Physics in 100 years

By Frank Wilczek

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April 2016, page 32

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The fundamental questions of the future will be profound, sophisticated, and difficult to answer. And the great projects of the future will be grand indeed.

/content/aip/magazine/physicstoday/article/69/4/10.1063/PT.3.3137
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Phys. Today 69, 4, 32 (2016); http://dx.doi.org/10.1063/PT.3.3137
/content/aip/magazine/physicstoday/article/69/4/10.1063/PT.3.3137

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- ISSN: 0031-9228, Online ISSN: 1945-0699
- DOI: http://dx.doi.org/10.1063/PT.3.3137
- Volume 69, Issue 4, pages 32-39
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Physics in 100 years

Frank Wilczek

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The fundamental questions of the future will be profound, sophisticated, and difficult to answer. And the great projects of the future will be grand indeed.

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What will the next 100 years in physics bring? I don't know, of course, but it is a mind-expanding question to contemplate. The considered guesses recorded here naturally reflect my own interests, knowledge, limitations, and prejudices. And to keep this article within acceptable size, I've had to be crazily selective in choosing what to include. Its conjectures will have served their purpose if they provoke you to think about the question yourself, even if in the end you answer it quite differently (see the announcement on page 36).

To gain perspective, let us look back before looking ahead.

A century ago physics was in turmoil. Albert Einstein had only just published his revolutionary new theory of gravity. Ernest Rutherford's recently discovered atomic nuclei, at the heart of matter, were mysterious, almost bizarre objects—terribly small, terribly dense, and subject to a bewildering variety of causeless transformations. Quantum theory, which featured Niels Bohr's atomic model, was a tissue of guesswork. Superconductivity was an empirical fact, but a theoretical enigma. The nature of the chemical bond and the energy source of stars—supremely important aspects of the natural world—embarrassed contemporary physics.

Fifty years ago the picture had become quite different. General relativity was an established subject with a vast literature and a handful of experimental applications. Together with Edwin Hubble's discovery of the expanding universe, it had opened new possibilities for scientific cosmology. The recently discovered microwave background radiation, together with a successful semiquantitative theory of cosmic nucleogenesis, pointed clearly to the Big Bang. Quantum mechanics was a mathematically precise, consistent, and wildly successful theory, though it seemed strange and troubling to many. It had become, as it remains, the language through which we speak with nature.

Atomic physics, chemistry, and materials science now had a firm foundation. Superconductivity had been explained through a theory of extraordinary beauty and fertility. Lasers, transistors, and nuclear magnetic resonance, among many other notable technologies, gave impressive demonstration of the depth and reliability of the new physics. Integrated circuits were a promising new idea, though the largest of them still contained just a handful of transistors. Nuclear physics, based on quantum theory, had evolved into a powerful discipline. Physicists understood, in broad terms, why stars shine, and they had learned how to put nuclear power to use, for bombs and for energy generation. On the other hand, the descriptions of the weak force and especially the strong force remained piecemeal and phenomenological, and experimental investigations of high-energy events in cosmic rays and at accelerators had produced many undigested surprises.

Twenty-five years ago physics had evolved further. Two standard models had been formulated, one for fundamental interactions and one for cosmology. Rigorous quantitative tests lay just ahead. (The models passed with flying colors and remain foundational today.) The computer revolution was well under way—enabled by a deep understanding of matter, especially the quantum theory of semiconductors. As I'll discuss below, its implications for physics are profound.

Over the past 100 years, the pace of foundational change in physics has slowed, while the pace of innovation that physics supports has quickened. Those shifts reflect the achievement of reliable, comprehensive standard models.

More symmetry

The principles of relativistic quantum field theory and local symmetry, embedded in our core theories of general relativity and the gauge theories of the strong, weak, and electromagnetic forces, have taken physicists a long way. We now have precisely formulated, battle-tested equations that provide secure foundations for chemistry, all plausible forms of engineering, the description of all observed astronomical objects, and a good deal of cosmology. Nevertheless, there is plenty of room for improvement.

Gravitons, gluons, W and Z bosons, and photons are all avatars of local symmetry. Their couplings and indeed their existence are reflections of that deep principle. In its symmetry-based standard model, it would appear, fundamental physics comes closest to achieving the vision of Pythagoras and Plato: a perfect correspondence between what is real and what is mathematically ideal.

Yet we can hope to do even better. The transformations supported by the local symmetries of the standard model fail to connect many things that "ought to" be connected, and they leave us with a disjointed description of matter. But building on the ideas that power the standard model, we can see how that awkward adolescent of symmetry, with promising but mismatched parts, might mature into graceful adulthood: As box 1 describes, the known particles fit beautifully into a larger symmetry scheme.

That tantalizing result has profound implications for future discovery. As explained in box 2, it suggests that gravity should be considered on the same footing as the other forces, rather than sui generis. It encourages us to think about further steps to bring in new kinds of symmetry and to contemplate concrete new phenomena.

To bring all the particles together, we need symmetry transformations that connect particles with different spin. That chasm can be spanned by extending the Lorentz symmetry of special relativity into something larger: supersymmetry. The extended symmetry requires that the particles we are familiar with have partners with different spin but equal values of electric charge, strong color charge, and weak color charge.

Unbroken supersymmetry would require that the partners also have equal mass, but of course, no such degeneracy is observed. We must be content with a fallback position: supersymmetry in the fundamental equations but not in the solution we use to model nature. In other words, supersymmetry is spontaneously broken. Remarkably, if the scale of supersymmetry breaking is not too large—that is, if the partners of known particles are not too heavy—a quantitative unification of couplings can be consummated, as illustrated in box 2.

A less technical way of thinking about the unification afforded by supersymmetry brings out its profound character. A great achievement of 20th-century physics was to transcend the difference between two superficially different aspects of matter: the wave aspect, epitomized by the classical description of light, and the particle aspect, epitomized by the classical description of atoms. At the level of individual quanta, both photons and electrons are wavicles. At the level of ensembles, however, their descriptions remain very different, involving either boson or fermion quantum statistics. Supersymmetry shows us how that difference, too, might be transcended.

The promising ideas sketched above about unification and supersymmetry have been maturing for several decades, but their glory days lie ahead. Their main success, beyond organizing the quantum numbers and coupling strengths of our core theories, has been to anticipate the now-observed small but nonzero neutrino masses. Baryon-number-violating processes, including proton decay, and the existence of superpartners are dramatic, make-or-break predictions of the circle of ideas described above. Either would open new worlds of phenomena to investigation. According to our best estimates, neither proton decay nor superpartners lie beyond the reach of a heroic search. They should be found, well within 100 years.

The specter of a multiverse

Other aspects of our core theories are less elegant. The fundamental entities introduced in box 1 appear in nature in three copies—the e, μ, and τ families. We have no compelling understanding of that threefold replication of substance nor, especially, of the complex pattern of masses and mixings their members exhibit. Our observations are accommodated by means of roughly two dozen independent parameters, which describe how the Higgs field couples to quarks and leptons (such as the electron and its neutrino). Although that number is fairly modest—much less, for example, than the number of entries in the periodic table—success has made us ambitious, and we'd like to do better.

But can we? Though all existing observations are consistent with the idea that the structure of our core theories and the values of the parameters they contain are the same everywhere and for all time, it is logically possible that such is not the case. Indeed, inflationary cosmology embodies a mechanism to produce very large regions with uniform properties within a still larger whole that is far from uniform, and string theory offers many possibilities for realizing that nonuniformity. To describe the situation, we speak of uniform universes within a larger, inhomogeneous multiverse. In the multiverse framework, the universe we have observed is one sample from an ensemble of universes with widely varying properties, much as our solar system is just one among many planetary systems with widely varying properties.

When calculating the probability of observing a given structure or parameter set in the ensemble of universes, we must apply a selection criterion. Universes that do not allow the emergence of observers should not be included among observable universes. If, after applying that selection criterion, we find that most or all possible universes share some feature, then we can claim to have an anthropic explanation of that feature. Conversely, if we find impressive anthropic explanations, we should regard them as evidence for the multiverse hypothesis that underlies them. As many authors have noted, small changes in any of several standard-model parameters would make the emergence of intelligent life problematic. Thus the specter of a multiverse looms large.

Accordingly, the values of hitherto unexplained parameters might be environmental accidents, incapable of theoretical elucidation. That seductive conclusion—broadly of the form "If we, clever as we are, haven't understood it, then it can't be understood"—has obvious dangers. It is a declaration of victory that excuses surrender. In 100 years we'll have a better sense of whether, and on what fronts, resistance is futile.

Axions

One aspect of masses and mixings offers a more inspiring vista. The general principles of our core theories allow the existence of a parameter θ that induces violation of symmetry under space-inversion and time-reversal transformations in the strong interaction. Experiments powerfully bound such violation, so we conclude that $|\theta| < 10^{-10}$; a priori we might have expected θ to be close to 1. Anthropic arguments carry no freight in resolving the dilemma, since it is implausible that any effects induced by having θ near 1 would inhibit the emergence of intelligent observers.

The extraordinarily tight bound on θ suggests that a new principle must be at work to explain the parameter's smallness. The best candidate is a new kind of symmetry, called Peccei–Quinn symmetry after its discoverers, Roberto Peccei and Helen Quinn. The new symmetry leads to remarkable physical consequences. It predicts the existence of a new ultralight, ultraweakly interacting particle, the axion. If they exist at all, axions would be copiously produced in the early universe. They provide an excellent candidate to compose the dark matter that astronomers have observed but not yet identified. Ingenious, challenging experiments are being mounted to detect axions, either as a cosmic background or through their effects. Within 100 years—and possibly much sooner—they should succeed.

Problems with gravity

Einstein's general relativity, as a theory of gravitation, is so tight conceptually that it allows only two free parameters: Newton's constant and the cosmological term. It has passed every test that physicists and astronomers have devised. Yet there are reasons to remain dissatisfied.

First, the strength of gravity is grossly disproportionate to the strength of other forces. If we believe in the unity of nature's operating system, how can that be? Second, the measured value of the mass density of space devoid of matter—the cosmological term, often called dark energy—is incommensurate with reasonable expectations. Why is it much smaller than theory suggests, yet not zero? Third, the equations that follow from straightforward quantization of general relativity break down in extreme conditions. What are the consequences? Those issues are important agenda items for the next 100 years of physics. In the boxes, I've indicated a promising way to approach the question of the weakness of gravity. Here I'll offer a few comments on the other issues.

Theorists have estimated several contributions to the cosmological term—positive and negative—whose individual absolute values far exceed the observed total value. Thus the term's observed smallness indicates delicate cancellations that our core theories do not explain. Perhaps, as suggested by Steven Weinberg, the explanation is anthropic. Too large a cosmological term would lead the universe to expand so rapidly that formation of structure in the universe would be inhibited. Neither galaxies nor stars nor planets would form, and thus observers could not emerge. Is that anthropic argument the best physics can do—is resistance futile? Or is some deeper principle at work?

The conceptual difficulty of reconciling our theory of gravity, general relativity, with the principles of quantum mechanics has been the subject of much hyperbole. I think it is important, therefore, first to bring it down to earth.

At a practical level, there is no problem. Astrophysicists and cosmologists routinely and successfully calculate behavior in physical situations for which both gravitation and quantum theory are in play simultaneously. Throughout that work, no significant ambiguities or singularities arise.

Problems do arise if we try to apply the equations to such extreme conditions as might occur during the earliest moments of the Big Bang or in the deep interior of black holes. Also, conceptual puzzles arise in thought experiments about the behavior of small black holes. But it would be a bracing achievement, and major progress, to identify any concrete, observable phenomenon that brings in truly characteristic features of quantum gravity beyond the semiclassical approximation in common use. Actual observation would bring the subject to another level.

String theory is an imposing framework in which general relativity and quantum theory are intimately connected. It supports a rich and only partly understood symmetry structure that can accommodate not only gauge symmetries but also supersymmetry and axions. At present, string theory's application to world modeling is amorphous. If it can be sculpted into a more definite shape, it might greatly illuminate many of the issues I've discussed. One hundred years should be time enough.

Ascending from the ant's-eye view

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Physical cosmology has greatly matured in the past several decades. We have gathered precise, overwhelming evidence that the universe began in a very special, conceptually simple initial state. The nongravitational forces were in thermal equilibrium at an extremely high temperature, yet the distribution of matter was extremely though not perfectly uniform, and space was rapidly expanding per the equations of general relativity. Note that uniformity represents extreme disequilibrium for gravity, which seeks to clump matter together. The gravitational instability of the starting point played out to form galaxy clusters, galaxies, stars, and planets—the universe of structures we see around us and live in.

The broad outlines of that cosmology are not in doubt, but many of its details are sketchy. At the frontiers of cosmology, several lines of evidence suggest that early in its history, the universe underwent an episode of cosmic inflation—a period of superluminal expansion that within a fraction of a second grew space by several tens of orders of magnitude. That extraordinary possibility is broadly supported by plausible ideas that arise in fundamental physics; in fact, it was suggested by them. It is fair to say, however, that at present inflation is a scenario rather than a physical theory. For example, no one has convincingly identified its physical origin. Since quantum fluctuations during inflation could plausibly give rise to the small inhomogeneities that seed structure formation and possibly to measurable gravitational waves, inflation's unresolved issues are not without empirical consequence. I expect that during the next 100 years, after progress in both theory and observation, inflation will evolve from a scenario to a script.

A recurring theme in natural philosophy is the tension between the God's-eye view of reality comprehended as a whole and the ant's-eye view of human consciousness, which senses a succession of events in time. Since the days of Isaac Newton, the ant's-eye view has dominated fundamental physics. We divide our description of the world into dynamical laws that, paradoxically, exist outside of time, and initial conditions on which those laws act. The dynamical laws do not determine which initial conditions describe reality. That division has been enormously useful and successful pragmatically, but it leaves us far short of a full scientific account of the world as we know it. The account it gives—things are what they are because they were what they were—raises the question, Why were things that way and not any other?

The God's-eye view seems, in the light of relativity theory, to be far more natural. Relativity teaches us to consider spacetime as an organic whole whose different aspects are related by symmetries that are awkward to express if we insist on carving experience into time slices. Hermann Weyl expressed the organic view memorably in his 1949 book Philosophy of Mathematics and Natural Science (Princeton University Press, page 116):

> The objective world simply is, it does not happen. Only to the gaze of my consciousness, crawling upward along the life line of my body, does a section of this world come to life as a fleeting image in space which continuously changes in time.

To me, ascending from the ant's-eye view to the God's-eye view of physical reality is the most profound challenge for fundamental physics in the next 100 years.

The rise of algorithms
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Twenty-five speed- and density-doubling cycles of Moore's law—a result of human ingenuity empowered by a profound understanding of matter—have given humans in general, and physicists in particular, computational tools of extraordinary capacity. Although the pace of exponential expansion may be leveling off, we can anticipate at least a few more cycles in coming decades. Useful quantum computers will come online too. That growing computational capacity will change the nature of the questions we ask, the answers we seek, and the investigations we pursue. Last but not least, it will change the nature of the investigators: what "we physicists" are.

The recent development of quantum chromodynamics (QCD), our theory of the strong interaction, gives a foretaste of things to come. The initial validation of the theory came through its accurate quantitative description of processes involving large energy and momentum transfers. Those so-called hard processes are amenable to a sophisticated perturbation theory, but they are a small subset of the phenomena of interest. They do not, for example, include nuclear physics, which motivated people to study the strong interaction in the first place. Much ingenuity has been directed toward solving the equations of QCD by analytical techniques. But the most successful approach by far has been to put the equations in a format that computers can run with and then to let them run.

Already in 1929 Paul Dirac stated in the Proceedings of the Royal Society of London (volume 123, page 714):

> The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known, and the difficulty is only that the exact application of these laws leads to equations much too complicated to be soluble. It therefore becomes desirable that approximate practical methods of applying quantum mechanics should be developed, which can lead to an explanation of the main features of complex atomic systems without too much computation.

Dirac's claim that we know the fundamental laws well enough to support calculation of any physical process relevant to chemistry, materials science, or anything else of practical interest looks better than ever. But the boundaries defining "much too complicated" and "too much computation" have changed radically. Modern computing machines are many orders of magnitude more capable than anything available in 1929, and there are good reasons to think that within 100 years we will have many more orders-of-magnitude improvement.

Are there materials that will support space elevators? (Figure 1 gives an artist's rendition.) Are there room-temperature superconductors? Those questions, and any number of others, will become accessible as computers do for nuclear physics, stellar physics, materials science, and chemistry what they have already done for aircraft design: supplement and ultimately supplant laboratory experimentation with computation.

Click to view

Figure 1. The space elevator, supported against gravity by centrifugal force, could forge a versatile link between the surface of Earth and the reaches of outer space. To realize the concept, we will need to manufacture new, strong materials, almost certainly designed with the help of computers. (Rendition by Pat Rawlings, courtesy of NASA.)

Increasingly, the development of algorithms will become a central focus of theoretical physics. Concepts and equations that computers can run with will be powerfully leveraged; concepts and equations that cannot be turned into algorithms will be regarded as deficient. That does not mean mindless number crunching will replace creative insight. On the contrary: Triumphs of creative understanding such as universality (suppression of irrelevant details), symmetry (informed iteration), and topology (emergence of discrete from continuous) are preadapted to algorithmic thinking.

The work of designing algorithms can be considered as a special form of teaching, aimed at extremely clever but literal-minded and inexperienced students—that is, computers—who cannot deal with vagueness. At present those students are poorly motivated and incurious, but those faults are curable. Within 100 years they will become the colleagues and ultimately the successors of their human teachers, with a distinctive style of thought adapted to their talents.

Grand projects

The Pyramids of Egypt, the Parthenon of Athens, the Alhambra in Spain, the cathedrals of medieval Europe, the Eiffel Tower—these and more are grand projects, through which a culture expresses its aspirations and identity. Extraordinary opportunities are before us, but to do them justice will require substantial investment of resources. Confident, ambitious communities will take them on proudly.

► Gravitational-wave astronomy has begun to open a new window on the universe, one that will allow access to hidden regions and violent events: In February of this year, the Laser Interferometer Gravitational-Wave Observatory reported the first direct observation of a gravitational wave. To exploit the full potential of gravitational-wave astronomy, we shall deploy arrays of precision instruments, spanning millions of kilometers, in space. One candidate, the Laser Interferometer Space Antenna, is illustrated in figure 2.

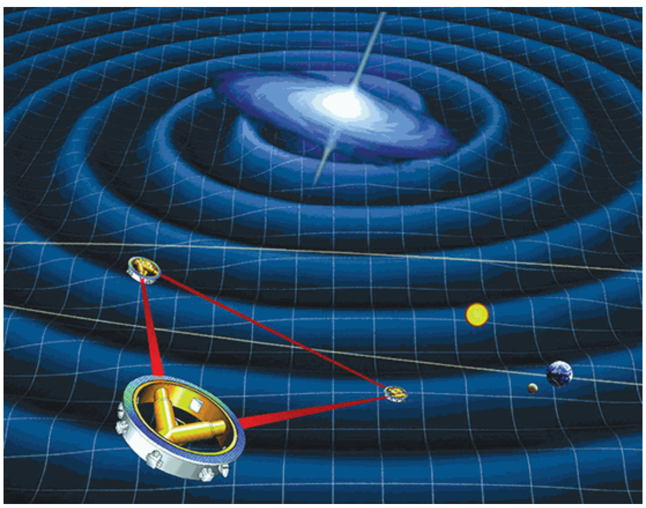

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Figure 2. The Laser Interferometer Space Antenna (LISA) could detect gravitational waves that have frequencies ranging from 0.1 mHz to 100 mHz. By way of comparison, the gravitational wave discovered with the Laser Interferometer Gravitational-Wave Observatory last February featured frequencies around 100 Hz. Spanning millions of kilometers, LISA will be by far the largest structure produced by humanity. It will be a lasting monument to our curiosity, ambition, and ingenuity. (Courtesy of NASA.)

► Exoplanetary astronomy will systematically survey our galaxy, gathering information on the masses, orbits, geology, and atmospheres of millions of planets. As a byproduct, we will learn how rare life is and what conditions it requires. What we discover might support tests and refinements of anthropic reasoning.

► Tactile astronomy will be advanced much more readily by an expanding swarm of robotic probes, virtual telepresence, and appropriate biological seeds than by fragile, human bodies ill-adapted to deep space. Human civilization will extend beyond the solar system; human colonization, not so much.

► Inverse astronomy will reach to shorter distances and higher energies at great accelerator projects.

► Quantum computation will both call on and enable algorithms for increasingly sophisticated quantum gadgetry. Within 100 years it will become the central method of chemistry and materials science.

During the next 100 years, not only physical instruments but also the notion of mind will assume new proportions. Two developments will be transformative: naturalized artificial intelligence and expanded sensoria.

Present-day mainstream computers are essentially two dimensional. They are based on chips that must be produced under exacting clean-room conditions, since any fault can be fatal to their operation. If they are damaged, they do not recover. Human brains differ in all those respects. They are 3D; they are produced in messy, loosely controlled conditions; and they can work around faults or injuries. There are strong incentives to achieve those features in systems that retain the density, speed, and scalability of semiconductor technology, and there is no clear barrier to doing so. Capable 3D, fault-tolerant, self-repairing computers will be developed. In engineering those features, we will learn lessons relevant to neurobiology.

In a similar vein, we may aspire to make body-like machines as well as brain-like computers. Self-assembling, self-reproducing, and autonomously creative machines will be developed. Their design will adapt both concepts and physical modules from the biological world.

Human perception leaves a lot on the table. Consider, for example, color vision. Whereas the electromagnetic signals arriving at our eyes are polarized and contain a continuous range of frequencies, what we perceive as color is a crude hash encoding that lumps the power spectrum into three bins and ignores polarization. Also, of course, we can't see frequencies, including UV and IR, outside the visible range. What we don't perceive includes valuable information about our natural environment, not to mention possibilities for data visualization and art.

Click to view

Viewing things with expanded perception can reveal aspects of reality that we are not otherwise aware of. This IR self-portrait of the author was taken at San Francisco's Exploratorium.

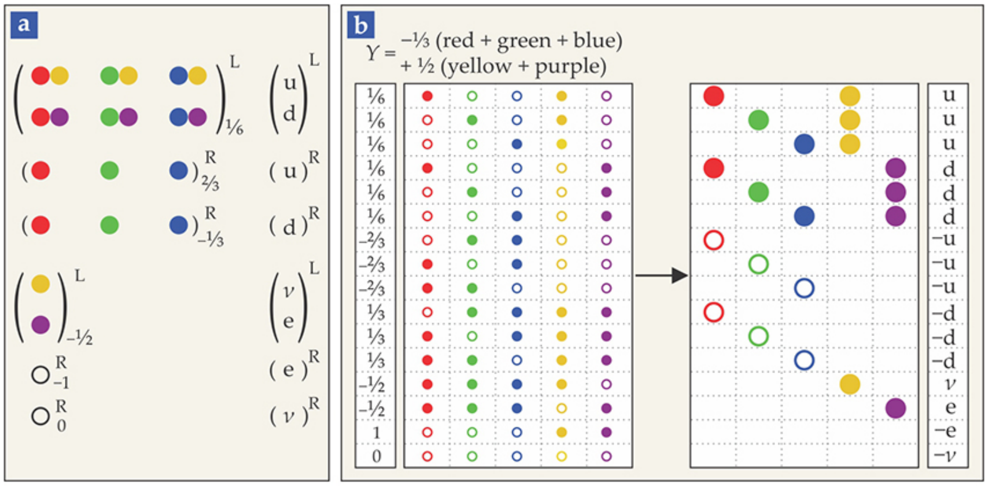
Modern microelectronics and computing offer attractive possibilities for accessing that information. By appropriate transformations, we can encode it in our existing channels in a sort of synesthesia. By vastly expanding the human sensorium, we will open the doors of perception and see the world as it really is.

The end is not near

Announcements of the end of physics are decidedly premature, as are closely related proclamations of postempirical physics. We can and will make progress on many fronts. We can and will gain new insights into and control over concrete, real-world physical phenomena. Brilliant prospects lie ahead. I've just described a few of them.

Box 1. Unification in pictures

In the standard model of particle physics, the strong, weak, and electromagnetic interactions are all described by their own symmetry, and each has its own variety of associated charge. As a result of that splitting, the fundamental particles are organized in a somewhat clumsy manner. This box reveals that organization pictorially and displays how it becomes more graceful when the particles are viewed under the umbrella of an illustrative larger symmetry group.



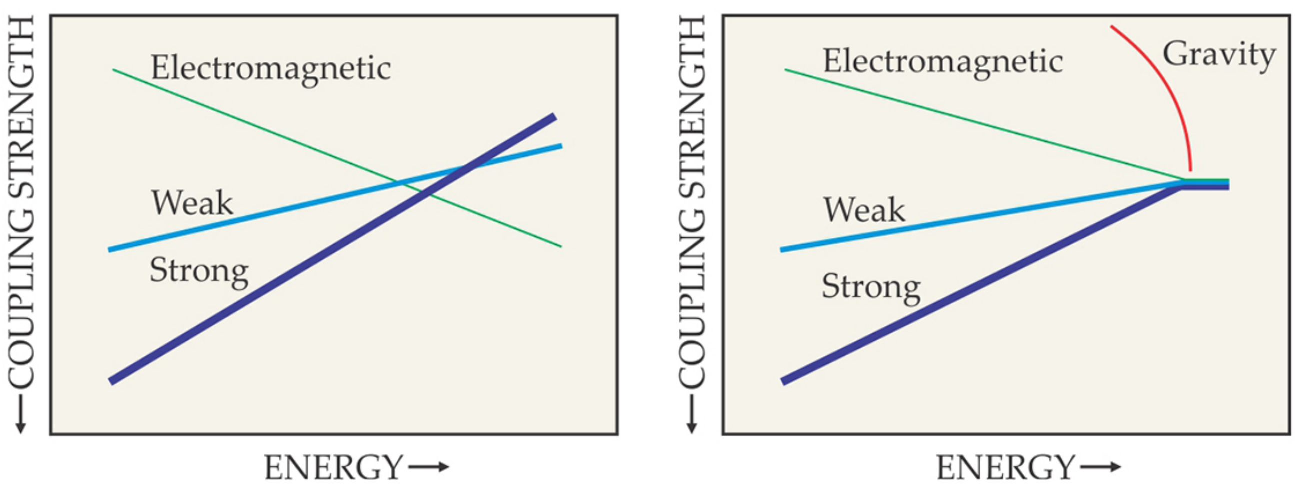
The black column of symbols in panel a shows the up (u) and down (d) quarks, the electron (e), and the electron neutrino (ν). Each of those particles can have a left-handed (L) or right-handed (R) helicity, according to whether spin and momentum are antiparallel or parallel; the left-handed particles are organized in doublets, so the column displays six distinct entities. The left side of panel a displays the properties of those entities that account for their strong, weak, and electromagnetic interactions. Gluons, which mediate the strong interaction, respond to three strong color charges, indicated by red, green, and blue. The weak interactions, which only act on left-handed particles, respond to two weak color charges, here indicated as yellow and purple. Electromagnetism is incorporated through couplings to electric charge. The average charge within each entity, also called its hypercharge (Y), is indicated by a numerical subscript and given in units of the proton charge |e|.

Panel b shows how the observed, scattered pattern of particles can be deduced from a unified template, derived from higher symmetry. The right column gives the names of the particles. Here, everything has left-handed helicity; right-handed particles in the earlier description are now represented through their left-handed antiparticles, which are indicated by a minus sign, so that u^R becomes –u and so forth. The left table shows all possible assignments of full or empty circles of strong and weak colors, subject to the constraint that the number of full circles is even. A full circle is interpreted as a positive half-unit of the corresponding charge, an empty circle as a negative half-unit. The hypercharge values, which appear in the left column, are now generated from the weak and strong color charges according to the formula on top.

To recover the properties displayed in panel a, I invoke the rule that adding equal amounts of all the strong color charges, or equal amounts of all the weak color charges, does not influence the strong or weak interactions. That allows me to change the color scheme on the left table of panel b to that on the panel's right table. Note that the color charges are now in full units and that the colors and hypercharges match the content of panel a, given that antiparticles have the opposite color charges and hypercharges from their corresponding particles.

Box 2. Unified forces

The impressively successful classification scheme illustrated in box 1 can be embedded in a comprehensive theoretical framework. A central prediction of that framework is that the basic strengths of the different interactions are equal. The observed strengths are not equal, but we understand that the basic strengths are revealed only at very high interaction energies. To get at them, we must correct for virtual particles, which can screen or antiscreen an interaction—an effect known as vacuum polarization. When we allow for the contributions of all the known particles, we find a suggestive approach to equality but a quantitative failure, as illustrated in the panel to the left. But as the right-hand panel shows, when we include the additional contributions from superpartners, as suggested by supersymmetry, we find accurate unification.



Gravity is much, much weaker than the other forces when it acts between elementary particles at accessible energies. But at the energy where the other forces are unified, its strength is comparable. Viewed from another angle, the hypothesis that all the basic forces are unified at the scale set by gauge-coupling unification quantitatively explains the observed feebleness of gravity.

Essay Contest: Physics in 2116

Physics Today would like you to join Frank Wilczek in thinking about what the next 100 years will bring to physics. We invite you to imagine yourself in 2116, ready to write an essay for the magazine in the style of a Search and Discovery news story. Your essay should report on an exciting discovery, an advance in physics, or a new technology. It should be at most 2000 words long and should not have been published previously.

We will award a prize of $7500 to the author of the winning essay. If more than one essay wins, the prize will be divided equally among the winning authors.

A distinguished jury of physicists will select the winner or winners in the final round of judging. The decisions of the judges and Physics Today are final.

Winning entries will be published in Physics Today. The winners will be asked to sign a standard transfer-of-copyright agreement.

You may submit only one entry, and it must be received by 1 June 2016. Include your daytime phone number and email address.

Employees of the American Institute of Physics and AIP Publishing are not eligible for this contest.

Entries should be mailed to physics2116@aip.org, with the title of your essay as the subject line.

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1. B. P. Abbott et al. (LIGO scientific collaboration and Virgo collaboration), "Observation of gravitational waves from a binary black hole merger," Phys. Rev. Lett. **116**, 061102 (2016). http://dx.doi.org/10.1103/PhysRevLett.116.0611020031-9007
2. P. W. Anderson, "More is different," Science **177**, 393 (1972). http://dx.doi.org/10.1126/science.177.4047.3930036-8075
3. O. Stapledon, Star Maker, Dover, (2008).
4. F. Wilczek, A Beautiful Question: Finding Nature's Deep Design, Penguin Press, (2015).

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DOI: http://dx.doi.org/10.1063/PT.3.3137

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By:Guest | Posted On: Apr 03, 2016 8:57 AM
Frank writes:

"The principles of relativistic quantum field theory and local symmetry, embedded in our core theories of general relativity and the gauge theories of the strong, weak, and electromagnetic forces, have taken physicists a long way. We now have precisely formulated, battle-tested equations that provide secure foundations for chemistry, all plausible forms of engineering, the description of all observed astronomical objects, and a good deal of cosmology."

As far as I know, not even QED in flat spacetime has yet to be given a precise mathematical definition. Furthermore, they provide secure foundations only in principle, not in practice; one can't even go from the (not mathematically well defined) standard model of particle physics to the properties of protons without making additional assumptions and simplifications.

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By:Guest | Posted On: Apr 03, 2016 5:16 PM
We don't have the luxury of 100 years to find out - I'll be surprised if we have 25 years before total environmental collapse and the 6th mass extinction anthropocene era ends
By:Guest | Posted On: Apr 06, 2016 9:07 AM
And what about quantum entanglement and non-locality?
By:Guest | Posted On: Apr 09, 2016 8:14 PM
“At the frontiers of cosmology, several lines of evidence suggest that early in its history, the universe underwent an episode of cosmic inflation—a period of superluminal expansion that within a fraction of a second grew space by several tens of orders of magnitude. That extraordinary possibility is broadly supported by plausible ideas that arise in fundamental physics; in fact, it was suggested by them. It is fair to say, however, that at present inflation is a scenario rather than a physical theory. For example, no one has convincingly identified its physical origin. Since quantum fluctuations during inflation could plausibly give rise to the small inhomogeneities that seed structure formation and possibly to measurable gravitational waves, inflation’s unresolved issues are not without empirical consequence.”
Does dark energy obey the equivalence principle? If dark energy has negative gravitational energy, then are there dark energy particles with negative inertial energy? Does the equivalence principle fail for ordinary matter because energy-density is not accurately represented by an energy-tensor at the Planck scale? Is inflation entirely due to a slight failure of Einstein's field equations?
R(mu,nu) + (-1/2) * g(mu,nu) * R = - ϰ * T(mu,nu) - Λ * g(mu,nu) — what might be wrong? Consider the possible correction R(mu,nu) + (-1/2) * g(mu,nu) * R = - ϰ * (T(mu,nu) / equivalence-principle-failure-factor) - Λ * g(mu,nu), where equivalence-principle-failure-factor = (1 - (T(mu,nu)/T(max))^2)^(1/2) — if T(max) = +∞ then Einstein’s field equations are recovered.
By:Guest | Posted On: Apr 12, 2016 7:48 AM
The notion of dark matter as a weakly interacting clump of stuff that travels with the matter. Dark matter fills 'empty' space. Dark matter strongly interacts with matter. Dark matter is displaced by matter.

'[0903.3802] The Milky Way's dark matter halo appears to be lopsided'

"the emerging picture of the dark matter halo of the Milky Way is dominantly lopsided in nature."

The Milky Way's halo is not a clump of dark matter traveling along with the Milky Way. The Milky Way's halo is lopsided due to the matter in the Milky Way moving through and displacing the dark matter, analogous to a submarine moving through and displacing the water.

What physicists mistake for the density of the dark matter is actually the state of displacement of the dark matter. Physicists think they are determining the density of the dark matter by how much it and the matter curve spacetime. What they fail to realize is the state of displacement of the dark matter is curved spacetime.
By:Guest | Posted On: Apr 29, 2016 6:41 PM
Yes the ideal is a adventure, but will take a period to produce the contents. Therefore investigate the tips, and the meaning of the task. If it takes a while, then allow that. This is what I shall do, the game is on, no reward needed. Everyone complete for good read.
By:Guest | Posted On: May 02, 2016 3:20 PM
any thoughts on physics of life (living matter)? seems new breakthrough is likely.

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