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Lists of unsolved problems in Science

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Abstract: Some of the unsolved problems in science are theoretical, meaning that existing hypothesis seem incapable of explaining a certain observed phenomenon. The others are experimental, meaning that there is a difficulty in creating an experiment to investigate a phenomenon in greater detail. This article outlines several conjectures or open problems in various scientific fields.

Keywords: Computer Science, Physics, Chemistry, Neuroscience, Biology, Linguistics, Astronomy.

Computer Science:

- P versus NP problem
- What is the relationship between BQP and NP?
- NC = P problem
- NP = co-NP problem
- P = BPP problem
- P = PSPACE problem
- L = NL problem
- PH = PSPACE problem
- L = P problem
- L = RL problem
- Unique games conjecture
- Is the exponential time hypothesis true?

- Is the strong exponential time hypothesis (SETH) true?
- Do one-way functions exist?
- Is public-key cryptography possible?
- Log-rank conjecture
- Can integer factorization be done in polynomial time on a classical (non-quantum) computer?
- Can clustered planar drawings be found in polynomial time?
- Can the discrete logarithm be computed in polynomial time?
- Can the graph isomorphism problem be solved in polynomial time?
- Can leaf powers and k-leaf powers be recognized in polynomial time?
- Can parity games be solved in polynomial time?
- Can the rotation distance between two binary trees be computed in polynomial time?
- Can graphs of bounded clique-width be recognized in polynomial time?
- Can one find a simple closed quasigeodesic on a convex polyhedron in polynomial time?
- Can a simultaneous embedding with fixed edges for two given graphs be found in polynomial time?
- The dynamic optimality conjecture: do splay trees have a bounded competitive ratio?
- Is there a k-competitive online algorithm for the k-server problem?
- Can a depth-first search tree be constructed in NC?
- Can the fast Fourier transform be computed in $o(n \log n)$ time?
- What is the fastest algorithm for multiplication of two n-digit numbers?
- What is the lowest possible average-case time complexity of Shellsort with a deterministic, fixed gap sequence?
- Can 3SUM be solved in strongly sub-quadratic time, that is, in time $O(n^{2-\epsilon})$ for some $\epsilon>0$?
- Can the edit distance between two strings of length n be computed in strongly sub-quadratic time? (This is only possible if the strong exponential time hypothesis is false.)
- Can X + Y sorting be done in $o(\{\boldsymbol{n}^2 \log n)$ time?
- What is the fastest algorithm for matrix multiplication?
- Can all-pairs shortest paths be computed in strongly sub-cubic time, that is, in time $O(V^{3-\epsilon})$ for some $\epsilon>0$?

- Can the Schwartz–Zippel lemma for polynomial identity testing be derandomized?
- Does linear programming admit a strongly polynomial-time algorithm?
- How many queries are required for envy-free cake-cutting?
- What is the algorithm for the lookup table that consistently generates playable mazes in the 1982 Atari 2600 game Entombed merely from the values of the five pixels adjacent to the next ones to be generated?
- Is there any perfect syllabification algorithm in the English language?
- Is there any perfect stemming algorithm in the English language?
- Is there any perfect POS tagging algorithm in the English language?

Information theory:

- **Capacity of a network**: The capacity of a general wireless network is not known. There are some specific cases for which the capacity is known, such as the AWGN channel and fading channel.
- **Capacity of the broadcast channel**: The capacity of the broadcast channel, or the case in which a single transmitter is sending information to many receivers is unknown in general, though it is known for several specific cases.
- **Capacity of the interference channel (Two User)**: The capacity of the interference channel, in the case where there are two transmitter and receiver pairs that interfere among each other, is unknown in general. Capacity is known in special cases: strong interference regime, injective-deterministic. Capacity is known in approximate sense or with in a gap for: injective-semi-deterministic, additive white Gaussian noise with per block power constraint.
- **Capacity of the two-way channel**: The capacity of the two-way channel (a channel in which information is sent in both directions simultaneously) is unknown.
- **The capacity of Aloha:** The ALOHAnet used a very simple access scheme for which the capacity is still unknown, though it is known in a few special cases.
- **Quantum capacity**: The capacity of a quantum channel is in general not known.
- **Distributed source coding**: The best way to compress multiple correlated information sources that do not communicate with each other is not known.

Statistics:

- How to detect and correct for **systematic errors**, especially in sciences where random errors are large (a situation Tukey termed uncomfortable science).
- The Graybill–Deal estimator is often used to estimate the common mean of two normal populations with unknown and possibly unequal variances. Though this estimator is generally unbiased, its admissibility remains to be shown.
- **Meta-analysis**: Though independent p-values can be combined using Fisher's method, techniques are still being developed to handle the case of dependent p-values.
- **Behrens–Fisher problem**: Yuri Linnik showed in 1966 that there is no uniformly most powerful test for the difference of two means when the variances are unknown and possibly unequal. That is, there is no exact test (meaning that, if the means are in fact equal, one that rejects the null hypothesis with probability exactly α) that is also the most powerful for all values of the variances (which are thus nuisance parameters). Though there are many approximate solutions (such as Welch's t-test), the problem continues to attract attention as one of the classic problems in statistics.
- **Multiple comparisons**: There are various ways to adjust p-values to compensate for the simultaneous or sequential testing of hypothesis. Of particular interest is how to simultaneously control the overall error rate, preserve statistical power, and incorporate the dependence between tests into the adjustment. These issues are especially relevant when the number of simultaneous tests can be very large, as is increasingly the case in the analysis of data from DNA microarrays.
- **Sampling of species problem**: How is a probability updated when there is unanticipated new data?
- **Doomsday argument**: How valid is the probabilistic argument that claims to predict the future lifetime of the human race given only an estimate of the total number of humans born so far?
- **Exchange paradox**: Issues arise within the subjectivistic interpretation of probability theory; more specifically within **Bayesian decision theory**. This is still an open problem among the subjectivists as no consensus has been reached yet. Examples include:

The two envelopes problem

The necktie paradox

- **Sunrise problem**: What is the probability that the sun will rise tomorrow? Very different answers arise depending on the methods used and assumptions made.

Astronomy:

- Planetary systems: How does accretion form planetary systems? Where did Earth's water come from?
- Are there any planets beyond Neptune? What is the explanation for the elongated orbits of a group of Kuiper belt objects?
- Rotation rate of Saturn: Why does the magnetosphere of Saturn exhibit a (slowly changing) periodicity close to that at which the planet's clouds rotate? What is the true rotation rate of Saturn's deep interior?
- Solar cycle: How does the Sun generate its periodically reversing large-scale magnetic field? How do other solar-like stars generate their magnetic fields, and what are the similarities and differences between stellar activity cycles and that of the Sun? What caused the Maunder Minimum and other grand minima, and how does the solar cycle recover from a minimum state?
- Coronal heating problem: Why is the **Sun's corona** (atmosphere layer) so much hotter than the Sun's surface? Why is the magnetic reconnection effect many orders of magnitude faster than predicted by standard models?
- What is the origin of the stellar mass spectrum? That is, why do astronomers observe the same distribution of stellar masses – the initial mass function – apparently regardless of the initial conditions?
- Supernovae: What is the exact mechanism by which an implosion of a dying star becomes an explosion?
- p-nuclei: What astrophysical process is responsible for the nucleogenesis of these rare isotopes?
- Fast radio bursts (FRBs): What causes these transient radio pulses from distant galaxies, lasting only a few milliseconds each? Why do some FRBs repeat at unpredictable

intervals, but most do not? Dozens of models have been proposed, but none have been widely accepted.

- The Oh-My-God particle and other ultra-high-energy cosmic rays: What physical processes create cosmic rays whose energy exceeds the GZK cuttoff?
- Nature of KIC 8462852, commonly known as Tabby's Star: What is the origin of unusual luminosity changes of this star?
- Galaxy rotation problem: Is dark matter responsible for differences in observed and theoretical speed of stars revolving around the centre of galaxies, or is it something else?
- Age–metallicity relation in the **Galactic disk**: Is there a universal age–metallicity relation (AMR) in the Galactic disk (both "thin" and "thick" parts of the disk)? Although in the local (primarily thin) disk of the Milky Way there is no evidence of a strong AMR, a sample of 229 nearby "thick" disk stars has been used to investigate the existence of an age–metallicity relation in the Galactic thick disk, and indicate that there is an age–metallicity relation present in the thick disk. Stellar ages from asteroseismology confirm the lack of any strong age-metallicity relation in the Galactic disc.
- Ultraluminous X-ray sources (ULXs): What powers X-ray sources that are not associated with active galactic nuclei but exceed the Eddington limit of a neutron star or stellar black hole? Are they due to intermediate mass black holes? Some ULXs are periodic, suggesting non-isotropic emission from a neutron star. Does this apply to all ULXs? How could such a system form and remain stable?
- Gravitational singularities: Does general relativity break down in the interior of a black hole due to quantum effects, torsion, or other phenomena?
- No-hair theorem: Do black holes have an internal structure? If so, how might the internal structure be probed?
- Black hole information paradox and black hole radiation: Do **black holes** produce thermal radiation, as expected on theoretical grounds? If so, and black holes can evaporate away, what happens to the information stored in them (since quantum mechanics does not provide for the destruction of information)? Or does the radiation stop at some point leaving black hole remnants?
- Firewalls: Does a firewall exist around a black hole?

- Final parsec problem: Supermassive black holes appear to have merged, and what appears to be a pair in this intermediate range has been observed, in PKS 1302-102. However, theory predicts that when **supermassive black holes** reach a separation of about one parsec, it would take billions of years to orbit closely enough to merge - more than the age of the universe.
- Dark matter: What is the identity of dark matter? Is it a particle? Is it the lightest superpartner (LSP)? Do the phenomena attributed to dark matter point not to some form of matter but actually to an extension of gravity?
- Dark energy: What is the cause of the observed accelerated expansion (de Sitter phase) of the universe? Why is the energy density of the dark energy component of the same magnitude as the density of matter at present when the two evolve quite differently over time; could it be simply that we are observing at exactly the right time? Is dark energy a pure cosmological constant or are models of quintessence such as phantom energy applicable?
- Baryon asymmetry: Why is there far more matter than antimatter in the observable universe?
- Cosmological constant problem: Why does the zero-point energy of the vacuum not cause a large cosmological constant? What cancels it out?
- Size and shape of the universe: The diameter of the observable universe is about 93 billion light-years, but what is the size of the whole universe? What is the 3-manifold of comoving space, i.e. of a comoving spatial section of the universe, informally called the "shape" of the universe? Neither the curvature nor the topology is presently known, though the curvature is known to be "close" to zero on observable scales. The cosmic inflation hypothesis suggests that the shape of the universe may be unmeasurable, but, since 2003, Jean-Pierre Luminet, et al., and other groups have suggested that the shape of the universe may be the Poincaré dodecahedral space. Is the shape unmeasurable; the Poincaré space; or another 3-manifold?
- Cosmic inflation: Is the theory of cosmic inflation in the very early universe correct, and, if so, what are the details of this epoch? What is the hypothetical inflaton scalar field that gave rise to this cosmic inflation? If inflation happened at one point, is it self-sustaining

through inflation of quantum-mechanical fluctuations, and thus ongoing in some extremely distant place?

- Horizon problem: Why is the distant universe so homogeneous when the Big Bang theory seems to predict larger measurable anisotropies of the night sky than those observed? Cosmological inflation is generally accepted as the solution, but are other possible explanations such as a variable speed of light more appropriate?
- Axis of evil: Some large features of the microwave sky at distances of over 13 billion light years appear to be aligned with both the motion and orientation of the solar system. Is this due to systematic errors in processing, contamination of results by local effects, or an unexplained violation of the Copernican principle?
- Origin and future of the universe: How did the conditions for anything to exist arise? Is the universe heading towards a Big Freeze, a Big Rip, a Big Crunch, or a Big Bounce? Or is it part of an infinitely recurring cyclic model?
- Is there other life in the Universe? Especially, is there other intelligent life? If so, what is the explanation for the Fermi paradox?
- Nature of Wow! signal: Was this singular event a real signal and, if so, what was its origin?

Linguistics:

- Is there a universal definition of *word*?
- Is there a universal definition of *sentence*?
- Are there any universal grammatical categories?
- Is syntactic structure constructed of part-whole relations of syntactic constituents or is it built of an asymmetrical dependency relation between words?
- Can the elements contained in words (morphemes) and the elements contained in sentences (words or syntactic constituents) be shown to follow the same principles of combination?
- How are domains for phonological processes related to syntactic structure? Do prosodic domains deviate from syntactic constituent structure?

- Is it possible to formally delineate languages from each other? That is to say, is it possible to use linguistic (rather than social) criteria to draw a clear boundary between two closely related languages with a dialect continuum between their respective standard forms (e.g. Occitan and Catalan)?
- How does grammaticalization function?
- What constitutes grammatical language, as viewed by native speakers of that particular language, i.e. the problem of gradient well-formedness?
- Is there one universal process with which the evolution of creole languages can be tracked?
- How does lexical substitution function given the potentially limitless number of different contexts, the limits of one's knowledge and the limits of one's understanding and usage of language?
- How do idiolects and dialects emerge? Are there any common patterns in their development? Can they be quantitatively and qualitatively measured at all and if so, how?
- How and when did language originate?
- How and when did different modes of language (spoken, signed, written) originate?
- Were *Homo sapiens* the first humans to use language? What about other species in the genus *Homo*?
- Is language continuous or discontinuous with earlier forms of communication? Did language appear suddenly or gradually?
- What language families are valid?
- Are any macro-families valid?
- Can any of the approximately 100 unclassified languages be classified? Or does our limited knowledge of them prevent that?
- Can we decipher any of the extant undeciphered writing systems?
- Language isolates have no demonstrated relatives, and essentially form language families on their own. Can any of the approximately 159 language isolates be shown to be related to other languages?
- Can we use the comparative method to reconstruct back to an arbitrary time depth, or do we need new methods to reconstruct the distant past of languages? Is there a time depth beyond which we cannot reconstruct?

- Can we ever demonstrate that all languages are ultimately related to each other, or that they aren't?
- Language emergence: Emergence of grammar
- Controversy: infant language acquisition / first language acquisition. How are infants able to learn language? One line of debate is between two points of view: that of psychological nativism, i.e., the language ability is somehow "hardwired" in the human brain, and that of the *"tabula rasa"* or blank slate, i.e., language is acquired due to brain's interaction with environment. Another formulation of this controversy is "nature versus nurture".
- Is the human ability to use syntax based on innate mental structures or is syntactic speech the function of intelligence and interaction with other humans? The question is closely related to those of language emergence and acquisition.
- The language acquisition device: How localized is language in the brain? Is there a particular area in the brain responsible for the development of language abilities or is it only partially localized?
- What fundamental reasons explain why ultimate attainment in second language acquisition is typically some way short of the native speaker's ability, with learners varying widely in performance?
- What are the optimal ways to achieve successful second-language acquisition?
- Animals and language: How much human language can animals be taught to use? How much of animal communication can be said to have the same properties as human language (e.g. compositionality of bird calls as syntax)?
- What role does linguistic intuition play, how is it formed and how does it function? Is it closely linked to exposure to a unique set of different experiences and their contexts throughout one's personal life?
- How to deal with variation in language (including idiolects, dialects, sociolects, jargons, argots, etc.) to achieve effective and successful communication between individuals and between groups, i.e. what are the best ways to ensure efficient communication without misunderstandings: in everyday life and in educational, scientific and philosophical discussions?

- What are the best ways to quantitatively and qualitatively compare linguistic competence and linguistic performance between individuals and between groups?
- How does time (and the semantic change that it brings) and physical age influence linguistic competence?
- How are argots formed, how do they function and what are the best ways to become proficient in an argot?
- What causes linguistic features to begin to undergo language change at some points in time and in some dialects but not others?
- Is there an objective gauge for the quality of translation?
- What are the best strategies for quality translation: fidelity or transparency, dynamic or formal equivalence, etc.?
- What are the best ways to deal with untranslatability, e.g. lexical gaps?
- How to best deal with translation loss and its accumulation, e.g. when translating from a translation (see Chinese whispers)?
- Can machine translations ever achieve the high degree of comprehensibility and quality of translations translated by a good professional human translator?
- What are the effective ways to achieve proper localization and internationalization?
- What makes a good dictionary?
- To what extent are dictionaries reliable in terms of their supposed universality when spoken language is constantly changing (semantic change, semantic extension, semantic compression, etc.)?
- What are good practices to avoid circular definitions in dictionaries? Is it possible to eliminate them at all, given the vagueness, polysemy, etc. in all languages?
- What are the best ways to ensure efficient communication without misunderstandings: in everyday life and in educational, scientific and philosophical discussions? Is total terminology standardization attainable at all? If yes, does it involve the mass use of freely available and easily accessible terminology databases?
- To what extent are termbases reliable and can their reliability be measured objectively? If yes, how and why? If no, why? What is the relationship between termbases and individual subjectivity and can subjectivity about word sense disambiguation be

overcome at all or is it a natural result of different experiences in one's unique personal life?

- How to successfully reduce lexicographic errors and lexicographic information costs?
- Is perfect computational word-sense disambiguation attainable by using software? If yes, how and why? If no, why? (This presupposes the solution to the unsolved problems in the other areas of linguistics as a basis.)
- Is accurate computational word-sense induction feasible? If yes, how and why? If not, why?
- Is there an objective way to determine which are the most difficult languages?
- To what extent are conlangs usable and useful as used as natural languages by humans?

Geosciences:

- How did Earth and other planets form? Were planets formed in situ? Or are orbital changes relatively frequent? What determined the different deep layering of the solar planets?
- Was there ever a collision of the Earth with another planet Theia, giving birth to our satellite? There is compelling evidence, such as measures of a shorter duration of the Earth's rotation and lunar month in the past, pointing to a Moon much closer to Earth during the early stages of the Solar System.
- What is the long-term heat balance of Earth? How did its internal temperature decay since it formed by **accretion of chondrites**? How abundant are radiogenic elements in the interior? Did a "faint young Sun" ever warm a "snowball Earth"?
- What made plate tectonics a dominant process only on Earth?. How did the planet cool down before plate tectonics? Was the Earth's crust formed during the early stages of its evolution or is it the result of a gradual distillation of the mantle that continues today along with crustal recycling? Is the crust still growing or does its recycling compensate for crust formation at mid-ocean ridges and other volcanic areas?
- Can the now widely available topographic data be used to derive past tectonic and climatic conditions (in the multi-million year scale)? Do we know enough about the erosion and transport processes? Does the stochasticity of meteorological and tectonic

events reflect in the landscape? How much has life contributed to shape the Earth's surface?

- Can classical geomorphological concepts such as peneplanation or retrogressive erosion be quantitatively understood? Old mountain ranges such as the Appalachian or the Urals seem to retain relief for $>10^8$ years, while subglacial fluvial valleys under Antarctica are preserved under moving ice of kilometric thickness since the Neogene. What controls the time-scale of topographic decay?
- What are the erosion and transport laws governing the evolution of the Earth's Surface? Rivers transport sediment particles that are at the same time the tools for erosion but also the shield protecting the bedrock. How important is this double role of sediment for the evolution of landscapes?
- How resilient is the ocean to chemical perturbations?
- What caused the huge salt deposition in the Mediterranean known as the Messinian salinity crisis? Was the Mediterranean truly desiccated? What were the effects on climate and biology, and what can we learn from extreme salt giants like this? How were the normal marine conditions reestablished?
- What controls the dynamics of storm tracks?
- Mechanisms that cause oscillations in equatorial climate remain under intense study. The El Nino Southern Oscillation (ENSO) of the equatorial Pacific Ocean temperature is difficult to predict more than a few months in advance. The Quasi-Biennial Oscillation (QBO) of the equatorial stratospheric winds is somewhat regular at ~28 months but the cause has been heavily debated. Are these stochastic, chaotic, or deterministically forced behaviors?
- What are skyquakes?
- The '**space problem**': How are granite magma chambers emplaced in the crust? What are the structures and locations of the magmatic systems that might cause supervolcanoes? What are the viscosities and densities of the magma chambers and the details of magma migration?
- What are the non-uniformities and rheological details of the mantle? What is the structure of the 660 km discontinuity and its relation to the correct model of the polar drift?

- What is the precise nature of chemical heterogeneity associated with the Gutenberg discontinuity?
- What are the light alloying elements in the Earth's outer core and how are they distributed? What are the heterogeneities of the core and their dynamical significance?
- Does the internal mantle structure provide the resonance for the Chandler wobble of the earth's axis or is it some other external mechanism? No available motions seem to be coherent drivers for the wobble period of 433 days.

Neuroscience:

- Consciousness: What is the neural basis of subjective experience, cognition, wakefulness, alertness, arousal, and attention? Is there a "hard problem of consciousness"? If so, how is it solved? What, if any, is the function of consciousness?
- Perception: How does the brain transfer sensory information into coherent, private percepts? What are the rules by which perception is organized? What are the features/objects that constitute our perceptual experience of internal and external events? How are the senses integrated? What is the relationship between subjective experience and the physical world?
- Learning and memory: Where do our memories get stored and how are they retrieved again? How can learning be improved? What is the difference between explicit and implicit memories? What molecule is responsible for synaptic tagging?
- Neuroplasticity: How plastic is the mature brain?
- Development and evolution: How and why did the brain evolve? What are the molecular determinants of individual brain development?
- Free will, particularly the neuroscience of free will
- Sleep: What is the biological function of sleep? Why do we dream? What are the underlying brain mechanisms? What is its relation to anesthesia?

- Cognition and decisions: How and where does the brain evaluate reward value and effort (cost) to modulate behavior? How does previous experience alter perception and behavior? What are the genetic and environmental contributions to brain function?
- Language: How is it implemented neurally? What is the basis of semantic meaning?
- Diseases: What are the neural bases (causes) of mental diseases like psychotic disorders (e.g. mania, schizophrenia), Amyotrophic lateral sclerosis, Parkinson's disease, Alzheimer's disease, or addiction? Is it possible to recover loss of sensory or motor function?
- Movement: How can we move so controllably, even though the motor nerve impulses seem haphazard and unpredictable?
- Computational theory of mind: What are the limits of understanding thinking as a form of computing?
- Computational neuroscience: How important is the precise timing of action potentials for information processing in the neocortex? Is there a **canonical computation** performed by cortical columns? How is information in the brain processed by the collective dynamics of large neuronal circuits? What level of simplification is suitable for a description of information processing in the brain? What is the **neural code**?
- How does general anesthetic work?
- **Neural computation:** What are all the different types of neuron and what do they do in the human brain?
- Noogenesis - the emergence and evolution of intelligence: What are the laws and mechanisms - of new idea emergence (insight, creativity synthesis, intuition, decision-making, eureka); development (evolution) of an individual mind in the ontogenesis, etc.?

Biology:

- Exactly how and when did life on Earth originate? Which, if any, of the many hypotheses is correct?
- Exactly how and when did different groups of viruses originate?

- Might life which does not originate from planet Earth also have developed on other planets? Might this life be intelligent?
- What are the chemical **origins of life**? How did non-living chemical compounds generate self-replicating, complex life forms?
- What selective advantages drove the development of sexual reproduction, and how did it develop?
- What is the cause of homosexuality, especially in the human species?
- How and why did the brain evolve? What are the molecular determinants of individual brain development?
- How do cells determine what size to grow to before dividing?
- In cell theory, what is the exact transport mechanism by which proteins travel through the Golgi apparatus?
- The mechanisms of action of many drugs including paracetamol, lithium, thalidomide and ketamine are not completely understood.
- What is the folding code? What is the folding mechanism? Can we predict the native structure of a protein from its amino acid sequence? Is it possible to predict the secondary, tertiary and quaternary structure of a polypeptide sequence based solely on the sequence and environmental information? Inverse protein-folding problem: Is it possible to design a polypeptide sequence which will adopt a given structure under certain environmental conditions? This has been achieved for several small globular proteins in recent years.
- Why do some enzymes exhibit faster-than-diffusion kinetics?
- Is it possible to accurately predict the secondary, tertiary and quaternary structure of a polyribonucleic acid sequence based on its sequence and environment?
- Is it possible to design highly active enzymes *de novo* for any desired reaction?
- Can desired molecules, natural products or otherwise, be produced in high yield through biosynthetic pathway manipulation?

- What is the **mechanism of allosteric transitions of proteins**?
  The concerted and sequential models have been hypothesised but neither has been verified.
- **How many genes do we have?**
- What are the **endogenous ligands of orphan receptors**?
- What substance is **endothelium-derived hyperpolarizing factor**?
- **Why does biological aging occur?** There are a number of hypotheses why senescence occurs including those that it is programmed by gene expression changes and that it is the accumulative damage of biological processes.
- **Consistency of movement.** How can we move so controllably, even though the motor nerve impulses seem haphazard and unpredictable?
- **How do organs grow to the correct shape and size?** How are the final shape and size of organs so reliably formed? These processes are in part controlled by the Hippo signaling pathway
- **Can developing biological systems tell the time?** To an extent, this appears to be the case, as shown by the CLOCK gene.
- **Why are babies so rarely born with cancer?**
- The high diversity of phytoplankton seems to violate the competitive exclusion principle.
- What is the cause of the apparent rapid diversification of multicellular animal life around the beginning of the Cambrian, resulting in the emergence of almost all modern animal phyla?
- Why does biodiversity increase when going from the poles towards the equator?
- What is the exact evolutionary history of flowers and what is the cause of the apparently sudden appearance of nearly modern flowers in the fossil record?
- There are at least 100 species of this phylum of marine dwelling animals (many undescribed), but none of them is known to be present in the fossil record.
- **Adult form of Facetotecta.** The adult form of this animal has never been encountered in the water, and it remains a mystery to what it grows into.

- Did snakes evolve from burrowing lizards or aquatic lizards? There is evidence for both hypotheses.
- Did turtles evolve from anapsids or diapsids? There is evidence for both hypotheses.
- How should Ediacaran biota be classified? Even what kingdom they belong to is unclear. Why were they so decisively displaced by Cambrian biota?
- A satisfactory explanation for the neurobiological mechanisms that allow homing in animals has yet to be found.
- How do the descendants of monarch butterfly all over Canada and the US eventually, after migrating for several generations, manage to return to a few relatively small overwintering spots?
- There is not much data on the sexuality of the **blue whale**.
- It is largely unknown how gall wasps induce gall formation in plants; chemical, mechanical, and viral triggers have been discussed.
- Alkaloids. The function of these substances in living organisms which produce them is not known
- Korarchaeota (archaea). The metabolic processes of this phylum of archaea are so far unclear.
- What is the function of the retrocerebral organ of rotifers (pseudocoelomate animals)?
- Glycogen body. The function of this structure in the spinal cord of birds is not known.
- A long-standing zoological dispute concerning the segmental composition of the heads of the various arthropod groups, and how they are evolutionarily related to each other.
- Only the right ovary in female **basking sharks** appears to function. The reason is unknown.
- There is a long-standing debate over whether the primary function of the **osteoderms**/scutes of **stegosaurs** is protection from predators, sexual display, species recognition, thermoregulation, or other functions.
- What is the biological function of sleep? Why do we dream? What are the underlying brain mechanisms? What is its relation to anesthesia?
- How plastic is the mature brain?

- General anesthetic. What is the mechanism by which it works?
- What are the neural bases (causes) of mental diseases like psychotic disorders (e.g. mania, schizophrenia), Parkinson's disease, Alzheimer's disease, or addiction? Is it possible to recover loss of sensory or motor function?
- What are all the different types of neuron and what do they do in the brain?
- How and where does the brain evaluate reward value and effort (cost) to modulate behavior? How does previous experience alter perception and behavior? What are the genetic and environmental contributions to brain function?
- How important is the precise timing of action potentials for information processing in the **neocortex**? Is there a canonical computation performed by cortical columns? How is information in the brain processed by the collective dynamics of large neuronal circuits? What level of simplification is suitable for a description of information processing in the brain? What is the neural code?
- What are the limits of understanding thinking as a form of computing?
- What is the brain basis of subjective experience, cognition, wakefulness, alertness, arousal, and attention? Is there a "hard problem of consciousness"? If so, how is it solved? What, if any, is the function of consciousness?
- How does the brain transfer sensory information into coherent, private percepts? What are the rules by which perception is organized? What are the features/objects that constitute our perceptual experience of internal and external events? How are the senses integrated? What is the relationship between subjective experience and the physical world?
- Where do our memories get stored and how are they retrieved again? How can learning be improved? What is the difference between explicit and implicit memories? What molecule is responsible for synaptic tagging?
- What are the laws and mechanisms - of new idea emergence (insight, creativity synthesis, intuition, decision-making, eureka); development (evolution) of an individual mind in the ontogenesis, etc.?

- Language. How is it implemented neurally? What is the basis of semantic meaning?

Chemistry:

- What are the electronic structures of high-temperature superconductors at various points on their phase diagrams?
- Can the transition temperature of high-temperature superconductors be brought up to room temperature?
- Is Feynmanium the last chemical element that can physically exist? That is, what are the chemical consequences of having an element with an atomic number above 137, whose 1s electrons must travel faster than the speed of light?
- Is Neutronium-4 possible?
- How can electromagnetic energy (photons) be efficiently converted to chemical energy? For example, can water be efficiently split to hydrogen and oxygen using solar energy?
- Is an *abiologic origin of chirality* as is found in (2*R*)-2,3-dihydroxypropanal (D-glyceraldehyde), and also in amino acids, sugars, etc., possible?
- Why are accelerated kinetics observed for some *organic reactions at the water-organic interface*?
- What is the *origin of the alpha effect*, that is, that nucleophiles with an electronegative atom with lone pairs adjacent to the nucleophilic center are particularly reactive?
- Why do some enzymes exhibit faster-than-diffusion kinetics?
- Is it possible to predict the secondary, tertiary and quaternary structure of a polypeptide sequence based solely on the sequence and environmental information? Inverse protein-folding problem: Is it possible to design a polypeptide sequence which will adopt a given structure under certain environmental conditions? This has been achieved for several small globular proteins in recent years.
- Is it possible to accurately predict the secondary, tertiary and quaternary structure of a polyribonucleic acid sequence based on its sequence and environment?
- What are the chemical **origins of life**? How did non-living chemical compounds generate self-replicating, complex life forms?

- Is it possible to design highly active enzymes *de novo* for any desired reaction?
- Can desired molecules, natural products or otherwise, be produced in high yield through biosynthetic pathway manipulation?

Physics:

- Theory of everything: Is there a theory which explains the values of all fundamental physical constants, i.e., of all coupling constants, all elementary particle masses and all mixing angles of elementary particles? Is there a theory which explains why the gauge groups of the standard model are as they are, and why observed spacetime has 3 spatial dimensions and 1 temporal dimension? Are "**fundamental physical constants**" really fundamental or do they vary over time? Are any of the fundamental particles in the standard model of particle physics actually composite particles too tightly bound to observe as such at current experimental energies? Are there elementary particles that have not yet been observed, and, if so, which ones are they and what are their properties? Are there unobserved fundamental forces?
- Arrow of time (e.g. entropy's arrow of time): Why does time have a direction? Why did the universe have such low entropy in the past, and time correlates with the universal (but not local) increase in entropy, from the past and to the future, according to the second law of thermodynamics? Why are CP violations observed in certain weak force decays, but not elsewhere? Are CP violations somehow a product of the second law of thermodynamics, or are they a separate arrow of time? Are there exceptions to the principle of causality? Is there a single possible past? Is the present moment physically distinct from the past and future, or is it merely an emergent property of consciousness? What links the quantum arrow of time to the thermodynamic arrow?
- Interpretation of quantum mechanics: How does the quantum description of reality, which includes elements such as the superposition of states and wavefunction collapse or quantum decoherence, give rise to the reality we perceive? Another way of stating this question regards the measurement problem: What constitutes a

"measurement" which apparently causes the wave function to collapse into a definite state? Unlike classical physical processes, some quantum mechanical processes (such as quantum teleportation arising from quantum entanglement) cannot be simultaneously "local", "causal", and "real", but it is not obvious which of these properties must be sacrificed, or if an attempt to describe quantum mechanical processes in these senses is a category error such that a proper understanding of quantum mechanics would render the question meaningless. Can a multiverse resolve it?

- Yang–Mills theory: Given an arbitrary compact gauge group, does a non-trivial quantum Yang–Mills theory with a finite mass gap exist? (This problem is also listed as one of the Millennium Prize Problems in mathematics.)
- Color confinement: **Quantum chromodynamics (QCD)** color confinement conjecture is that color charged particles (such as quarks and gluons) cannot be separated from their parent hadron without producing new hadrons. There is not yet an analytic proof of color confinement in any non-abelian gauge theory.
- Physical information: Are there physical phenomena, such as wave function collapse or black holes, that irrevocably destroy information about their prior states? How is quantum information stored as a state of a quantum system?
- Dimensionless physical constant: At the present time, the values of the dimensionless physical constants cannot be calculated; they are determined only by physical measurement. What is the minimum number of dimensionless physical constants from which all other dimensionless physical constants can be derived? Are dimensional physical constants necessary at all?
- Fine-tuned universe: The values of the fundamental physical constants are in a narrow range necessary to support carbon-based life. Is this because there exist other universes with different constants, or are our universe's constants the result of chance, or some other factor or process? In particular, Tegmark's mathematical multiverse hypothesis of abstract mathematical parallel universe formalized models, and the landscape multiverse hypothesis of spacetime regions having different formalized

sets of laws and physical constants from that of the surrounding space — require formalization.

- Quantum field theory: Is it possible to construct, in the mathematically rigorous framework of algebraic QFT, a theory in 4-dimensional spacetime that includes interactions and does not resort to perturbative methods?
- Problem of time: In quantum mechanics time is a classical background parameter and the flow of time is universal and absolute. In general relativity time is one component of four-dimensional spacetime, and the flow of time changes depending on the curvature of spacetime and the spacetime trajectory of the observer. How can these two concepts of time be reconciled?
- Cosmic inflation: Is the theory of cosmic inflation in the very early universe correct, and, if so, what are the details of this epoch? What is the hypothetical inflaton scalar field that gave rise to this cosmic inflation? If inflation happened at one point, is it self-sustaining through inflation of quantum-mechanical fluctuations, and thus ongoing in some extremely distant place?
- Horizon problem: Why is the distant universe so homogeneous when the Big Bang theory seems to predict larger measurable anisotropies of the night sky than those observed? Cosmological inflation is generally accepted as the solution, but are other possible explanations such as a variable speed of light more appropriate?
- Origin and future of the universe: How did the conditions for anything to exist arise? Is the universe heading towards a Big Freeze, a Big Rip, a Big Crunch, or a Big Bounce? Or is it part of an infinitely recurring cyclic model?
- Size of universe: The diameter of the observable universe is about 93 billion light-years, but what is the size of the whole universe?
- Baryon asymmetry: Why is there far more matter than antimatter in the observable universe?
- Cosmological constant problem: Why does the zero-point energy of the vacuum not cause a large cosmological constant? What cancels it out?

- Dark matter: What is the identity of dark matter? Is it a particle? Is it the lightest superpartner (LSP)? Or, do the phenomena attributed to dark matter point not to some form of matter but actually to an extension of gravity?
- Dark energy: What is the cause of the observed accelerated expansion (de Sitter phase) of the universe? Why is the energy density of the dark energy component of the same magnitude as the density of matter at present when the two evolve quite differently over time; could it be simply that we are observing at exactly the right time? Is dark energy a pure cosmological constant or are models of quintessence such as phantom energy applicable?
- Dark flow: Is a non-spherically symmetric gravitational pull from outside the observable universe responsible for some of the observed motion of large objects such as galactic clusters in the universe?
- Axis of evil: Some large features of the microwave sky at distances of over 13 billion light years appear to be aligned with both the motion and orientation of the solar system. Is this due to systematic errors in processing, contamination of results by local effects, or an unexplained violation of the Copernican principle?
- Shape of the universe: What is the 3-manifold of comoving space, i.e. of a comoving spatial section of the universe, informally called the "shape" of the universe? Neither the curvature nor the topology is presently known, though the curvature is known to be "close" to zero on observable scales. The cosmic inflation hypothesis suggests that the shape of the universe may be unmeasurable, but, since 2003, Jean-Pierre Luminet, et al., and other groups have suggested that the shape of the universe may be the Poincaré dodecahedral space. Is the shape unmeasurable; the **Poincaré space**; or another 3-manifold?
- The largest structures in the universe are larger than expected. Current cosmological models say there should be very little structure on scales larger than a few hundred million light years across, due to the expansion of the universe trumping the effect of gravity. But the Sloan Great Wall is 1.38 billion light-years in length. And the largest structure currently known, the Hercules–Corona Borealis Great Wall, is up to 10 billion light-years in length. Are these actual structures or random density

fluctuations? If they are real structures, they contradict the 'End of Greatness' hypothesis which asserts that at a scale of 300 million light-years structures seen in smaller surveys are randomized to the extent that the smooth distribution of the universe is visually apparent.

- Vacuum catastrophe: Why does the predicted mass of the quantum vacuum have little effect on the expansion of the universe?
- Quantum gravity: Can quantum mechanics and general relativity be realized as a fully consistent theory (perhaps as a quantum field theory)? Is spacetime fundamentally continuous or discrete? Would a consistent theory involve a force mediated by a hypothetical graviton, or be a product of a discrete structure of spacetime itself (as in loop quantum gravity)? Are there deviations from the predictions of general relativity at very small or very large scales or in other extreme circumstances that flow from a quantum gravity theory?
- Black holes, black hole information paradox, and black hole radiation: Do black holes produce thermal radiation, as expected on theoretical grounds? Does this radiation contain information about their inner structure, as suggested by gauge–gravity duality, or not, as implied by Hawking's original calculation? If not, and black holes can evaporate away, what happens to the information stored in them (since quantum mechanics does not provide for the destruction of information)? Or does the radiation stop at some point leaving black hole remnants? Is there another way to probe their internal structure somehow, if such a structure even exists?
- Extra dimensions: Does nature have more than four spacetime dimensions? If so, what is their size? Are dimensions a fundamental property of the universe or an emergent result of other physical laws? Can we experimentally observe evidence of higher spatial dimensions?
- The cosmic censorship hypothesis and the chronology protection conjecture: Can singularities not hidden behind an event horizon, known as "naked singularities", arise from realistic initial conditions, or is it possible to prove some version of the "**cosmic censorship hypothesis**" of Roger Penrose which proposes that this is impossible? Similarly, will the closed timelike curves which arise in some solutions

to the equations of general relativity (and which imply the possibility of backwards time travel) be ruled out by a theory of quantum gravity which unites general relativity with quantum mechanics, as suggested by the "chronology protection conjecture" of Stephen Hawking?

- Locality: Are there non-local phenomena in quantum physics? If they exist, are non-local phenomena limited to the entanglement revealed in the violations of the Bell inequalities, or can information and conserved quantities also move in a non-local way? Under what circumstances are non-local phenomena observed? What does the existence or absence of non-local phenomena imply about the fundamental structure of **spacetime**? How does this elucidate the proper interpretation of the fundamental nature of quantum physics?
- Hierarchy problem: Why is gravity such a weak force? It becomes strong for particles only at the Planck scale, around 10^{19} GeV, much above the electroweak scale (100 GeV, the energy scale dominating physics at low energies). Why are these scales so different from each other? What prevents quantities at the electroweak scale, such as the Higgs boson mass, from getting quantum corrections on the order of the Planck scale? Is the solution supersymmetry, extra dimensions, or just anthropic fine-tuning?
- Planck particle: The Planck mass plays an important role in parts of mathematical physics. A series of researchers have suggested the existence of a fundamental particle with mass equal to or close to that of the Planck mass. The Planck mass is however enormous compared to any detected particle. It is still an unsolved problem if there exist or even have existed a particle with close to the Planck mass. This is indirectly related to the hierarchy problem.
- Magnetic monopoles: Did particles that carry "magnetic charge" exist in some past, higher-energy epoch? If so, do any remain today? (Paul Dirac showed the existence of some types of magnetic monopoles would explain charge quantization.)
- Neutron lifetime puzzle: While the neutron lifetime has been studied for decades, there currently exists a lack of consilience on its exact value, due to different results from two experimental methods ("**bottle**" versus "beam").

- Proton decay and spin crisis: Is the proton fundamentally stable? Or does it decay with a finite lifetime as predicted by some extensions to the standard model? How do the quarks and gluons carry the spin of protons?
- Supersymmetry: **Is spacetime supersymmetry realized at TeV scale?** If so, what is the mechanism of supersymmetry breaking? Does supersymmetry stabilize the electroweak scale, preventing high quantum corrections? Does the lightest supersymmetric particle (LSP or Lightest Supersymmetric Particle) comprise dark matter?
- Generations of matter: Why are there three generations of quarks and leptons? Is there a theory that can explain the masses of particular quarks and leptons in particular generations from first principles (a theory of Yukawa couplings)?
- Neutrino mass: What is the mass of neutrinos, whether they follow Dirac or Majorana statistics? Is the mass hierarchy normal or inverted? Is the CP violating phase equal to 0?
- Strong CP problem and axions: Why is the strong nuclear interaction invariant to parity and charge conjugation? Is Peccei–Quinn theory the solution to this problem? Could axions be the main component of dark matter?
- Anomalous magnetic dipole moment: Why is the experimentally measured value of the muon's anomalous magnetic dipole moment ("**muon g−2**") significantly different from the theoretically predicted value of that physical constant?
- Proton radius puzzle: What is the electric charge radius of the proton? How does it differ from gluonic charge?
- Pentaquarks and other exotic hadrons: What combinations of quarks are possible? Why were pentaquarks so difficult to discover? Are they a tightly-bound system of five elementary particles, or a more weakly-bound pairing of a baryon and a meson?
- Mu problem: problem of supersymmetric theories, concerned with understanding the parameters of the theory.
- Koide formula: An aspect of the problem of particle generations. The sum of the masses of the three charged leptons, divided by the square of the sum of the roots of

these masses, to within one standard deviation of observations, is $\mathbf{Q = \frac{2}{3}}$. It is unknown how such a simple value comes about, and why it is the exact arithmetic average of the possible extreme values of $\frac{1}{3}$ (equal masses) and 1 (one mass dominates).

- Astrophysical jet: Why do only certain accretion discs surrounding certain astronomical objects emit relativistic jets along their polar axes? Why are there quasi-periodic oscillations in many accretion discs? Why does the period of these oscillations scale as the inverse of the mass of the central object? Why are there sometimes overtones, and why do these appear at different frequency ratios in different objects?
- Diffuse interstellar bands: What is responsible for the numerous interstellar absorption lines detected in astronomical spectra? Are they molecular in origin, and if so which molecules are responsible for them? How do they form?
- Supermassive black holes: What is the origin of the M-sigma relation between supermassive black hole mass and galaxy velocity dispersion? How did the most distant quasars grow their supermassive black holes up to 10^{10} solar masses so early in the history of the universe?
- Kuiper cliff: Why does the number of objects in the Solar System's Kuiper belt fall off rapidly and unexpectedly beyond a radius of 50 astronomical units?
- Flyby anomaly: Why is the observed energy of satellites flying by planetary bodies sometimes different by a minute amount from the value predicted by theory?
- Galaxy rotation problem: Is dark matter responsible for differences in observed and theoretical speed of stars revolving around the centre of galaxies, or is it something else?
- Supernovae: What is the exact mechanism by which an implosion of a dying star becomes an explosion?
- p-nuclei: What astrophysical process is responsible for the nucleogenesis of these rare isotopes?

- Ultra-high-energy cosmic ray: Why is it that some cosmic rays appear to possess energies that are impossibly high, given that there are no sufficiently energetic cosmic ray sources near the Earth? Why is it that (apparently) some cosmic rays emitted by distant sources have energies above the **Greisen–Zatsepin–Kuzmin limit**?
- Rotation rate of Saturn: Why does the magnetosphere of Saturn exhibit a (slowly changing) periodicity close to that at which the planet's clouds rotate? What is the true rotation rate of Saturn's deep interior?
- Origin of magnetar magnetic field: What is the origin of magnetar magnetic field?
- Large-scale anisotropy: Is the universe at very large scales anisotropic, making the cosmological principle an invalid assumption? The number count and intensity dipole anisotropy in radio, **NRAO VLA Sky Survey (NVSS)** catalogue is inconsistent with the local motion as derived from cosmic microwave background and indicate an intrinsic dipole anisotropy. The same NVSS radio data also shows an intrinsic dipole in polarization density and degree of polarization in the same direction as in number count and intensity. There are several other observation revealing large-scale anisotropy. The optical polarization from quasars shows polarization alignment over a very large scale of Gpc. The cosmic-microwave-background data shows several features of anisotropy, which are not consistent with the Big Bang model.
- Age–metallicity relation in the Galactic disk: Is there a universal age–metallicity relation (AMR) in the **Galactic disk** (both "thin" and "thick" parts of the disk)? Although in the local (primarily thin) disk of the Milky Way there is no evidence of a strong AMR, a sample of 229 nearby "thick" disk stars has been used to investigate the existence of an age–metallicity relation in the Galactic thick disk, and indicate that there is an age–metallicity relation present in the thick disk. Stellar ages from asteroseismology confirm the lack of any strong age-metallicity relation in the Galactic disc.
- The lithium problem: Why is there a discrepancy between the amount of lithium-7 predicted to be produced in Big Bang nucleosynthesis and the amount observed in very old stars?

- Ultraluminous X-ray sources (ULXs): What powers X-ray sources that are not associated with active galactic nuclei but exceed the Eddington limit of a neutron star or stellar black hole? Are they due to intermediate mass black holes? Some ULXs are periodic, suggesting non-isotropic emission from a neutron star. Does this apply to all ULXs? How could such a system form and remain stable?
- Fast radio bursts (FRBs): What causes these transient radio pulses from distant galaxies, lasting only a few milliseconds each? Why do some FRBs repeat at unpredictable intervals, but most do not? Dozens of models have been proposed, but none have been widely accepted.
- Quantum chromodynamics: What are the phases of strongly interacting matter, and what roles do they play in the evolution of cosmos? What is the detailed partonic structure of the nucleons? What does QCD predict for the properties of strongly interacting matter? What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime? Do glueballs exist? Do gluons acquire mass dynamically despite having a zero rest mass, within hadrons? Does QCD truly lack CP-violations? Do gluons saturate when their occupation number is large? Do gluons form a dense system called Colour Glass Condensate? What are the signatures and evidences for the Balitsky-Fadin-Kuarev-Lipatov, Balitsky-Kovchegov, Catani-Ciafaloni-Fiorani-Marchesini evolution equations?
- Nuclei and nuclear astrophysics: Why is there a lack of convergence in estimates of the mean lifetime of a free neutron based on two separate- and increasingly precise-experimental methods? What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes? What is the nature of exotic excitations in nuclei at the frontiers of stability and their role in stellar processes? What is the nature of neutron stars and dense nuclear matter? What is the origin of the elements in the cosmos? What are the nuclear reactions that drive stars and stellar explosions? What is the heaviest possible chemical element?
- Abraham-Minkowski controversy: What is the momentum of light in optical media? Whether Abraham's or Minkowski's momentum is right?

- Bose–Einstein condensation: How do we rigorously prove the existence of Bose–Einstein condensates for general interacting systems?
- Singular trajectories in the Newtonian *N*-body problem: Does the set of initial conditions for which particles that undergo near-collisions gain infinite speed in finite time have measure zero? This is known to be the case when $\boldsymbol{N \leq 4}$, but the question remains open for larger *N*.
- The Navier-Stokes equation explains Fluid dynamics. Although this equation was discovered in the 19th century, the existence of solutions and their proof are still not well established.
- Turbulence: Is it possible to make a theoretical model to describe the statistics of a turbulent flow (in particular, its internal structures)? Also, under what conditions do smooth solutions to the **Navier–Stokes equations** exist? The latter problem is also listed as one of the Millennium Prize Problems in mathematics.
- Stochasticity and robustness to noise in gene expression: How do genes govern our body, withstanding different external pressures and internal stochasticity? Certain models exist for genetic processes, but we are far from understanding the whole picture, in particular in development where gene expression must be tightly regulated.
- Memory: How is long-term memory stored on a biological substrate undergoing constant turnover?
- Quantitative study of the immune system: What are the quantitative properties of immune responses? What are the basic building blocks of immune system networks?
- Unified brain processing theory : How to unify physics and neuroscience?
- Homochirality: What is the origin of the preponderance of specific enantiomers in biochemical systems?
- Magnetoreception: How do animals (e.g. migratory birds) sense the Earth's magnetic field?
- Plasma physics and fusion power: Fusion energy may potentially provide power from abundant resource (e.g. hydrogen) without the type of radioactive waste that fission energy currently produces. However, can ionized gases (plasma) be confined long

enough and at a high enough temperature to create fusion power? What is the physical origin of H-mode?

- Solar cycle: How does the Sun generate its periodically reversing large-scale magnetic field? How do other solar-like stars generate their magnetic fields, and what are the similarities and differences between stellar activity cycles and that of the Sun? What caused the Maunder Minimum and other grand minima, and how does the solar cycle recover from a minima state?
- Coronal heating problem: Why is the Sun's corona (atmosphere layer) so much hotter than the Sun's surface? Why is the magnetic reconnection effect many orders of magnitude faster than predicted by standard models?
- The injection problem: Fermi acceleration is thought to be the primary mechanism that accelerates astrophysical particles to high energy. However, it is unclear what mechanism causes those particles to initially have energies high enough for Fermi acceleration to work on them.
- Solar wind interaction with comets: In 2007 the Ulysses spacecraft passed through the tail of comet C/2006 P1 (**McNaught**) and found surprising results concerning the interaction of the solar wind with the tail.
- Alfvénic turbulence: In the solar wind and the turbulence in solar flares, coronal mass ejections, and magnetospheric substorms are major unsolved problems in space plasma physics.
- High-temperature superconductors: What is the mechanism that causes certain materials to exhibit superconductivity at temperatures much higher than around 25 kelvins? Is it possible to make a material that is a superconductor at room temperature?
- Amorphous solids: What is the nature of the glass transition between a fluid or regular solid and a glassy phase? What are the physical processes giving rise to the general properties of glasses and the glass transition?
- Cryogenic electron emission: Why does the electron emission in the absence of light increase as the temperature of a photomultiplier is decreased?

- Sonoluminescence: What causes the emission of short bursts of light from imploding bubbles in a liquid when excited by sound?
- Topological order: Is topological order stable at non-zero temperature? Equivalently, is it possible to have three-dimensional self-correcting quantum memory?
- Fractional Hall effect: What mechanism explains the existence of the **u** = $\frac{5}{2}$ state in the fractional quantum Hall effect? Does it describe **quasiparticles** with non-Abelian fractional statistics?
- Liquid crystals: Can the nematic to smectic (A) phase transition in liquid crystal states be characterized as a universal phase transition?
- Semiconductor nanocrystals: What is the cause of the **nonparabolicity** of the energy-size dependence for the lowest optical absorption transition of quantum dots?
- Metal whiskering: In electrical devices, some metallic surfaces may spontaneously grow fine metallic whiskers, which can lead to equipment failures. While compressive mechanical stress is known to encourage whisker formation, the growth mechanism has yet to be determined.