past. (From the viewpoint of an outside observer, 'radiating into the past' means that advanced waves would be seen as converging from infinity onto the radiating object.) While advanced waves are often dismissed by fiat as an unphysical solution of the equations, a highly successful version of electrodynamic theory has been constructed by presuming that advanced waves are real (and are not observed because they are normally cancelled out by interference effects) (Wheeler & Feynman, 1945).

The success of this 'absorber theory' led to the 'Transactional Interpretation' of quantum mechanics, which, while it does not specifically predict retrocausal effects, offers a completely natural framework for analyzing their occurrence (Cramer, 1986).

The notion of tachyons—particles which, unlike normal matter, must always move faster than light and slow down when they gain

energy—has been a speculative topic in relativity since the 1960s. While the aforementioned Benford *et al.* (1970) article more or less stopped serious study of tachyons in its tracks, the new understanding of the fairly innocuous nature of retrocausation may allow such study to be revived, and in particular might defuse the standard assumption that any quantum field theory that predicts the existence of a tachyonic particle is *ipso facto* nonphysical.

General relativity abounds with causality-violating solutions to Einstein's equations of space and time. The anisotropic cosmological solution found by Gödel (1949) contains 'closed time-like curves', meaning that by moving in an appropriate trajectory an object can enter its own past. Certain configurations of spinning masses were found by Tipler (1974) to induce the same phenomenon. The traversable wormholes of Echeverria *et al.* (1991) are of course a general-relativistic construct.

Such phenomena as these involve masses and mass densities that are quite literally astronomical, and therefore might seem irrelevant to the question of psi. However, the potential for causality violation appears to be present even in empty space if one considers the still mostly speculative properties of quantum gravity. As noted above there are profound incompatibilities between quantum field theory and general relativity; every attempt to construct a full quantum theory of gravitation has failed. However, it is generally believed that in any such theory the geometry of spacetime itself must, due to the quantum-mechanical uncertainty principle, break down at very short scales into what has been called 'spacetime foam'.[5] Spacetime, at this scale, should be seen to exist as a quantum superposition of every possible geometry, including every possible topology of wormhole connections between closely separated point-instants. This would seem to imply a non-vanishing probability for particles to carry information along grossly non-causal paths through space and time.

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[5] The spacetime foam effect is eliminated by some formulations of string theory, which purports to be a successful quantum theory of gravity. However, given the current lack of empirical content in string theory, levying string-based criticisms against other physical models would seem premature.

The Observation Problem

One of the thorniest physical conundra for psi phenomena emerges indirectly from recent experiments by Radin.[6] These emerged from an attempt to produce a psi-based version of a classical physics experiment. It is well known that when quantum particles, such as photons, are projected through a pair of adjacent slits they will produce an interference pattern, depending on their wavelength and the slit spacing, which is quite different from the broad diffraction spread produced by a single slit. It is also well established that a 'which-way' measurement—that is, one that establishes which of the two slits a particular photon travels through—destroys the interference pattern. It has furthermore been established that what destroys the interference pattern is the possibility of making a measurement; if an appropriate instrument is in place, the interference vanishes, even if the instrument's outputs are simply being discarded without examination (e.g. the data leads are wired directly to ground).

In response to the experimental claims of the PEAR laboratory Jeffers decided to conduct an experiment (ambiguously PK or ESP) using double-slit interference as his random source (Ibison & Jeffers 1998). The goal of the experiment was to have subjects attempt to psychically view which slit individual photons were passing through; if successful this observation should disrupt the interference pattern. Jeffers found no effects. Subsequently, however, he brought his apparatus to the PEAR laboratory for a replication in which PEAR would deploy its own population of operators. The replication at PEAR found statistically significant effects (Ibison & Jeffers 1998). Aside from differences in operator pool and experimental ambience, however, PEAR made an important protocol change: operators were not instructed to psychically observe the photons inside the sealed chamber, but simply to shift the reported on-screen feedback in the intended direction. In other words, from the operator's viewpoint the PEAR version of the double-slit was simply a micro-PK experiment with a different random source. This protocol change was made because one of the experimenters (Dobyns) found Jeffers' proposed mechanism incredible and saw the experiment as 'designed to fail'. The contrast between the photon throughput of the device (ca. 50,000

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[6] This experiment was presented in "Gazing at the Mind's Eye", Radin's presentation to the 2008 Annual Meeting of the Society for Scientific Exploration, and appears not to have been published at the time of this writing.

photons/sec) and the rate at which human consciousness can process stimuli suggested that the number of individual photons which an operator could hope to observe as specific entities would be a negligibly small fraction of the total; hence the dilution of the interference pattern, even if operators were maximally successful at the assigned observational task, would be undetectably small.

Radin proceeded to perform his own version of a psi-interference experiment with a single subject, a trained meditator with experience in remote viewing. The experimental setup involved a Mach-Zehnder interferometer, which uses a beam-splitter rather than a double-slit and creates interference between photons sent down two widely separated beam paths before being reunited. Statistically large effects were seen when this meditator focused his remote-viewing attention on one of the beam paths, psychically performing a which-way measurement.

The reason this experimental result of Radin's creates physical quandaries is the nature of which-way measurement. As noted, simply having the detector in place is sufficient to destroy interference. However, remote viewing employs no apparatus. Insofar as spots indefinitely remote in both space and time can be remote-viewing targets, the 'detector' must be construed as always being in place, or alternatively it can be deployed retroactively (and retrocausally) at a remote viewer's whim when he chooses to examine past events. Combining the effects of which-way measurement with the potential for performing one psychically, it suddenly becomes mysterious that any double-slit interference pattern should ever have been observed in any experiment whatsoever. In this case consistency of physical observation, rather than physical theory, seems to require that remote viewing has a limited reach in time and that interference-based experiments are generally successful because no remote viewer directs his conscious attention to them before the information becomes unavailable.

In summary, most of the features of psi phenomena that appear physically problematic turn out to have models available from known or theoretically accepted phenomena. The worst problems appear to be energy transmission issues in macro-PK and the quantum observation problem for interference phenomena.

Potential Revisions to Physics

There is a fairly obvious hierarchy to the ways in which data on psi phenomenology can be reconciled with known physics.

1. It is possible that existing physics requires no revision. At a minimum, this appears to require rejecting all reports of macro-PK as in some way erroneous.
2. It may be possible to accommodate psi phenomena with a minor extension such as adding a new field to the known set.
3. Incorporating psi into physics may require a paradigm-shifting theory comparable in scope to quantum mechanics or general relativity.
4. Psi may be ultimately inexplicable by physics; this is the position most often held by dualists who consider psi phenomena, and the mind itself, to be mediated by a different kind of 'stuff' from the physical universe.

Detailed discussion of these possibilities will progress most naturally in descending order, from most to least sweeping.

Psi Is Not Physical

This approach to the problem tends to lead to questions that are quite literally metaphysical, such as what exactly we mean when we speak of something being physical. One point of logical attack presents itself in the fact that all evidence for the existence of psi is to some extent physical in nature. The role of the physical in PK experiments is obvious, but even in ESP experiments the manifestations of psi are ultimately reported and recorded through physical actions such as speech or writing. Psi is thus something that can interact at least indirectly with physical things.[7] It is sometimes proposed as a

[7] If PK effects are discounted or explained in alternate terms then one may construct a dualistic model in which consciousness or mind is the only nonphysical entity that directly interacts with physical things, and psi is a purely nonphysical interaction between minds. Since this model attaches psi inextricably to consciousness it seems merely to add a taxonomical complication to the 'nonphysical' without appreciably changing the logical structure discussed in the main text.

definition that anything that interacts with physical things must itself be a physical thing. Accepting this as a definition of physicality is a perfectly legitimate logical step so long as one recalls that such 'physicality by definition' does not allow one to infer that something should have any of the other qualities usually associated with physicality, such as having mass-energy content, occupying a definite location in space, etc. The possibility of this logical step demonstrates that insofar as the 'nonphysical' realm can interact with the physical, its description is part of the legitimate domain of physics, even if that description requires entirely new concepts and principles of 'physical' law. Category 4 of 'nonphysical psi' can thus be seen to be a special case of Category 3, 'paradigm shift in physics'.

Psi Requires a Paradigm Shift in Physics

In this context a 'paradigm shift' is taken to mean a complete restructuring of the fundamental concepts of the theory. Examples of previous paradigm shifts include General Relativity, in which the absolute space and time of Newton are replaced with the dynamic spacetime whose curvature explains gravitation; and quantum mechanics, in which the real particles of Newtonian mechanics are replaced with abstract states (of which Schroedinger's famous wave functions are only one particular representation). A significant proportion of the parapsychological community seems to expect that the explanation of psi will ultimately require some sort of mind/body dualism. As discussed above this seeming retreat from physics is actually the first step in constructing such a paradigm-shifting theory, although few advocates have thus far carried it beyond that first step. More specific theories of this class, but still not sufficiently developed for quantitative evaluation, have been proposed by Jahn and Dunne (Jahn, 2002; Jahn & Dunne, 1986, 2001, 2004).

The earlier discussion of the ways in which physical experimentation has been directed away from psi phenomena suggests, by analogy with the cases of quantum mechanics and relativity, that the paradigm-shifting approach may in the long run be the most parsimonious way of constructing a physical theory that includes psi. An important constraint of such a theory, however, is that it must reduce to the earlier version of physics when the conditions that forced the revision do not apply. In other words, just as relativistic physics gives the same answers as Newtonian dynamics in situations where the speed of light can be treated as effectively infinite, and quantum

mechanics does likewise in circumstances where Planck's constant can be treated as indistinguishable from zero, any version of 'psi-dynamics' that incorporates psi in physics as a fundamental quantity must give the same answers as conventional physics in cases where psi effects can be ignored. In general, this constraint of reduction places severe restrictions on the mathematical forms that such a theory can take. These constraints may be less severe for a theory that incorporates psi, in that they can be seen as applying only to the interface in which psi interacts with the more mundane components of physics.

A consideration that may work in favor of the paradigm-shift approach is that physicists currently expect at least one more change at this level to occur in the not-too-distant future. The irreconcilable conflict between general relativity and quantum field theory means that at least one theory, and possibly both, must be fundamentally revised for there to be a coherent explanation of all of physics. A successful theory of psi at this fundamental level might just be able to reconcile this conflict. Even if this is too ambitious a hope, the ability of physics to survive this incompatibility between its two most fundamental theories suggests that a comparably paradigm-shifting theory of physics with psi might be forgiven a comparable degree of incongruity, provided it explained a broad range of phenomena, made quantitative empirical predictions which passed experimental test, and correctly reduced to simple Newtonian physics when psi terms were set to zero.

Psi Requires Extensions to Current Physics

Far and away the most popular method of reconciling psi with physics is to stipulate the existing structure of physics and add a new feature capable of accommodating psi. For a few examples, Tiller (2003) attempts to accommodate healing effects by extending the number of dimensions of spacetime; Rauscher and Targ (2006) attempt to explain precognition and remote viewing by proposing that spacetime coordinates should be complex-valued rather than real-valued; and Beichler (2001) provides a bibliography and review of numerous attempts at a psi-based extension of physics spanning much of the 20th century.

In general, such attempts have not been broadly persuasive for at least one of a variety of reasons. They may, for example, fail to account for the broad range of psi phenomena, being designed with only one type of empirical effect in mind. From the perspective of physics, there are two related types of problems which render such theories

unpersuasive. First, theories that invoke new fields, new particle species, or additional spatial dimensions do not in general offer a satisfactory explanation for why these physical features of the universe appear only in psi-related contexts and not in ordinary physical observations. Second, such theories tend to make psi 'too easy'. It is difficult to see, in most such theories, why strong psi manifestations should be a rare phenomenon requiring either special circumstances, exceptional individuals, or extensive training to elicit. Yet another problem does not apply to any particular extended-physics theory in isolation, but emerges from their very multiplicity. Most of these theories are mutually contradictory; for example, they may posit a different total number of dimensions for spacetime. In such a situation it is obvious that at best all but one of the proposed theories must be wrong, and it is entirely possible that all of them are. Finally, relatively few of the theoretical proposals have been developed sufficiently to make testable empirical predictions. The exceptions have generally seen only small-scale empirical testing by their own proponents, which will not be persuasive to wider communities until other experimenters take up the task.

Currently, quantum field theory (the special-relativistic form of quantum mechanics) has been applied to elementary-particle physics so successfully that the resulting model is routinely referred to as the Standard Model. This provides a complete explanation of electromagnetism along with the strong and weak nuclear forces, and has been verified to extraordinary levels of numerical precision.[8] Making a strong change to the Standard Model, such as adding a new field or changing its spacetime dimensionality, is very difficult to do without in some way contradicting this extensive and sensitive match to experiments. (String theory gets away with proposing extra dimensions by having them 'compactified' such that the total extent of the Universe in the added directions is too small to change the Standard Model's

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[8] Small but vocal communities of dissidents dispute the premises of the Standard Model, and with sufficient effort one can find publications even to this day arguing that quantum mechanics, relativity, or both are mistaken. Since such contrarian positions are not only held by extremely small minorities, but are also in my opinion ill-founded as regards both theory and evidence, I choose neither to cite them nor to describe them in detail, but simply mention their existence to avoid giving a false impression of monolithic unanimity in the physics community.

predictions at any testable scale.) This places an additional hurdle on the integration of any proposed extension with the rest of physics.

Psi within Current Physics

Previous sections have pointed out that the contradictions between known physics and psi phenomena are not as profound or fundamental as is generally assumed. However, the energy conservation and transmission issues indicate that macro-PK, at least, seems to have no acceptable explanation within currently known physics, forcing us either to adopt some form of revised model or to assume, along with the skeptics, that all reports of this sort of psi manifestation are erroneous. It seems contrary to the principles of empiricism to discard an entire body of well-established data because they are incompatible with theory, so it seems one is forced to the conclusion that physics will eventually be revised either by extension or by reformulation to account for macro-PK effects.

On the other hand, there is no guarantee that all psi manifestations are the same phenomenon or operate through the same mechanism, so it seems worthwhile to examine possible models of other types of psi manifestation under currently known physics.

It should be mentioned here that a number of proposed models for certain types of psi known under the general category of 'observation theories' propose that the explanation of psi lies in the quantum-mechanical phenomenon sometimes called 'collapse of the wavefunction' under observation. One fundamental problem with these theories is that the so-called 'wavefunction collapse' is currently a complete mystery. While its consequences are exactly specified by the laws of quantum mechanics, there is no formalism that describes what actually happens during this process or even whether it is properly to be described as a process, and physicists are still divided among multiple 'interpretations' concerning its physical meaning (Penrose, 1989, 2004 —the citations given here are to explanations which will be accessible to educated non-physicists). Given its status as an enigma, wavefunction collapse seems to be itself in need of explanation, rather than something that can explain other phenomena. For this reason observation theories shall not be discussed further here despite their currency in some branches of parapsychology.

ESP

For the current analysis ESP covers the acquisition of information which could have reached the percipient by some known form of signaling, leaving retrocausal cases (precognition, presentiment, etc.) in a separate category. It was noted previously that both signaling and entanglement can account for the distance-independence which is one of the physical criticisms of ESP.

If ESP is mediated by a signal, there seem to be three basic categories of possible explanation, listed here with their physical consequences.

1. The signal is of some known physical type but which human sensory mechanisms are not believed to detect. (If the percipient is receiving a signal that known sensory mechanisms do detect, the phenomenon is not ESP but a sensory confound resulting from poor experimental design or implementation.) This is implausible for the longer-range cases, but possible in principle. The implications for physics are nil, although the implications for biology and physiology may be profound.

2. The signal is of a known physical type but is propagating in ways that avoid the usual obstacles such as distance, sensory isolation, etc. This is compatible with known physics in the sense that it involves processes which might be possible in principle but are not definitely known to occur, and will be discussed further in the section on retrocausation.

3. The signal is of unknown physical type. This requires an extension of physics as discussed above.

4. The signal is 'nonphysical' in the loose sense discussed earlier. This requires a paradigm-shifting physical model.

An alternative to signaling for many ESP cases can be found in the quantum-mechanical phenomenon of entanglement, which has been demonstrated in numerous experiments in recent decades (Aspect, Dalibard & Roger, 1982). Figure 1 illustrates a schematic structure that is isomorphic between experimental demonstrations of entanglement and many, perhaps all, experimental tests of ESP. The block labeled "Preparation" represents, in an entanglement experiment, the preparation of two particles in an entangled quantum state; in an ESP experiment it represents the decision to perform an experiment and the

recruitment of any necessary participants. In an entanglement experiment Events A and B are typically detection events at two separated detectors. In an ESP experiment Event A would be the attempted ESP task and Event B the features of the target of the task; this might be a remotely presented image in a ganzfeld trial, the outbounder description in some RV trials or the properties of the target site in others, etc. Finally, in the box labeled "Correlation" the data from the two events (or sets of events) are collected and are found to contain correlations that cannot be explained by classical data transmission.

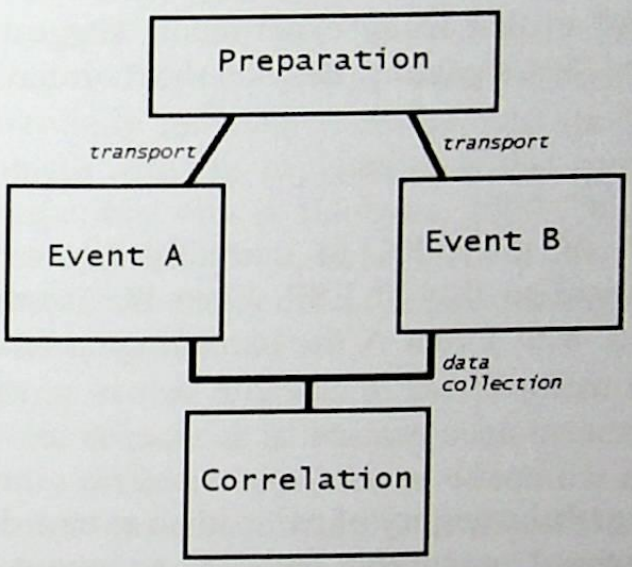

FIGURE 1.
Isomorphic structural framework for entanglement experiments and psi experiments.

In principle any interaction between quantum particles entangles at least some of the variables describing their states. In practice entanglement experiments require some care in preparing a state where two particles are measurably entangled and extreme care in preventing that entanglement from being disrupted by outside interactions. It is generally believed that the dense, high-temperature environment of a biological entity precludes the persistence of an entangled state for any length of time, so it is problematic to suppose that the entanglement-like correlations of ESP data are the result of literal entanglement of particles. However, the problem with preserving entanglement is that when one particle of an entangled pair interacts with its environment, it becomes entangled in turn with the particles of that environment, and

the single item of information relevant to the state of the original entangled partner becomes impossible to find among the vast number of environmental states. Every instant of life for a biological organism, on the other hand, involves similarly astronomical numbers of quantum interactions, each of which creates its own entanglement, and organic brains are known to operate by a form of massively parallel processing. It thus seems at least a viable speculation that living organisms may be able to solve the 'environmental entanglement' problem at least partially for large amounts of entanglement information. Some additional credence might be added to this speculation by the observations of von Lucadou (2006) that psi phenomena are entanglement-like in that many experiments suggest that they cannot actually be used for signaling despite the correlations between the separated events.

Micro-PK

The relation of micro-PK to currently known physical law is essentially identical to that of ESP. Even the isomorphic relation to Figure 1 applies, with Event A the human agent and Event B the PK target.

Retrocausation

The third physical category of psi is in an extraordinarily ambiguous position with regard to current physics. As noted above, numerous physical theories show the potential for retrocausal phenomena. These have traditionally been dismissed as unphysical due to the need to maintain causality, but the analysis of Echeverria *et al.* (1991) has proven that there is in fact no such need. In consequence of the perceived need, however, possible evidence for retrocausal physical phenomena has been dismissed or ignored, leaving physical science in the peculiar position that retrocausal phenomena are theoretically expected, widely disbelieved by the community, and empirically almost completely untested. Such empirical tests as have been performed, however, strongly support the existence of the phenomenon (Bierman, 2006; Broughton, 2006; Dobyns, 2006; Nelson & Bancel, 2006; Radin, 2006).[9] For purposes of the current analysis it therefore seems

[9] To cite all references on this topic would require an article in its own right, or perhaps a book. The citations given, together with the references they cite in turn, provide an overview of recent research.

reasonable to stipulate that retrocausation occurs and can be accommodated within known physics by one or more of the mechanisms discussed earlier.

Interestingly, this makes it easier to explain both ESP and micro-PK in terms of current physics. For ESP, the relationship is obvious: in any experiment in which the percipient receives eventual feedback of the target, hypothetical mechanisms for perceiving a distant site or object can be replaced by direct retrocausal awareness of an experience in the percipient's personal future.

At least two mechanisms exist for accounting for micro-PK, including its distance independence, via retrocausation. One is the DAT model proposed by May, Utts, and Spottiswoode (1995), in which operators attempting a PK task adjust their behavior so that data collection is preferentially initiated when the outcome will correspond to intention. A problem with this explanation is that some experimental databases are incompatible with it. (Dobyns, 2000: Dobyns & Nelson, 1998) However, the mechanism of Echeverria *et al.* (1991) provides another means by which the existence of retrocausation seems to imply the existence of something akin to PK.

The solution given in that analysis to the problem of paradoxical, self-inconsistent event sequences is that any such sequence implies the existence of a slightly different sequence in which the events are self-consistent and therefore possible. Usually, in fact, there will be many such alternatives and one must resort to quantum mechanics to assign probabilities to the possible outcomes. The situation allows a Holmesian paraphrase: 'Once the impossible is eliminated, whatever remains, however improbable, must come to pass'.

Consider, as a *Gedankenexperiment*, a reliable computer equipped with a reliable retrocausal information channel. Let it be set up in a paradoxical configuration, e.g. that at 10 a.m. it will send a signal to itself at 9 a.m. which will cause it to shut itself down. Since this is an impossible sequence, some alternative event, such as a failure in the computer, its power supply, or the communication circuit, must happen instead. Even though such events are very low probability for a 'reliable' system, their probability cannot be reduced to zero, and the vanishing probability of the paradoxical sequence means that one of the alternatives must occur in its stead.

Now expand the apparatus to include a physical RNG connected to the computer, and expand its program to query the RNG and to send the shutdown signal only if it receives a 0 bit in response. There is now

a paradox-free course of events that has probability 0.5, as opposed to the minute probability of an equipment failure. It would appear to follow that an unbiased RNG connected to such a system will (almost) always produce 1s, even if it produces a proper even mix of 1s and 0s in isolation.[10]

If the computer connected to the RNG is replaced by a human being with some capacity for retrocausal communication between past and future selves, most of the essential ingredients still seem to be present. The reliability of the communication is presumably fairly low, but this is a quantitative rather than qualitative change. Any retrocausal communication presumably takes place at a subconscious level, since the agent is attempting to conduct a PK experiment rather than a precognition experiment. What does seem to be missing is the conscious intent to create a time paradox. However, the desire for a specific outcome would seem to create a possible substitute in that the PK agent only wants to know about positive outcomes. While, presumably, most of the time a paradox will be avoided by a failure of the erratic precognition channel, sometimes it will be avoided by the RNG producing the desired outcome. This differs from the DAT mechanism in that the statistical unit becomes the element of observer feedback rather than the initiation of data collection, changing the statistical signature of the outcomes.

Summary

The relation of current physical knowledge to psi phenomena as discussed above seems to lead to the following conclusions;

- Most physics-based criticisms of psi phenomena are inadequately supported by theory and may actually be contradicted by evidence.
- Most forms of psi for which there is observational support can therefore be accommodated within the current theoretical framework of physics, particularly if at least one of several possible theoretical channels for retrocausal effects can be confirmed to exist.

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[10] For proper rigor this analysis should be conducted in terms of quantum mechanical amplitudes rather than classical probabilities; however, there does not seem to be anything in the theory of quantum measurement that would significantly alter these conclusions.

- Macro-PK is an exception in that it cannot be accommodated with existing theory and can only be explained by an extension or reformulation of physics.
- Other psi phenomena will become easier to explain under such extension or reformulation.
- Since at least one paradigmatic reformulation in physics is both expected and required by the current state of conflict between the most fundamental theories, it is not unreasonable to consider such reformulation as a way to incorporate psi. A single reformulation might even succeed in accomplishing both tasks.

Future Directions for Research.

These are the questions about psi that seem most interesting from the perspective of physics, along with some suggestions for how they might be answered:

a) Will adding psi to the mix allow physicists to achieve the 'Theory of Everything' that will successfully incorporate gravity into quantum mechanics? Although it is a difficult challenge to get mathematical physicists to take psi seriously, the worst roadblock to answering this question is the lack of quantitative information regarding psi effect sizes, which derives in no little part from the erratic nature of replication in psi experiments. Gaining a good working understanding of the replication problem would be a prerequisite for theoretical unification.

b) Has psi been making unrecognized contributions to physics experiments? This could be answered by retrospective meta-analysis of the physics literature on contentious issues where experimenters had significant emotional or personal investment in specific outcomes. A challenge of this meta-analysis would be to distinguish an actual experimenter psi effect from simple methodological sloppiness.

c) Are sensitive experiments vulnerable to psi influences via a PK mechanism? Addressing this prospective version of the preceding retrospective question would require collaboration between a physics research team and parapsychologists; it is also pointless unless human participants who can reliably be expected to produce micro-PK effects can be recruited.

d) Is macro-PK a real phenomenon, and if so what conditions are required to elicit it reliably? (The reliability question is of course crucial to all forms of psi, but macro-PK is of special interest on physical grounds.) Serious and systematic investigation of current claims, even or especially anecdotal ones, seems to be needed to answer this question.

e) What is the relationship of psi sensing, whether as remote viewing or any other mode, to issues of quantum measurement? Can Radin's 'which-way' interference effect be confirmed with other researchers and remote viewers? Can continuous RV observation impose a quantum Zeno effect? Can RV observation prevent a 'quantum eraser' experiment from working? The subsequent questions are simply specific instances of the first one; these can all be answered by direct experimentation, although fairly delicate and expensive physics equipment may be required to set them up.

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