



Science Service

Gamow: constant ratios of fundamental constants to measure the universe.

THEORETICAL PHYSICS

Universal Constants

Fundamental constants could be a link between cosmology and particle physics

by Dietrick E. Thomsen

Unification is an intellectual passion for some physicists. Theirs is a discipline that seems more and more in danger of running off into dozens of separate specialties that seem to lack contact with each other. But a few physicists concern themselves with the attempt to draw together disparate elements, to find fundamental unifying first principles from which different classes of phenomena can be shown to descend.

For example, there should be a link between the world of the cosmologist and that of the particle physicist. The objects that the cosmologist deals with are built up out of the subatomic particles that are the concern of the particle physicist; the physics of one should be profoundly related to the physics of the other.

Albert Einstein was one of the foremost, though by no means the first or the only, physicist to seek such connections. He spent much of his time trying to find a single theory to encompass different classes of natural forces, from gravity, which operates over astronomical distances, to the nuclear forces, whose effects are confined pretty much to the dimensions of a nucleus. Such forces can be represented geometrically by so-called force fields, and Einstein

sought to unify them theoretically by deriving the different fields from the underlying geometry of the universe. He succeeded fairly well for gravitation, but was unable to get any of the other forces into the scheme.

In contrast to Einstein's geometrical approach, the unifying attempts of the late Dr. George Gamow of the University of Colorado represent an arithmetical one. Dr. Gamow's last contribution to this work, which he completed in collaboration with his former student, Dr. R. A. Alpher of the General Electric Research and Development Center, suggests a fundamental connection between the physical characteristics of subatomic particles and critical features of cosmological theories.

The arithmetic in question involves the so-called fundamental or natural constants that repeatedly appear in physical calculations. These numbers include the universal gravitational constant, which relates the size of a gravitational force to the masses of the bodies concerned; the charge on the electron, of which all other natural charges are multiples; Planck's constant, which is the ratio of energy to frequency for a quantum of radiation; the masses of subatomic particles, and several others. The values of these numbers and their



Physics Today

Dirac predicted changing gravity.

relationships to one another are taken by many to be of basic significance in the structure of the universe.

The line of work to which the latest contribution of Drs. Alpher and Gamow relates was begun more than 30 years ago by Prof. P. A. M. Dirac of Cambridge University.

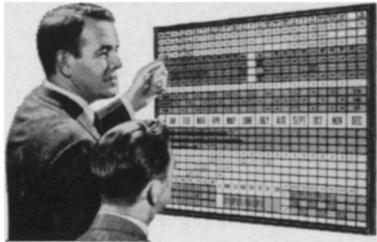
Prof. Dirac started from the idea that, as he puts it, "The fundamental constants of physics . . . provide for us a set of absolute units for measurement of distance, time, mass, etc." Using such units he found a near numerical equality between the ratio between the electrical and gravitational forces bridging electron and proton on the one hand, and the age of the universe on the other.

The ratio of the forces involves the electron's elementary charge, the gravitational constant and the masses of both particles. Prof. Dirac calculated the ratio to about 10^{39} , a thousand billion billion billion billion.

Prof. Dirac also computed a basic unit of time, which he called a tempon. The unit is the time in which light would cover a distance equal to the so-called classical radius of an electron. The tempon turns out to be 10^{-23} , or one hundred-thousand-billion-billionth, of a second. In tempons, the age of the

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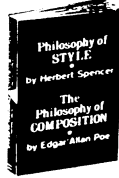
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... universe and atom

universe, which he took as two billion years, also came out to about 10^{39} .

The age of the universe obviously changes with time. Unless the agreement of the two numbers was a momentary coincidence, and Prof. Dirac inferred it was not, the ratio of the two forces should also change. So Prof. Dirac suggested that the gravitational constant was not constant at all but decreased with time in order to make the force ratio change properly.

The difficulty with this decreasing gravity, as Dr. Edward Teller, now director of the Lawrence Radiation Laboratory at Livermore, Calif., pointed out a few years later, is that it provides for a sun shining far too brightly in the distant past. In the Cambrian era, said Teller, from which paleontologists have dug up evidence of life, the sun would have been so hot that the oceans would have boiled and life forms which left fossil remains could not have existed.

In the years since Dirac's computations estimates of the age of the universe have been extended, until they are now at least ten billion years. This reopened the question of Prof. Dirac's suggestion, since it put the time of boiling seas back beyond the period for which there is paleontological evidence of life on earth.

In 1967 Dr. Gamow calculated a new test of Prof. Dirac's suggestion and discovered that according to modern theories of the nuclear processes that go on in the sun, "at the time of its origin the sun simply did not have what it takes (in original fuel supply) to have been shining as brightly and as long as would be required by Dirac's hypothesis."

Therefore, Drs. Alpher and Gamow, with Dr. Robert Herman of General Motors Research Laboratory, set out to see whether they could find some such cosmic ratios that remained constant instead of changing with time.

Being believers in a big bang cosmology—Drs. Alpher and Gamow were among its originators—they started from its principle that the universe at its beginning would have consisted almost entirely of electromagnetic radiation. This would gradually change into matter, and eventually matter would come to dominate the universe.

Drs. Alpher, Gamow and Herman calculated the crossover time, the time at which the densities of matter and radiation were equal, to be about a million years from the origin. This is a significant constant in theories of the development of galaxies and other substructures. In Prof. Dirac's tempons, it is 3×10^{36} —three billion billion billion billion.

They point out that this is close to

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the ratio of electrical to gravitational forces between two protons rather than between an electron and a proton. The proton-proton ratio comes out to 1×10^{36} —one billion billion billion billion.

Thus, say Drs. Alpher and Gamow, "one is dealing with the equality of constants . . . rather than variables as in Dirac's work. . . . Again, however, as with Dirac's observation, either this is all a remarkable coincidence or else it has much deeper significance."

They then looked at another physical constant that should have universal significance: the ratio of the heat capacity of the radiation in the universe—the amount of energy gained by a cubic centimeter when the temperature rises one degree—to the heat capacity of the matter. They found that ratio to be constant for all time, with the exception of certain very early stages of the expansion.

The value of this ratio comes to ten billion in the cosmological model favored by the three authors, and in their latest paper, Drs. Alpher and Gamow set out to see how it can be derived from the ratio of the forces between the protons.

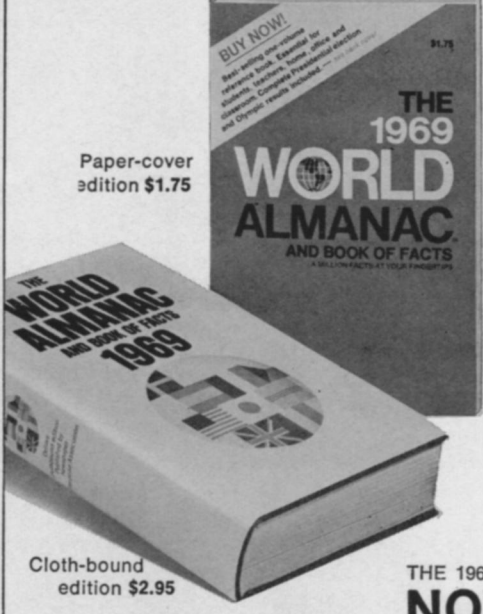
By the end of their derivation they find the ratio of the heat capacities to equal six billion times the square root of the crossover time—an arithmetic link between subatomic and cosmological factors.

"We have," they say, "the remarkable result that on the one hand the cosmological quantity t_c , the matter-radiation density crossover time in atomic units, is numerically equal to [the ratio of the proton forces], a quantity characteristic of elementary particles. On the other hand, the independent cosmological quantity [the ratio of the heat capacities], which is clearly a critical constant in singling out a particular model from all possible models of the expanding universe, is also uniquely described in terms of t_c and thence [the force ratio]."

From these relationships they calculate that the universe emerged from its early stages with about a billion photons per baryon. A photon is a radiation particle; a baryon is a heavy subatomic particle: a proton, a neutron or one of a number of various heavier ones.

Their calculation infers, say Drs. Alpher and Gamow, "that the physics of the interactions between baryon pairs and high-energy photons should yield such a number from first principles."

And if they are right, they may have taken an arithmetic step toward the day when cosmologies are checked in accelerator laboratories. \diamond



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