Primordial Magnetic Monopole Pair Production In The Early Universe

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Abstract: A new model, The Roberts Model, is proposed for Primordial Magnetic Monopole pair Production in the early universe. Results for the production of Primordial Magnetic Monopole pairs using this new model are consistent with the Parker Bound.

PACS.14.80.HV-Magnetic Monopoles.
PACS.98.80.Cq-Particle Theory models of the early universe.

1.-Introduction

The “Big Bang” was a phase transition during which Primordial Magnetic Monopole production is widely believed to have taken place\(^{(1,2)}\). The mass of a primordial magnetic monopole is given by \(M = 10^{17}\) Gev and if charge conservation is invoked, as it should be, single magnetic monopole Production is unphysical. Hence we see that \(M_{\text{pair}} = 2.0 \times 10^{17}\) Gev is the relevant quantity to be included in our considerations here.

In a recent RHIC magnetic monopole paper\(^{(3)}\) I determined a) \(M_{\text{pair}} \) vs \(T_0\) and b) \(M_{\text{pair}} \) vs \(\varepsilon_0\).

Where \(T_0\) and \(\varepsilon_0\) are the temperatures and energy densities of the quark-gluon plasma necessary
to produce magnetic monopole pairs of various masses. We will extrapolate backwards to the period immediately following the big bang and estimate $T_0$ and $\epsilon_0$ necessary to produce primordial magnetic monopoles as well as $V_0$ the volume of the early universe immediately following the phase transition (“The Big Bang”).

During the cosmological inflationary period, which subsequently took place, the universe expanded from $V_0$ to $10^{78} V_0$ which has non-trivial consequences for the primordial magnetic monopole flux. We will take a careful look at the physical vacuum’s effect on this process, theorizing that it is crucial in forming the interaction region hence enabling one to define the integrated Luminosity making it possible to calculate $n_{pairs}$ the number of primordial magnetic monopole pairs formed immediately following the phase transition that is popularly called “The Big Bang”.

Our results are that $n_{pairs} = 1.2 \times 10^{13}$ for the number of primordial magnetic monopole pairs formed immediately following the big bang and the flux of primordial magnetic monopole pairs is given by

$$\Phi_{MM}^{Roberts} = 1.3 \times 10^{-19} \text{cm}^{-1} \text{sec}^{-1} \text{sr}^{-1}$$

which is less than

$$\Phi_{MM}^{Parker} = 10^{-15} \text{cm}^{-1} \text{sec}^{-1} \text{sr}^{-1}$$

Where $\Phi_{MM}^{Parker}$ is the Parker Bound. This is a reasonable result in that if $\Phi_{MM}^{Roberts}$ were to equal or exceed the Parker Bound all magnetic fields in the galaxy and possibly the universe would be destroyed.

In the rest of this paper, the above results will be motivated and amplified. In section 2 the basic idea behind the model that it is necessary to formulate to form the interaction region is discussed.

In section 3 the Luminosity, Integrated Luminosity and cross-section for the production of primordial Magnetic monopole pairs are formulated for the period immediately following the Big Bang and $T_0$, $\epsilon_0$ and $V_0$ are calculated so that we may get numerical values for the above-mentioned quantities.

In section 4 the number of primordial magnetic monopole pairs produced in the early universe $n_{pairs}$ is calculated. An upper limit to $\Phi_{MM}^{Roberts}$ the flux of primordial magnetic monopole pairs, in the universe, is calculated and compared to the Parker Bound $\Phi_{MM}^{Parker}$. In section 5 concluding remarks are given.

2.- The Basic Idea Behind The Model For The Interaction Region

A knowledge of $T_0$, $\epsilon_0$ and $V_0$ is necessary to begin to understand the properties of the interaction region immediately following the big bang. The mass $M_{pair}$ of the primordial Magnetic Monopole pairs $M_{pair} = 2 \times 10^{17}$ GeV. In a previous paper we computed the temperature and energy density, respectively, necessary to form Magnetic Monopole pairs. Assuming that in the epoch immediately following the big bang Magnetic Monopole pairs were formed via a thermal process, consisting of a fireball, we may extrapolate $T_0$ and $\epsilon_0$ to find the values that were necessary to produce Primordial Magnetic Monopole pairs for our value of $M_{pair}$. From $T_0$ and $\epsilon_0$ we may then calculate $V_0$.

The physical interaction region arises as the reaction of the physical vacuum to the tremendous burst of energy as, manifested in the primordial fireball, formed via the big bang. The universe
reacted to this tremendous burst of energy by forming an envelope around it similar to the way that the flow of charge in an electric circuit gives rise to resistance. Another way to look at this is that the vacuum acts to shield the universe from this infinite burst of energy by an alternate, much quicker renormalization mechanism than the photon cloud (which is operator for particles taking part in the electromagnetic interaction), by forming an envelope such that the destruction of the fabric of space-time is prevented.

The expansion of the universe is a consequence of the fireball and subsequently the particles, that were produced by it, expanding both adiabatically and isobarically against the envelope formed by the physical vacuum. Hence particles collide within and bounce off of the envelope, thus forming the interaction region. Initially the interaction region was quite compact, but expanded from $V_0$ to $10^{78}V_0$ during the first cosmological inflationary period.

### 3. Parameters In The Interaction Region Are Calculated

The envelope formed by the vacuum forms the interaction region. From the RHIC Magnetic Monopole paper\(^{(3)}\) we may extrapolate backwards to the energy density and temperature necessary to produce Primordial Magnetic Monopole pairs. From these we will calculate the Luminosity, Integrated-Luminosity and $\sigma_{th}$ the production cross-section for primordial Magnetic Monopole pairs. We must compute $\mathcal{L}$, The Effective Luminosity in the interaction region to get a handle on the primordial magnetic monopole pair production process. Clearly\(^{(4)}\) $\mathcal{L} = cm^{-2}sec^{-1}$ and $[\varepsilon_0] = \text{GeV cm}^{-3}$. Now $t_{flux tube} =$ time necessary for the vacuum to form an envelope; $4.0 \times 10^{-20}$ sec so that:

$$\mathcal{L}' = \frac{\varepsilon_0}{t_{flux tube}}.$$  \hspace{1cm} (3.1)

We need a constant $\Omega$ such that $[\Omega] = \text{cm GeV}^{-1}$ and it is quite reasonable to choose:

$$\Omega = \frac{\mu_{up quark}}{m_{up quark}}.$$  \hspace{1cm} (3.2)

Which has the numerical value $\Omega = 4.0 \times 10^{-14} \text{ cm GeV}^{-1}$. Hence we see that our result for the Effective Luminosity is

$$\mathcal{L} = \Omega \mathcal{L}' = 4.0 \times 10^{-14} \frac{\varepsilon_0}{t_{flux tube}} (cm^{-2} sec^{-1}).$$  \hspace{1cm} (3.3)

Extrapolating from previous results\(^{(3)}\) we see that the energy density, of the interaction region, Necessary to produce Primordial Magnetic Monopole pairs of mass $2 \times 10^{17} \text{ Gev}$ is given by $

\varepsilon = 8.0 \times 10^{55} \text{ Gev cm}^{-3}$, thus yielding $\mathcal{L} = 8.0 \times 10^{61} \text{ cm}^{-2} \text{ sec}^{-1}$ for the effective luminosity. Next we need the Integrated Luminosity. Firstly, extrapolations from reference (3) indicate that $T_0 = 2.0 \times 10^{15} \text{ Gev}$ while $V_0 = 2.5 \times 10^{-39} \text{ cm}^3$.

We make the assumption that when the photon cloud forms (thus turning on the electromagnetic Force), the effective charge and energy become finite and primordial magnetic monopole production stops. Conventionally, one chooses $dt = 10^{-35} \text{ sec}$ as the time for particle production to take place in the early universe. Hence the Integrated luminosity becomes:

$$\int dt \mathcal{L} = 8.0 \times 10^{27} \text{ cm}^{-2}.$$  \hspace{1cm} (3.4)
We need $\sigma_{thr}$ which is given by (3):

$$\sigma_{thr} = 4.84\pi \frac{M^2}{X_F} \exp\left(\frac{X_F}{2T_{th}}\right) GeV^{-2} .$$

(3.5)

Using the following input parameters; $E_{max} = 2.0 \times 10^{17}$ GeV , $X_F = 1.6$, $E = 1.6 \times 10^{17}$ Gev , $\gamma_B = \frac{X_F}{2\gamma_F} = 7.5$ and noting that 1 in $10^{19}$ collisions in the interaction region form flux tubes we see that $\sigma_{thr} \approx 1.52 \times 10^{-15}$ cm$^2$.

4.-Calculation of $n_{MM}$, $\phi_{MM}^{Roberts}$ and $\phi_{MM}^{Parker}$ and comparison of the fluxes

The number of Primordial Magnetic Monopole pairs produced in the early universe is given by:

$$n_{MM} = \sigma_{thr} \int dt \mathcal{L} .$$

(4.1)

For the Roberts Model then $n_{MM} = 1.2 \times 10^{13}$ , and the upper limit of the flux of primordial Magnetic monopole pairs in the universe, in the Roberts Model is given by the following Estimate (Here it must be noted that V for the very first cosmological inflationary period is used):

$$\phi_{MM}^{Roberts} = \frac{n_{MM}}{t_{universe} \times 4\pi \text{Sr}} \times \frac{1}{d_{universe}}$$

(4.2)

Where $t_{universe} = $ the age of the universe and $d_{universe} = $the diameter of the universe.

Now $t_{universe} \approx 4.34 \times 10^{17}$ sec and $d_{universe} \approx 1.68 \times 10^{13}$ cm so that $\phi_{MM}^{Roberts} \approx 1.3 \times 10^{-19}$ cm$^{-1}$ sec$^{-1}$

And $\phi_{MM}^{Parker} = 10^{-15}$ cm$^{-1}$ sec$^{-1}$.

5.- Concluding Remarks

$$\phi_{MM}^{Roberts} < \phi_{MM}^{Parker}$$

(5.1)

Is a physically reasonable and desirable result for reasons explained in this paper.

In this paper we have formulated a model for Primordial Magnetic Monopole pair production and shown that the results of this model are physically reasonable.

6.- References :

(2) E.J. Weinberg; Physics Letters 126B, no. 6 (1983).
(4) “[ ]” is the symbol for “the dimensions of” in this paper.
(5) L.E. Roberts; Frontiers of Science and Theory 1, no1,30 (2018).