search & discovery

A mathematician's version of the fine-structure constant

A theoretical paper that predicts a value for the fine-structure constant $\alpha = e^2/\hbar c$ in terms only of simple rational powers of integers and π, agrees with the experimental value for α within one-half part per million, that is within one-third standard deviation or less. The present experimental accuracy of α (about 1.5 ppm) corresponds roughly to the thickness of a sheet of paper out of the length of a football field.

This astonishing agreement of theory with experiment has recently been widely discussed among theorists, many of whom say that they have difficulty understanding the theory. The paper,[1] published in the 20 October 1969 issue of *Comptes Rendus*, attracted little attention initially. It was written by Armand Wyler, a young mathematician who got his PhD from the Federal Institute of Technology in 1966. After a year as an instructor at Stanford and a year at MIT, he is at the Mathematics Institute in Zurich. He will spend the academic year 1971–72 as a member of the Institute for Advanced Study.

Wyler has now published a second paper,[2] in the 11 January issue of *Comptes Rendus*, which says that the ratio of the mass of the proton to the mass of the electron is just $6\pi^5$, a number that also agrees with experiment, although the value is not as well known as that for α.

In the first paper Wyler considers a seven-dimensional group, O(5,2). Five of the dimensions are real rotations, and the other two dimensions, called "pseudorotations," are timelike; that is, five of the dimensions are real and two of the dimensions are imaginary. Wyler then calculates volume elements for the seven-dimensional group and for the subgroup of the five real dimensions, and takes their quotient. The result,

$$(9/8\pi^4)(\pi^5/2^4 5!)^{1/4}$$

is equated to α. This simple, closed-form expression yields a value for $\alpha^{-1}_{th} = 137.03608245$.

What connection do the groups Wyler uses have with physics? That is a hard question raised by many critics of the work. In the nonrelativistic approximation for the hydrogen atom, one uses

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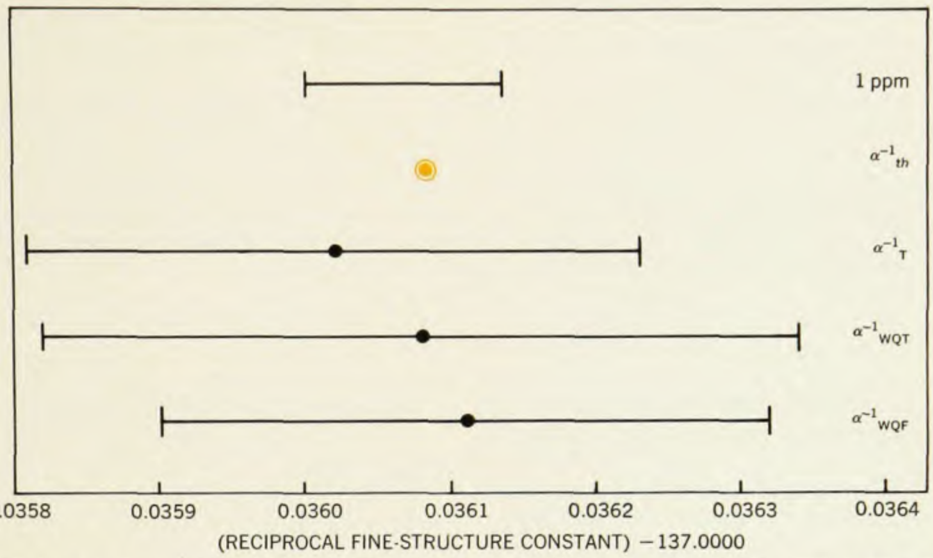


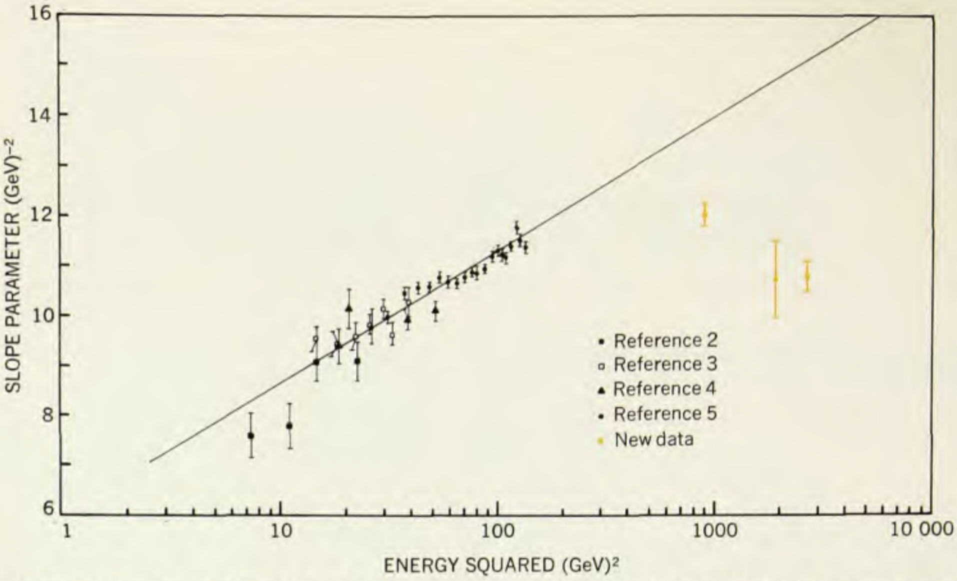
Values for α^{-1} compared. α^{-1}_{th} is the theoretical prediction of Armand Wyler, in terms only of simple rational powers of integers and π. α^{-1}_{T} is from a 1969 analysis of fundamental constants.[3] α^{-1}_{WQT}, also from the same analysis, comes from experiments that do not involve quantum electrodynamics. α^{-1}_{WQF} depends on a recent determination[4] of e/h using the ac Josephson effect.

Surprising proton–proton data from CERN

Although the CERN Intersecting Storage Rings have barely been turned on, exciting experimental data are already pouring out. Carlo Rubbia (Harvard) reported,[1] first at the Washington APS meeting and more recently, with additional data, at the Amsterdam International Conference on Elementary Particles on 2 July, surprising results from elastic proton–proton scattering. The experiment was done by a collaboration from Aachen, CERN, Harvard, Genoa and Torino. They measured the scattering for center-of-mass energies of 30.4, 45.0 and, more recently at 56 GeV (which is equivalent to performing a conventional high-energy scattering experiment at about 1400 GeV). Their determination of the slope parameter is in complete contradiction with the predictions of a naive formulation of Regge theory.

If you plot the differential cross section at a given energy as a function of the four-momentum transfer squared, t (which is equivalent to plotting it as a function of scattering angle at fixed energy), you find at high energies and small values of t, that the curve is an exponential. The shape of the curve can be characterized by e^{bt} (where t is negative) and b is the slope parameter. Some theorists say that the slope essentially measures the geometrical size of the proton.

According to standard Regge ideas, the high-energy scattering is dominated by the Pomeranchuk trajectory. The scattering cross section is expected to grow like $s^{\alpha t}$, where s is the energy squared and α is some function. If you write the cross section instead as $e^{\alpha t \log s}$ and expand $\alpha(t)$ for small values of t, you get a constant times e^{bt}. The slope parameter b is proportional to log s. A plot of the slope parameter versus log s for all available energies, as high as the 30-GeV CERN proton synchrotron, the Brookhaven Alternating Gradient Synchrotron,



Slope parameter as a function of energy squared shows a simple straight-line behavior for energies of 70 GeV and below. New data from the CERN Intersecting Storage Rings (shown in color) reported by Carlo Rubbia and his collaborators completely contradicts predictions of a naive formulation of Regge theory.

and more recently the Serpukhov 70-GeV synchrotron, was clearly a straight line.[2-5]

In the figure the simple straight-line behavior for energies 70 GeV and below shows a dramatic change at still higher energies. At the three energies measured by Rubbia and his collaborators, the slope parameter does not continually increase. It appears to be flattening out or even turning down.

One noted theorist interprets this behavior as showing that the proton size is no longer continuing to expand. Others object to such a pictorial interpretation and say that a proton size that changes with energy is not a very useful concept.

Proponents of Reggeism will now presumable attempt to explain the ISR data with modifications of existing theory, just as was done with the earlier data from Serpukhov. Proponents of colliding-beam devices are congratulating themselves about the excitement that the ISR is now injecting into high-energy physics, offering a look into the future to be found at 1000 GeV and above. —GBL

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a four-dimensional group, which can be extended to five by adding time-like dimensions; it is the O(4,1) group. When one applies relativity, however, the group is no longer used. Instead we have the so-called conformal group O(4,2), which is fully relativistic and is the natural invariance group of the Maxwell equations of electrodynamics. Many physicists have suspected that the conformal group should play a greater role in the future of physics than it has in the past. Wyler's is the first attempt to use the conformal group in a radically new way.

One critic said that even if Wyler turns out to be correct, there would be no sequel to the work because it has, at least now, no conceivable connection with other concepts in physics.

The Wyler theory might well be correct, another theorist commented, because if you just play with numbers the probability for obtaining such good agreement is very small indeed.

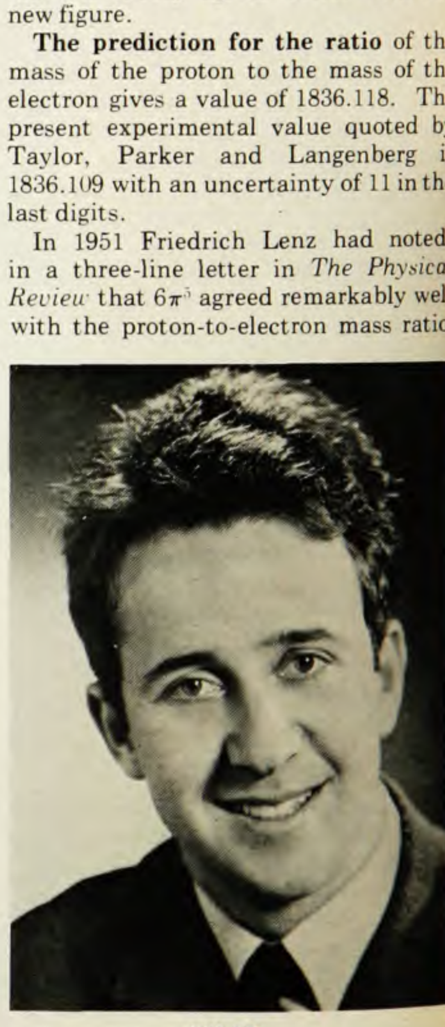
A noted theorist said that just because he does not understand the Wyler theory, he does not think one can with good conscience disregard it.

How good is the agreement between theory and experiment? The figure compares the Wyler value with the current experimental situation. α^{-1}_{T} is the final recommended value resulting from a detailed analysis of the fundamental physical constants by Barry Taylor, W. H. Parker and Donald Langenberg.[3] It equals 137.03602 with an uncertainty of 21 in the last digits. α^{-1}_{WQT} is a value derived in the same work from experiments not involving quantum electrodynamics; it depends strongly on a determination of e/h using the ac Josephson effect in superconductors. α^{-1}_{WQF} is a value based on a recent, more accurate determination of e/h by Thomas Finnegan, Arnold Denenstein and Langenberg.[4] The error bars represent one standard deviation. Langenberg believes that further experimental work is most unlikely to carry α^{-1} more than two or three parts per million away from the values shown.

Another surprising aspect of the 1969 Wyler paper is that he quotes a value for α of 1/137039, a number far from the most recent experimental figure. In fact his theory agrees better with the new figure.

The prediction for the ratio of the mass of the proton to the mass of the electron gives a value of 1836.118. The present experimental value quoted by Taylor, Parker and Langenberg is 1836.109 with an uncertainty of 11 in the last digits.

In 1951 Friedrich Lenz had noted[5] in a three-line letter in *The Physical Review* that $6\pi^5$ agreed remarkably well with the proton-to-electron mass ratio.



WYLER

Last year I. J. Good,[6] extending ideas of Sir Arthur Eddington, came up with the same formula.

Although some theorists believe that the fine-structure constant may have something to do with a geometrical calculation, most would argue against a geometrical interpretation of the proton-to-electron mass ratio. Most theorists would argue that the ratio would certainly involve strong-interaction dynamics. —GBL

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Livermore's new linear accelerator

A linac that can accelerate either positrons or electrons is now operating at Lawrence Radiation Laboratory, Livermore. The accelerator can produce variable-energy beams of up to 100-MeV electrons or 80-MeV positrons. The positrons are used to produce a high-intensity monochromatic photon beam that will explore photonuclear processes over a wide energy range. The electrons will primarily be used for neutron-physics studies through creation of a pulsed neutron source.

The 100-MeV electron accelerator is a five-section pulsed traveling-wave machine that can operate with beam pulses as short as 5 nanosec and as long as 3.0 microsec. It has a duty cycle of 10^{-3}. In the short-pulse mode the instantaneous current is 10 amps.

To produce positrons, electrons are accelerated through the first three sections and then strike a target such as tantalum to produce positron–electron pairs. The positrons are then accelerated through the final two sections. The positron beams are energy analyzed and then pass through thin targets of low atomic-number material (such as beryllium), where the positrons annihilate in flight with bound atomic electrons; this process produces a stream of annihilation photons. By using a small solid angle in the forward direction, one obtains a narrow spectrum of photons (less than 1% wide) of adjustable energy. The equipment has an extensive beam-handling system that can direct the charged-particle beams to seven different target locations.

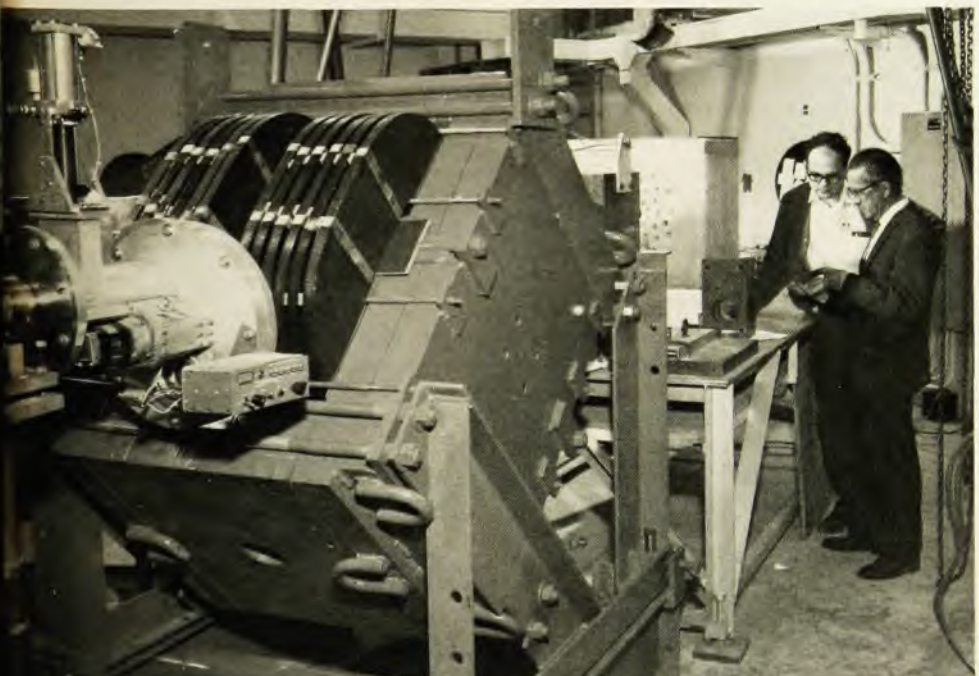
To produce neutrons the pulsed electron beam is stopped in a thick target of high atomic-number material, either through a (γ,n) reaction or (γ,n) plus (γ,f), if fissionable material is used. Neutron yield is about 10^{14} per sec in a 4π distribution at the target. The spectrum obtained contains a range of neutron energies from thermal to as high as 50 MeV. There are several underground neutron drift tubes radiating from the target area and leading to permanent detection stations.

The accelerator, built with funds from AEC's Division of Military Applications, cost $1.9 million, and associated buildings and equipment cost $2.6 million. Stanley Fultz, operations manager of the accelerator, and Clifton Whitten, have played major roles in planning and designing the machine. The research program manager is Charles Bowman.

Other electron linacs. At Oak Ridge ORELA produces 140-MeV electrons with an instantaneous short-pulse current of 15 amps. Its longest pulse length is almost 1 microsec; its shortest is 3 nanosec. The machine is used primarily to produce neutrons for time-of-flight measurements.

At the National Bureau of Standards the 150-MeV electron linac has an instantaneous short-pulse current of 4 amps. Its longest pulse length is 6 microsec and its shortest, 1 nanosec. The machine has extensive beam transport, sending the energy-analyzed beam into many isolated experimental areas. Emphasis is on electron-scattering experiments, photonuclear physics and nuclear and radiation-standards development. This summer the Bureau is installing an adjustable positron source that will produce up to 40 MeV; it will primarily be used as a monoenergetic-photon source.

At MIT a 400-MeV electron linac is nearing completion; it is expected to be at full energy late next year. Average currents of over 100 microamps are expected. At high energies, it will have a duty ratio of almost 2%, and at about 200 MeV a 6% duty ratio. Experimental emphasis will be on electron-scattering experiments; for that purpose MIT is developing an energy-loss spectrometer whose resolution is expected to be better than 10^{-4}. —GBL



Experimental cave at Livermore linac. The positron beam passes through a horizontal tube (left), strikes a target, thus creating monochromatic gamma rays. "Waste" positrons are bent downward by a magnet and absorbed in a particle "dump." The gamma rays go to the white rectangular apparatus (next to Raymond Alvarez and Stanley Fultz), where the gammas generate neutrons.

Space-science study group recommends soft pedal

If NASA follows the recommendations of a study group of National Research Council and National Academy of Sciences Space Science Board, expensive unmanned missions such as the "Grand Tour" of the solar system will be deferred and the space agency will concentrate its efforts for the next decade on relatively small missions. The re-