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# 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 $M_{pair}$ = 2.0x$10^{17}$Gev is the relevant quantity to be included in our considerations here.

In a recent RHIC magnetic monopole $paper^{(3)}$ I determined a)$M_{pair}$ vs $T_0$ and b) $M_{pair}$ vs $\in_0$

Where $T_0$ and $\in_0$ 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 $\in_0$ 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 x $10^{13}$ 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

$$\varphi_{M\overline{M}}^{Roberts} = 1.3 \times 10^{-19} cm^{-1} sec^{-1} sr^{-1} \text{ which is less than } \varphi_{M\overline{M}}^{Parker} = 10^{-15} cm^{-1} sec^{-1} sr^{-1}$$

Where $\varphi_{M\overline{M}}^{Parker}$ is the Parker Bound. This is a reasonable result in that if $\varphi_{M\overline{M}}^{Roberts}$ 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 e 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 $T_{0,}$ $\in_0$ $and$ $V_0$ 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 $\#n_{pair}$ Is calculated. An upper limit to $\varphi_{M\overline{M}}^{Roberts}$ the flux of primordial magnetic monopole

Pairs, in the universe, is calculated and compared to the Parker Bound $\varphi_{M\overline{M}}^{Parker}$. In section 5 concluding remarks are given.

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

A knowledge of $T_0$ ,$\in_0$ and $V_0$ is necessary to begin to understand the properties of the interaction region immediately following the big $bang^{(4)}$. The mass $M_{pair}$ of the primordial Magnetic Monopole pairs $M_{pair}$ = 2 x $10^{17}$ Gev. In a previous $paper^{(3)}$ $T_0$ and $\in_0$ the temperature and energy density, respectively, necessary to form Magnetic Monopole pairs was computed. 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 $\in_0$ to find the values that were necessary to produce Primordial Magnetic Monopole pairs for our value of $M_{pair}$. From $T_0$and $\in_0$ 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 operant 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 isobaric ally against the envelope formed by the physical vacuum. Hence particles collide with 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 backwords to the energy density and temperature necessary to produce Primordial Magnetic Monopole pairs. From these we will calculate the Luminosity, Integrated-Luminosity and $\sigma_{thr}$ 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 $[\in_0] = \frac{Gev}{cm^3}$ .Now

$t_{flux\ tube}$ =time necessary for the vacuum to form an envelope= 4.0 x $10^{-20}$ sec so that:

$$\mathcal{L}' = \frac{\in_0}{t_{flux\ tube}} . \qquad (3.1)$$

We need a constant $\Omega$ such that $[\Omega] = \frac{cm}{Gev}$ and it is quite reasonable to choose:

$$\Omega = \frac{R_{up\ quark}}{M_{up\ quark}} \qquad (3.2)$$

Which has the numerical value $\Omega$ = 4.0 x $10^{-14}$ $cm/_{Gev}$. Hence we see that our result for the Effective Luminpisity is

$$\mathcal{L} = \Omega\mathcal{L}' = 4.0\ \text{x}10^{-14} \frac{\in_0}{t_{flux\ tube}} \quad (cm^{-2}sec^{-1}) . \qquad (3.3)$$

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 x $10^{17}$Gev is given by $\in 0$ = 8.0 x $10^{55}$ $Gev/_{cm^3}$ thus yielding $\mathcal{L}$=8.0 x $10^{61}$ $cm^{-2}$sec for the effective luminosity . Next we need the Integrated Luminosity. Firstly, extrapolations from reference (3) indicate that $T_0$ = 2.0 x $10^{15}$Gev while $V_0$ = 2.5 x $10^{-39}$ $cm^3$ .

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 = $10^{-35}$sec as the time for particle production to take place in the early universe. Hence the Integrated luminosity becomes:

$$\int dt\ \mathcal{L} = 8.0\ \text{x}\ 10^{27}\ cm^{-2} . \qquad (3.4)$$

We need $\sigma_{thr}$ which is given $by^{(3)}$ :

$$\sigma_{thr} = 4.84\pi\frac{M^2}{X_F}\boldsymbol{exp}\left(-\frac{X_F}{2T_0}\frac{E_{max}}{\gamma_B}\right)Gev^{-2} \quad . \qquad (3.5)$$

Using the following input parameters; $E_{max}$ =2.0 x $10^{17}$Gev , $X_F$ = 1.6, E = 1.6 x $10^{17}$ Gev , $\gamma_B = \frac{\gamma_0}{2\gamma_F}$ = 7.5 and noting that 1 in $10^{19}$ collisions in the interaction region form flux $tubes^{(5)}$ we see

That $\sigma_{thr} \approx 1.52 \text{ x}10^{-15}\ cm^2$ .

4.-Calculation of $\#\boldsymbol{n}_{\boldsymbol{M\overline{M}}}$ , $\boldsymbol{\varphi}_{\boldsymbol{M\overline{M}}}^{\boldsymbol{Roberts}}$ and $\boldsymbol{\varphi}_{\boldsymbol{M\overline{M}}}^{\boldsymbol{Parker}}$ and comparison of the fluxes

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

$$\#n_{M\overline{M}} = \sigma_{thr} \int dt\, \boldsymbol{\mathcal{L}} \quad . \qquad (4.1)$$

For the Roberts Model then $\#n_{M\overline{M}}$ = 1.2 x $10^{13}$ , 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):

$$\varphi_{M\overline{M}}^{Roberts} = \frac{\#n_{M\overline{M}}}{d_{universe}t_{universe}} \text{ x } \frac{1}{4\pi Sr} \qquad (4.2)$$

Where $t_{universe}$ = the age of the universe and $d_{universe}$ =the diameter of the universe. Now $t_{universe} \approx$ 4.34 x $10^{17}$sec and $d_{universe} \approx$ 1.68 x $10^{13}$cm so that $\varphi_{M\overline{M}}^{Roberts} \approx$1.3 x $10^{-19}\,\frac{cm^{-1}}{sec.Sr}$

And $\varphi_{M\overline{M}}^{Parker} = 10^{-15}\,\frac{cm^{-1}}{sec.Sr}$ .

5.- Concluding Remarks

$$\varphi_{M\overline{M}}^{Roberts} \;<\; \varphi_{M\overline{M}}^{Parker} \qquad (5.1)$$

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 :

(1) G. Lazarides; Physics Letters **94B**,no.2 (1980).
(2) E.J. Weinberg; Physics Letters **126B**,no. 6 (1983).
(3) L.E. Roberts; Nuovo Cimento **92A** , 247 (1986)
(4) "[ ]" is the symbol for "the dimensions of" in this paper.
(5) L.E. Roberts; Frontiers of Science and Theory *1*, no1,30 (2018).