Holography, charge and baryon asymmetry

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Abstract

The reason for baryon asymmetry in our universe has been a pertinent question for many years. The holographic principle suggests a charged preon model underlies the Standard Model of particle physics, and any such charged preon model requires baryon asymmetry. This note estimates the baryon asymmetry predicted by charged preon models in closed inflationary Friedmann universes.

The reason for the dominance of matter over antimatter in our universe has been a relevant issue for years [1]. The holographic principle [2], developed from black hole thermodynamics, says all physics at a given point is described by the finite number of bits of information on the particle horizon at the greatest distance from which a light signal could reach the point since the end of inflation. This suggests a charged preon model underlies the continuum mathematics of Standard Model particle physics. There is a temperature associated with the horizon and thermodynamics on the horizon implies gravity is explained by Einstein’s theory of general relativity [3]. This note shows that, in charged preon models, thermodynamics on the horizon requires baryon asymmetry, and the baryon asymmetry estimated for a closed universe is consistent with observations. This simple explanation for baryon asymmetry suggests baryon asymmetry and the resulting matter dominance in the universe are observational evidence for a substructure beneath the Standard Model. It also suggests the particle horizon is an appropriate focus for efforts to link gravity with quantum mechanics.

The holographic principle says all information available about physics within a horizon at distance \( d \) from an observer is given by the finite amount of information on the horizon. The number of bits of information on the horizon, specified by one quarter of the horizon area in Planck units [2], is \( \pi d^2/\delta^2 \ln 2 \). The Planck length \( \delta = \sqrt{\frac{\hbar c}{G}} \), where \( G = 6.67 \times 10^{-8} \text{ cm}^3/\text{g sec}^2 \), \( \hbar = 1.05 \times 10^{-27} \text{ g cm}^2/\text{sec} \), and \( c = 3 \times 10^{10} \text{ cm/sec} \). The following analysis relies on Bousso’s [2] formulation of the holographic principle in terms of the light sheets of the causal horizon, circumventing earlier objections [4] to using the holographic principle.
in cosmological contexts. In particular, the argument applies to a vacuum-dominated closed universe, created spontaneously by a quantum fluctuation, that can never collapse \[5\].

Because it involves continuum mathematics, the Standard Model can only approximate an underlying finite-dimensional holographic theory. In particular, a finite dimensional model involving only bits of information on the horizon must describe all physics occurring within the horizon. Linking bits of information on the horizon with Standard Model particles requires a holographic model describing constituents (preons) of Standard Model particles in terms of bits of information on the horizon.

All Standard Model particles have charges 0, 1/3, 2/3 or 1 in units of the electron charge \(\pm e\), so bits in a preon model must be identified with fractional electric charge. Furthermore, in any physical system, energy must be transferred to change information in a bit from one state to another. Labeling the low energy state of a bit \(e/3n\) and the high energy state \(-e/3n\) (where \(n\) is some non-zero integer depending on the particular preon model chosen) then amounts to defining electric charge. If the universe is charge neutral (as it must be if it began by a spontaneous quantum fluctuation from nothing) there must be equal numbers of \(e/3n\) and \(-e/3n\) charges. A holographic charged preon model in such a universe then embodies charge conservation, a precondition for gauge invariance and Maxwell’s equations.

Protons have charge \(e\) and anti-protons have charge \(-e\). Therefore, regardless of the details of how bits of information on the horizon specify a proton or anti-proton, the preon configuration specifying a proton must differ in 3\(n\) bits from the configuration specifying an anti-proton. Then, because \(e/3n\) bits and \(-e/3n\) bits do not have the same energy, the number of protons and anti-protons created in the early universe must be slightly different. In other words, if \(e/3n\) bits have lower energy than \(-e/3n\) bits, there will inevitably be more matter than anti-matter in the universe. However, a small difference in energy of the bits on the horizon specifying a proton or anti-proton is not inconsistent with protons and anti-protons having identical mass.

The temperature at the time of baryon formation was \(T_B = 2m_p c^2 / k = 2.18 \times 10^{13} \circ K\), where the Boltzmann constant \(k = 1.38 \times 10^{-16} (g \text{ cm}^2/\text{sec}^2)/\circ K\), and the proton mass \(m_p = 1.67 \times 10^{-14} \text{ g}\). So, the scale factor of the universe at the time of baryogenesis was \([6]\) \(R_B = R_0 \left(\frac{2.725}{T_B}\right) \approx 10^{15}\text{cm}\), where \(2.725 \circ K\) is today’s cosmic microwave background temperature and the scale factor of the universe today is \(R_0 \approx 10^{28}\text{cm}\). The time \(t_B\) of baryogenesis, in seconds after the end of inflation, can be determined from the Friedmann equation \((\frac{dR}{dt})^2 - (\frac{8\pi G}{3}) \varepsilon (\frac{R}{c})^2 = -\kappa c^2\). After inflation, the universe is so large it is almost flat, so the curvature parameter \(\kappa \approx 0\). The energy density is \(\varepsilon(R) = \varepsilon_r \left(\frac{R_0}{R}\right)^4 + \varepsilon_m \left(\frac{R_0}{R}\right)^3 + \varepsilon_v\), where \(\varepsilon_r\), \(\varepsilon_m\) and \(\varepsilon_v\) are, respectively, today’s radiation, matter and vacuum energy densities. Since the radiation energy density \([8]\) \(\varepsilon_r = 4 \times 10^{-13} \text{ erg/cm}^3\), the matter energy density \(\varepsilon_m \approx 9 \times 10^{-9} \text{ erg/cm}^3\), and vacuum energy density was negligible in the early post-inflationary universe, the radiation term dominated when \(R \ll 10^{-5} R_0\), be-
fore radiation/matter equality. Integrating \((\frac{dR}{dt})^2 - (\frac{8\pi G}{3c^2}) \frac{\rho m c^4}{R^2} = (\frac{dR}{dt})^2 - \frac{A^2}{R^2} = 0\), where \(A = \sqrt{\frac{8\pi Gc e R^3}{3c^2}}\), from the end of inflation at \(t = 0\) to \(t\) gives \(\frac{1}{2} (R^2 - R_0^2) = At\), where \(R_t\) is the scale factor of the universe at the end of inflation. Therefore, \(t_B = \frac{(R_0^2 - R_t^2)}{2A} \approx \frac{R_0^2}{2A} \approx 10^{-7}\) seconds, if \(R_B \gg R_t\). The distance \(d_B\) from any point in the universe to the particle horizon for that point \(\mathbf{K}\) is \(d_B = cR_B \int_0^{t_B} \frac{dt'}{R(t')} = \left[\frac{cR_B}{A} \sqrt{R_t^2 + 2At}\right]_0^{t_B} = \frac{cR_B}{A} \left[\sqrt{R_t^2 + 2At} - R_t\right]\). Since \(R_B \gg R_t\), \(d_B \approx cR_B \sqrt{\frac{2R_B}{A}} \approx 10^4\) cm.

The surface gravity on the particle horizon at baryogenesis is \(g_{HB} = \frac{4\pi Gc^3}{3\epsilon c^4 R_{HB}}\), so the associated horizon temperature \(T_{HB}\) is \(\frac{\hbar}{\sqrt{2\pi m c^3}} g_{HB} \approx 6 \times 10^{-7}\) K. The temperature at any epoch is uniform throughout a post-inflationary homogeneous isotropic Friedman universe, and the causal horizon at baryogenesis is at distance \(d_B\) from every point in the universe. The temperature at every point on the causal horizon for every point in the universe is the same because the surface gravity of the uniform sphere within the horizon is the same at every point on every horizon. The bits on all causal horizons are in thermal equilibrium, and there are only two quantum states accessible to those bits. Therefore, the use of equilibrium statistical mechanics is justified and the occupation probabilities of the two bit states in thermal equilibrium at temperature \(T_{HB}\) are proportional to their corresponding Boltzmann factors. So, if the energy of an \(e/3n\) bit on the horizon at the time of baryon formation is \(E_{bit} - E_d\) and the energy of a \(-e/3n\) bit is \(E_{bit} + E_d\), the proton/antiproton ratio at baryogenesis is \(\left(\frac{e^{\epsilon_{E_{bit} - E_d}/kT_{HB}}}{e^{\epsilon_{E_{bit} + E_d}/kT_{HB}}}\right)^{3n} = e^{6nE_d/kT_{HB}}\). Since \(e^{6nE_d/kT_{HB}} \approx 1 + \frac{6nE_d}{kT_{HB}}\), the proton excess is \(\frac{6nE_d}{kT_{HB}}\).

Any holographic preon model must link bits of information on the horizon to bits of information specifying the location of preon constituents of Standard Model particles within the universe. The wavefunction specifying the probability distribution for a location of a particular bit within the universe has only two energy levels. The energy released when a bit in the universe drops from the \(1\) to the \(0\) state raises another bit from the \(0\) to the \(1\) state, and that is the mechanism for charge conservation. The energy must be transferred by a massless quantum with wavelength related to the size of the universe. There is no reliable definition of the size (as opposed to the scale factor) of a flat or open universe, so it is necessary to restrict the analysis to closed Friedman universes. The only macroscopic length characteristic of the size of a closed Friedman universe with radius (scale factor) \(R(t)\) is the circumference \(2\pi R(t)\). If the energy \(2E_d\) to change the state of a bit associated with a preon within the universe (and the corresponding bit on the horizon) at baryogenesis equals the energy of massless quanta with wavelength characteristic of the size of a closed Friedman universe with radius \(R_B\), \(2E_d = \frac{\hbar}{R_B}\). Then, substituting from above, the proton excess at baryogenesis is \(\frac{6nE_d}{kT_{HB}} = \left(\frac{12n\pi^2}{R_0}\right)\left(\frac{2.739}{R_B}\right)\sqrt{\frac{3}{8\pi \epsilon c}}\). The
dependence on \( R_0 \) arises because \( R_B \), the radius of the universe at baryogenesis, depends on \( R_0 \), today’s cosmic microwave background temperature 2.725 \(^\circ\)K, and the temperature \( T_B \) at baryogenesis. For \( R_0 \approx 10^{28} \) cm, the proton excess is \( \frac{6nE_n}{kT_B} \approx 0.9n \times 10^{-9} \) The WMAP estimate \( \| \) of the baryon density to cosmic microwave background photon density ratio is \( 6.1 \times 10^{-10} \). Assuming half of all baryons are protons and each cosmic microwave photon began as one of the gamma rays from a baryon-antibaryon annihilation, the WMAP results indicate a proton excess at baryogenesis of about \( 3 \times 10^{-9} \).

If \( R_0 \approx 10^{28} \) cm, this model also predicts a positron excess of \( \approx 1.7n \times 10^{-6} \) when the universe cools to the point where electron-positron pairs can survive. This primordial positron excess is a primary source of positrons that might help explain cosmic ray positron excess in the PAMELA experiment \( \| \). The positron excess might also explain part of the asymmetric 511 keV gamma radiation from the galactic center \( \| \).

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