Theoretical physics

Theoretical physics is a branch of physics which employs mathematical models and abstractions of physics to rationalize, explain and predict natural phenomena. The importance of mathematics in theoretical physics is sometimes emphasized by expression "mathematical physics".

The advancement of science depends in general on the interplay between experimental studies and theory. In some cases, theoretical physics adheres to standards of mathematical rigor while giving little weight to experiments and observations. For example, while developing special relativity, Albert Einstein was concerned with the Lorentz transformation which left Maxwell's equations invariant, but was apparently uninterested in the Michelson-Morley experiment on Earth's drift through luminiferous ether. On the other hand, Einstein was awarded the Nobel Prize for explaining the photoelectric effect, previously an experimental result lacking a theoretical formulation.

Overview

A **physical theory** is a model of physical events. It is judged by the extent to which its predictions agree with empirical observations. The quality of a physical theory is also judged on its ability to make new predictions which can be verified by new observations. A physical theory differs from a mathematical theorem in that while both are based on some form of axioms, judgment of mathematical applicability is not based on agreement with any experimental results.

A physical theory involves one or more relationships between various measurable quantities. Archimedes realized that a ship floats by displacing its mass of water, Pythagoras understood the relation between the length of a vibrating string and the musical tone it produces, and how to calculate the length of a rectangle's diagonal. Other examples include entropy as a measure of the uncertainty regarding the positions and motions of unseen particles and the quantum mechanical idea that (action and) energy are not continuously variable.

Sometimes the vision provided by pure mathematical systems can provide clues to how a physical system might be modeled; e.g., the notion, due to Riemann and others, that space itself might be curved.

Theoretical advances may consist in setting aside old, incorrect paradigms (e.g., Burning consists of evolving phlogiston, or Astronomical bodies revolve around the Earth) or may be an alternative model that provides answers that are more accurate or that can be more widely applied.

Physical theories become accepted if they are able to make correct predictions and no (or few) incorrect ones. The theory should have, at least as a secondary objective, a certain economy and elegance (compare to mathematical beauty), a notion sometimes called "Occam's razor" after the 13th-century English philosopher William of Occam (or Ockham), in which the simpler of two theories that describe the same matter just as adequately is preferred. (But conceptual simplicity may mean mathematical complexity.) They are also more likely to be accepted if they connect a wide range of phenomena. Testing the consequences of a theory is part of the scientific method.

Physical theories can be grouped into three categories: *mainstream theories*, *proposed theories* and *fringe theories*.

History

Theoretical physics began at least 2,300 years ago, under the Pre-socratic philosophy, and continued by Plato and Aristotle, whose views held sway for a millennium. In medieval times, during the rise of the universities, the only acknowledged intellectual disciplines were theology, mathematics, medicine, and law. As the concepts of matter, energy, space, time and causality slowly began to acquire the form we know today, other sciences spun off from the rubric of natural philosophy. During the Middle Ages and Renaissance, the concept of experimental science, the counterpoint to theory, began with scholars such as Ibn al-Haytham and Francis Bacon. The modern era of theory began perhaps with the Copernican paradigm shift in astronomy, soon followed by Johannes Kepler's expressions for planetary orbits, which summarized the meticulous observations of Tycho Brahe.

The great push toward the modern concept of explanation started with Galileo, one of the few physicists who was both a consummate theoretician and a great experimentalist. The analytic geometry and mechanics of Descartes were incorporated into the calculus and mechanics of Isaac Newton, another theoretician/experimentalist of the highest order. Joseph-Louis Lagrange, Leonhard Euler and William Rowan Hamilton would extend the theory of classical mechanics considerably. Each of these individuals picked up the interactive intertwining of mathematics and physics begun two millennia earlier by Pythagoras.

Among the great conceptual achievements of the 19th and 20th centuries were the consolidation of the idea of energy by the inclusion of heat, then electricity and magnetism and light, and finally mass. The laws of thermodynamics, and most importantly the introduction of the singular concept of entropy began to provide a macroscopic explanation for the properties of matter.

The pillars of modern physics, and perhaps the most revolutionary theories in the history of physics, have been relativity theory and quantum mechanics. Newtonian mechanics was subsumed under special relativity and Newton's gravity was given a kinematic explanation by general relativity. Quantum mechanics led to an understanding of blackbody radiation and of anomalies in the specific heats of solids — and finally to an understanding of the internal structures of atoms and molecules.

All of these achievements depended on the theoretical physics as a moving force both to suggest experiments and to consolidate results — often by ingenious application of existing mathematics, or, as in the case of Descartes and Newton (with Leibniz), by inventing new mathematics. Fourier's studies of heat conduction led to a new branch of mathematics: infinite, orthogonal series.

Modern theoretical physics attempts to unify theories and explain phenomena in further attempts to understand the Universe, from the cosmological to the elementary particle scale. Where experimentation cannot be done, theoretical physics still tries to advance through the use of mathematical models.

Prominent theoretical physicists

Famous *theoretical physicists* include

- Galileo Galilei (1564–1642)
- Christiaan Huygens (1629–1695)
- Isaac Newton (1643–1727)
- Leonhard Euler (1707–1783)
- Joseph Louis Lagrange (1736–1813)
- Pierre-Simon Laplace (1749–1827)
- Joseph Fourier (1768–1830)
- Nicolas Léonard Sadi Carnot (1796–1842)
- William Rowan Hamilton (1805–1865)
- Rudolf Clausius (1822–1888)
- James Clerk Maxwell (1831–1879)
- J. Willard Gibbs (1839–1903)
- Ludwig Boltzmann (1844–1906)
- Hendrik A. Lorentz (1853–1928)
- Henri Poincaré (1854–1912)
- Nikola Tesla (1856–1943)
- Max Planck (1858–1947)
- Albert Einstein (1879–1955)
- Emmy Noether (1882–1935)
- Max Born (1882–1970)
- Niels Bohr (1885–1962)
- Erwin Schrödinger (1887–1961)
- Louis de Broglie (1892–1987)
- Satyendra Nath Bose (1894–1974)
- Wolfgang Pauli (1900–1958)
- Enrico Fermi (1901–1954)
- Werner Heisenberg (1901–1976)

- Paul Dirac (1902–1984)
- Eugene Wigner (1902–1995)
- Robert Oppenheimer (1904–1967)
- Sin-Itiro Tomonaga (1906–1979)
- Hideki Yukawa (1907–1981)
- John Bardeen (1908–1991)
- Lev Landau (1908–1967)
- Anatoly Vlasov (1908–1975)
- Nikolay Bogolyubov (1909–1992)
- Subrahmanyan Chandrasekhar (1910–1995)
- Richard Feynman (1918–1988)
- Julian Schwinger (1918–1994)
- Feza Gursey (1921–1992)
- Chen Ning Yang (1922–)
- Freeman Dyson (1923–)
- Gunnar Källén (1926–1968)
- Abdus Salam (1926–1996)
- Murray Gell-Mann (1929–)
- Riazuddin (1930–)
- Roger Penrose (1931–)
- George Sudarshan (1931–)
- Sheldon Glashow (1932–)
- Tom W. B. Kibble (1932–)
- Steven Weinberg (1933–)
- Gerald Guralnik (1936–)
- C. R. Hagen (1937–)
- Leonard Susskind (1940–)
- Michael Berry (1941–)
- Stephen Hawking (1942–)
- Alexander Polyakov (1945–)
- Gerardus 't Hooft (1946–)
- Jacob Bekenstein (1947–)
- Bertrand Halperin (1950–)
- Robert Laughlin (1950–)
- Edward Witten (1951–)
- Lee Smolin (1955-)
- Brian Greene (1963-)

Mainstream theories

Mainstream theories (sometimes referred to as *central theories*) are the body of knowledge of both factual and scientific views and possess a usual scientific quality of the tests of repeatability, consistency with existing well-established science and experimentation. There do exist mainstream theories that are generally accepted theories based solely upon their effects explaining a wide variety of data, although the detection, explanation and possible composition are subjects of debate.

Examples

- Black hole thermodynamics
- Classical mechanics
- Condensed matter physics
- Conservation of energy
- Dark Energy
- Dark matter
- Dynamics
- Electromagnetism
- Field theory
- Fluid dynamics
- General relativity
- Molecular modeling
- Particle physics
- Physical cosmology
- Quantum chromodynamics
- Quantum computers
- Quantum electrochemistry
- Quantum electrodynamics
- Quantum field theory
- Quantum information theory
- Quantum mechanics
- Solid mechanics
- Solid state physics or Condensed Matter Physics and the electronic structure of materials
- Special relativity
- Standard Model
- Statistical mechanics
- Thermodynamics

Proposed theories

The **proposed theories** of physics are usually relatively new theories which deal with the study of physics which include scientific approaches, means for determining the validity of models and new types of reasoning used to arrive at the theory. However, some proposed theories include theories that have been around for decades and have eluded methods of discovery and testing. Proposed theories can include fringe theories in the process of becoming established (and, sometimes, gaining wider acceptance). Proposed theories usually have not been tested.

Examples

- Causal Sets
- Dark energy or Einstein's Cosmological Constant
- Einstein-Rosen Bridge

- Emergence
- Grand unification theory
- Loop quantum gravity
- M-theory
- String theory
- Supersymmetry
- Theory of everything
- Unparticle physics

Thought experiments vs real experiments

"Thought" experiments are situations created in ones mind, asking a question akin to "Suppose you are in this situation. Assuming such is true, what would follow?". They are usually created to investigate phenomena that are not readily experienced in every-day situations. Famous examples of such thought experiments are Schrödinger's cat, the EPR thought experiment, simple illustrations of time dilation, and so on. These usually lead to real experiments designed to verify that the conclusion (and therefore the assumptions) of the thought experiments are correct. The EPR thought experiment lead to the Bell inequalities, which were then tested to various degrees of rigor, leading to the acceptance of the current formulation of quantum mechanics and probabilism as a working hypotheses.

Further reading

- Landau, L. D.; Lifshitz, E. M. (1976). *Course of Theoretical Physics*. U.S.S.R. Academy of Sciences. ISBN 0-7506-2896-0.
- Morse, Philip; Feshbach, Herman (2005). *Methods of Theoretical Physics*. Feshbach Publishing. ISBN 0-9762021-2-3.

List of unsolved problems in physics

This is a list of some of the major **unsolved problems in physics**. Some of these problems are theoretical, meaning that existing theories seem incapable of explaining a certain observed phenomenon or experimental result. The others are experimental, meaning that there is a difficulty in creating an experiment to test a proposed theory or investigate a phenomenon in greater detail.

Theoretical problems

The following problems are either fundamental theoretical problems, or theoretical ideas which lack experimental evidence and are in search of one, or both, as most of them are. Some of these problems are strongly interrelated. For example, extra dimensions or supersymmetry may solve the hierarchy problem. It is thought that a full theory of quantum gravity should be capable of answering most of these problems (other than the Island of stability problem).

Quantum gravity, cosmology, and general relativity

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)?[1] 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 (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 "see" evidence of higher spatial dimensions?

Cosmic inflation

Is the theory of cosmic inflation correct, and if so, what are the details of this epoch? What is the hypothetical inflaton field giving rise to inflation? If inflation happened at one point, is it self-sustaining through inflation of quantum-mechanical fluctuations, and thus ongoing in some impossibly distant place?

Multiverse

Are there physical reasons to expect other universes that are fundamentally non-observable? For instance: Are there quantum mechanical "alternative histories" or "many worlds"? Are there "other" universes with physical laws resulting from alternate ways of breaking the apparent symmetries of physical forces at high energies, possibly incredibly far away due to cosmic inflation? Is the use of the anthropic principle to resolve global cosmological dilemmas justified?

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?[2] 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?

Arrow of time

What do the phenomena that differ going forward and backwards in time tell us about the nature of time? How does time differ from space? 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? Why do people appear to agree on what the present moment is? (See also Entropy (arrow of time) below)

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 relate to quantum entanglement? How does this elucidate the proper interpretation of the fundamental nature of quantum physics?

Future of the universe

Is the universe heading towards a Big Freeze, a Big Rip, a Big Crunch or a Big Bounce? Is our universe part of an infinitely recurring cyclic model?

High energy physics/Particle physics

See also: Beyond the Standard Model

Higgs mechanism

Does the Higgs boson particle exist? What are the implications if it does not? Is there only one type of them?

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?

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.[3])

Proton decay and unification

How do we unify the three different quantum mechanical fundamental interactions of quantum field theory? As the lightest baryon, are protons absolutely stable? If not, then what is the proton's half-life?

Supersymmetry

Is spacetime supersymmetry realized in nature? If so, what is the mechanism of supersymmetry breaking? Does supersymmetry stabilize the electroweak scale, preventing high quantum corrections? Does the lightest supersymmetric particle comprise dark matter?

Generations of matter

Are there more than three generations of quarks and leptons? Why are there generations at all? 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)?

Fundamental symmetries and neutrinos

What is the nature of the neutrinos, what are their masses, and how have they shaped the evolution of the universe? Why is there now more detectable matter than antimatter in the universe? What are the unseen forces that were present at the dawn of the universe but disappeared from view as the universe evolved?

Nuclear physics

Quantum chromodynamics

What are the phases of strongly interacting matter, and what roles do they play in the cosmos? What is the internal landscape of the nucleons? What does QCD predict for the properties of strongly interacting matter? What governs the transition of quarks and gluons into pions and nucleons? What is the role of gluons and gluon self-interactions in nucleons and nuclei? What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime?

Nuclei and Nuclear astrophysics

What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes? What is the origin of simple patterns in complex nuclei? 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?

Island of stability

What is the heaviest possible stable or metastable nucleus?

Other problems

Quantum mechanics in the correspondence limit (sometimes called Quantum chaos)

Is there a preferred 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 is the Measurement problem – what constitutes a "measurement" which causes the wave function to collapse into a definite state?

Physical information

Are there physical phenomena, such as black holes or wave function collapse, which irrevocably destroy information about their prior states?

Theory of everything ("Grand Unification Theory")

Is there a theory which explains the values of all fundamental physical constants?[4] Is there a theory which explains why the gauge groups of the standard model are as they are, why observed space-time has 3 + 1 dimensions, and why all laws of physics are as they are? Do "fundamental physical constants" vary over time? Are any of the particles in the standard model of particle physics actually composite particles too tightly bound to observe as such at current experimental energies? Are there fundamental particles that have not yet been observed and if so which ones are they and what are their properties? Are there unobserved fundamental forces implied by a theory that explains other unsolved problems in physics?

Gauge theory

Do non-Abelian gauge theories with a mass gap actually exist?

Empirical phenomena lacking clear scientific explanation

Cosmology

Existence of the Universe

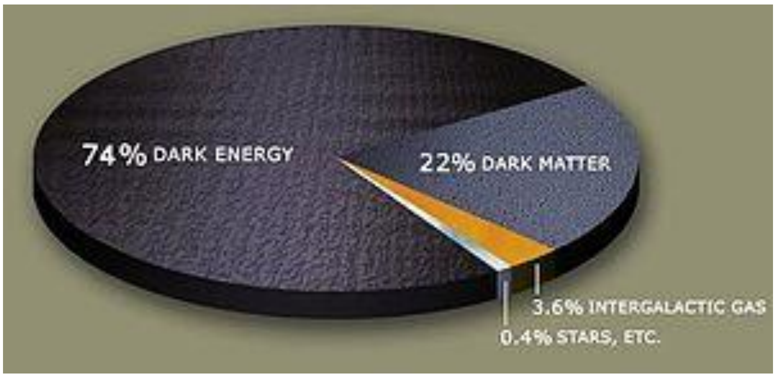
What is the origin of matter, energy, spacetime and the fundamental forces that form the universe / multiverse?

Baryon asymmetry

Why is there far more matter than antimatter in the observable universe?

Cosmological constant problem

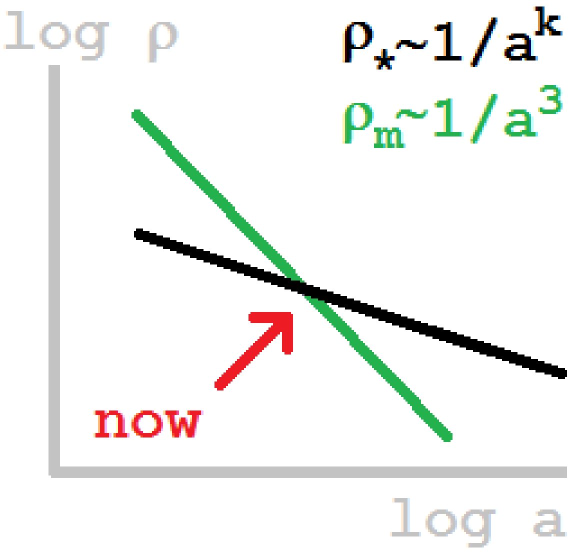
Why does the zero-point energy of the vacuum not cause a large cosmological constant? What cancels it out?



Estimated distribution of dark matter and dark energy in the universe

Dark matter

What is dark matter?[5] Is it related to supersymmetry? Do the phenomena attributed to dark matter point not to some form of matter but actually to an extension of gravity?



The log-log plot of dark energy density ρ_* and material density ρ_m Vs scale factor a . The two straight lines intersect at current epoch.[6]

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

What is the cause of a large swath of galaxy clusters all moving towards one part of the universe?[7]

Entropy (arrow of time)

Why did the universe have such low entropy in the past, resulting in the distinction between past and future and the second law of thermodynamics?[4]

Horizon problem

Why is the distant universe so homogeneous, when the Big Bang theory seems to predict measurable anisotropies of the night sky larger than those observed? Cosmological inflation is generally accepted as the solution, but are other possible explanations such as the variable speed of light hypothesis more appropriate?

Ecliptic alignment of CMB anisotropy

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?

High energy physics/Particle physics

Electroweak symmetry breaking

What is the mechanism responsible for breaking the electroweak gauge symmetry, giving mass to the W and Z bosons? Is it the simple Higgs mechanism of the Standard Model,[4] or does nature make use of strong dynamics in breaking electroweak symmetry, as proposed by Technicolor?

Neutrino mass

What is the mechanism responsible for generating neutrino masses? Is the neutrino its own antiparticle? Or could it be an antiparticle that simply cannot join and annihilate with a normal particle because of its irregular state?

Faster-than-light neutrino anomaly

The Oscillation Project with Emulsion-tRacking Apparatus (OPERA) is an experiment to test the phenomenon of neutrino oscillations. In September 2011, CERN and OPERA announced that time of flight measurements made by their collaboration had indicated muon neutrinos traveling at faster than lightspeed. Is this the result of an experimental error, or is it a true violation of special relativity?

Inertial mass/gravitational mass ratio of elementary particles

According to the equivalence principle of general relativity, the ratio of inertial mass to gravitational mass of all elementary particles is unity. However, there is no experimental confirmation for many particles. In particular, we do not know what the weight of a macroscopic lump of antimatter of known mass would be.

Proton spin crisis

As initially measured by the European Muon Collaboration, the three main ("valence") quarks of the proton account for about 12% of its total spin. Can the gluons that bind the quarks together, as well as the "sea" of quark pairs that are continually being created and annihilated, properly account for the rest of it?

Quantum chromodynamics (QCD) in the non-perturbative regime

The equations of QCD remain unsolved at energy scales relevant for describing atomic nuclei, and, among others, mainly numerical approaches seem to begin to give answers at this limit. How does QCD give rise to the physics of nuclei and nuclear constituents?

Confinement

Why has there never been measured a free quark or gluon, but only objects that are built out of them, like mesons and baryons? How does this phenomenon emerge from QCD?[citation needed]

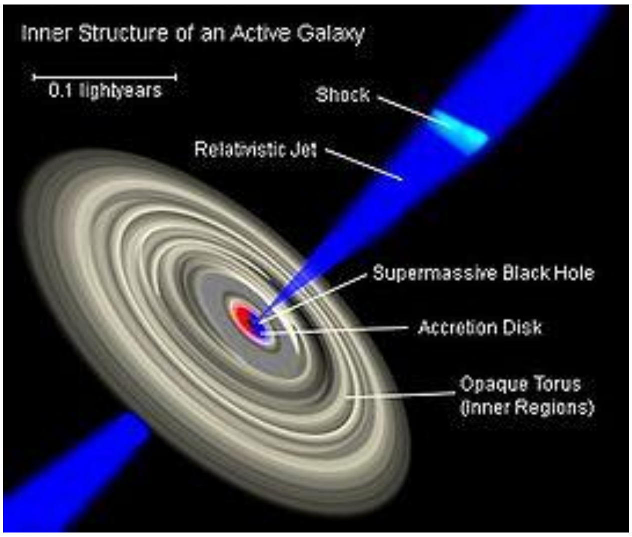
Strong CP problem and axions

Why is the strong nuclear interaction invariant to parity and charge conjugation? Is Peccei–Quinn theory the solution to this problem?

Hypothetical particles

Which of the hypothetical particles predicted by supersymmetric theories and other fairly well known theories actually occur in nature?

Astronomy and astrophysics



Relativistic jet. The environment around the AGN where the relativistic plasma is collimated into jets which escape along the pole of the supermassive black hole

Accretion disc jets

Why do the accretion discs surrounding certain astronomical objects, such as the nuclei of active galaxies, 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?

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?

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?

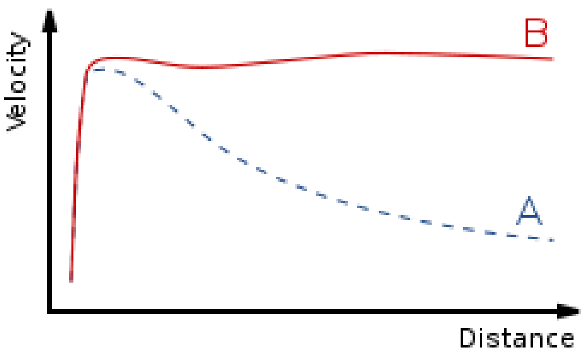
Gamma ray bursts

How do these short-duration high-intensity bursts originate?[4]

Supermassive black holes

What is the origin of the M-sigma relation between supermassive black hole mass and galaxy velocity dispersion?[8]

Observational anomalies



Rotation curve of a typical spiral galaxy: predicted (**A**) and observed (**B**). Can the discrepancy between the curves be attributed to dark matter?

Hipparcos anomaly: What is the actual distance to the Pleiades?[*citation needed*]

Pioneer anomaly[5]: What causes the small additional sunward acceleration of the Pioneer spacecraft?[4][5]

Flyby anomaly: Why is the observed energy of satellites flying by earth 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 center of galaxies, or is it something else?

Supernovae

What is the exact mechanism by which an implosion of a dying star becomes an explosion?

Ultra-high-energy cosmic ray[5]

Why is it that some cosmic rays appear to possess energies that are impossibly high (the so called *OMG particle*), 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?[4][5]

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? [9]

Origin of magnetar magnetic field

What is the origin of magnetar magnetic field?

Condensed matter physics

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?[10][11]

Cold fusion

What is the explanation for the controversial reports of excess heat, radiation and transmutations?[5][12][13]

Cryogenic electron emission

Why does the electron emission in the absence of light increase as the temperature of a photomultiplier is decreased?[14][15]

High-temperature superconductors

What is the mechanism that causes certain materials to exhibit superconductivity at temperatures much higher than around 50 kelvins?[4]

Sonoluminescence

What causes the emission of short bursts of light from imploding bubbles in a liquid when excited by sound?[16]

Turbulence

Is it possible to make a theoretical model to describe the statistics of a turbulent flow (in particular, its internal structures)?[4] Also, under what conditions do smooth solutions to the Navier-Stokes equations exist?

Biological physics

These fields of research normally belong to biology, and traditionally were not included in physics but are included here because increasingly it is physicists who are researching them using methods and tools more popular in physics research than biology.[17][18]

Synaptic plasticity
It is necessary for computational and physical models of the brain, but what causes it, and what role does it play in higher-order processing outside the hippocampus and visual cortex?

Axon guidance
How do axons branching out from neurons find their targets? This process is crucial to nervous system development, allowing the building up of the brain.

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.

Quantitative study of the immune system
What are the quantitative properties of immune responses? What are the basic building blocks of immune system networks? What roles are played by stochasticity?

Consciousness
What mechanism causes sentience within arrangements of otherwise non-sentient particles (as with the human brain, for example)? Is this mechanism reproducible?

Problems solved in recent decades

Long-duration gamma ray bursts (2003)
Long-duration bursts are associated with the deaths of massive stars in a specific kind of supernova-like event commonly referred to as a collapsar. However, there are also long-duration GRBs that show evidence against an associated supernova, such as the Swift event GRB 060614.

Solar neutrino problem (2002)
Solved by a new understanding of neutrino physics, requiring a modification of the Standard Model of particle physics—specifically, neutrino oscillation.

Age Crisis (1990s)
The estimated age of the universe was around 3 to 8 billion years younger than estimates of the ages of the oldest stars in our galaxy. Better estimates for the distances to the stars, and the recognition of the accelerating expansion of the universe, reconciled the age estimates.

Quasars (1980s)
The nature of quasars was not understood for decades.[19] They are now accepted as a type of active galaxy where the enormous energy output results from matter falling into a massive black hole in the center of the galaxy.[20]

References

1. ^ Alan Sokal (July 22, 1996), "Don't Pull the String Yet on Superstring Theory", *New York Times*, http://query.nytimes.com/gst/fullpage.html?res=9D0DE7DB1639F931A15754C0A960958260
2. ^ Joshi, Pankaj S. (January 2009), "Do Naked Singularities Break the Rules of Physics?", *Scientific American*, http://www.sciam.com/article.cfm?id=naked-singularities
3. ^ Dirac, Paul, "Quantised Singularities in the Electromagnetic Field". *Proceedings of the Royal Society* **A 133**, 60 (1931).
4. ^ *a* *b* *c* *d* *e* *f* *g* *h* Baez, John C. (March 2006). "Open Questions in Physics". *Usenet Physics FAQ*. University of California, Riverside: Department of Mathematics. http://math.ucr.edu/home/baez/physics/General/open_questions.html. Retrieved March 7, 2011.

5. ^ a b c d e f Brooks, Michael (March 19, 2005). "13 Things That Do Not Make Sense". *New Scientist*. Issue 2491. http://www.newscientist.com/article/mg18524911.600-13-things-that-do-not-make-sense.html. Retrieved March 7, 2011.
6. ^ Steinardt, Paul (1997), "Cosmological Challenges For the 21st Century", in Val Fitch et. al., Critical problems in physics: proceedings of a conference celebrating the 250th anniversary of Princeton University, Princeton, New Jersey: Princeton University Press, pp. 138–140, ISBN 9780691057842
7. ^ "Dark Flow" Discovered at Edge of the Universe: Hundreds of Millions of Stars Racing Towards a Cosmic Hotspot. Dailygalaxy.com (2009-08-26). Retrieved on 2011-10-20.
8. ^ Ferrarese, Laura; Merritt, David (2000), "A Fundamental Relation between Supermassive Black Holes and their Host Galaxies", *The Astrophysical Journal* **539**: L9–L12, arXiv:astro-ph/0006053, Bibcode 2000ApJ...539L...9F, doi:10.1086/312838, http://adsabs.harvard.edu/abs/2000ApJ...539L...9F
9. ^ "Scientists Find That Saturn's Rotation Period is a Puzzle". NASA. June 28, 2004. http://www.nasa.gov/mission_pages/cassini/media/cassini-062804.html. Retrieved 2007-03-22.
10. ^ Kenneth Chang (July 29, 2008), "The Nature of Glass Remains Anything but Clear", *The New York Times*, http://www.nytimes.com/2008/07/29/science/29glass.html
11. ^ "*The deepest and most interesting unsolved problem in solid state theory is probably the theory of the nature of glass and the glass transition.*" P.W. Anderson (1995), "Through the Glass Lightly", *Science* **267**: 1615
12. ^ John R. Vacca (2004), *The World's 20 Greatest Unsolved Problems*, Prentice Hall, ISBN 9780131426436, http://books.google.com/books?id=ouMmAAAACAAJ
13. ^ Feder, T.; John, O. (2004), "Cold Fusion Gets Chilly Encore", *Physics Today* **58**: 27, Bibcode 2005PhT....58a..31F, doi:10.1063/1.1881896, http://www.physicstoday.com/pt/vol-58/iss-1/PDF/vol58no1p31a.pdf
14. ^ Cryogenic electron emission phenomenon has no known physics explanation. Physorg.com. Retrieved on 2011-10-20.
15. ^ doi:10.1209/0295-5075/89/58001
16. ^ *Proceedings: Mathematical, physical, and engineering sciences* (Royal Society) **453**, 1997, "An unsolved problem in modern physics concerns the phenomenon of sonoluminescence"
17. ^ The Nobel Prizes in Physics 1901–2000. Nobelprize.org (2000-02-09). Retrieved on 2011-10-20.
18. ^ The Office of Science – What is Physics?. Sc.doe.gov. Retrieved on 2011-10-20.
19. ^ "The MKI and the discovery of Quasars". Jodrell Bank Observatory. http://www.jb.man.ac.uk/public/story/mk1quasars.html. Retrieved 2006-11-23.
20. ^ Hubble Surveys the "Homes" of Quasars Hubblesite News Archive, 1996-35