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A1_8 Hunting for Monopoles ii. A retarding mechanism for magnetic charges

K. Flatt, M. Garreffa, W.H.A. Longman, S. Turnpenney

Department of Physics and Astronomy, University of Leicester. Leicester, LE1 7RH.

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Abstract

An earlier article in this journal discussed the possibility of detecting magnetic monopoles using a wire loop: when a magnetic monopole passes through the loop, a current is induced. It was remarked in that paper that a device to retard monopoles would be useful for assisting such searches. Here, we follow up this finding by investigating the feasibility of using a wire coil to perform such a task. It is found that such a device is unlikely given current technology given that the coil would carry over 100 A in the best case and 10^{16} A in the worst.

Magnetic monopoles are hypothetical particles with a quantised magnetic charge, similar to the pole of a bar magnet, and appear in many attempts at grand unified theories [1]. In an earlier paper in this issue, we used a toy model to understand the key features of detecting such a particle: a monopole passing through a wire loop of radius R would induce a current due to Faraday's Law. We were able to derive a relationship to describe how the current would behave with time, giving a curve that would be characterised by a time constant $\tau = R/v$ with v the speed with which the monopole passed through the detector [2]. In that paper, we remarked that for relativistic monopoles the time constant would be tiny and thus any detection would simply appears a spike in current. To give better confidence in readings, it would be advantageous to be able to retard the monopole so that the time constant is larger, hence giving a better characterised curve. Here we present one possible device to do this job. Inside a wire coil, a magnetic field is produced which is approximately constant and pointing along the axis of the coil. A monopole moving in such a field would thus experience a force against the direction of motion and be slowed down.

In order to find the current I which would need to pass through the coil to bring relativistic monopoles down to a speed practical for experimentation, we define a 'magnetic potential' V_B analogous to the standard electric potential. That is, the work per ampere-metre done by a monopole in a field $\vec{B}$ which would be given by

$$V_B = -\int \mathbf{B} \cdot d\mathbf{l}, \tag{1}$$

where $d\mathbf{l}$ is a length element and the integral is along the path taken. The total work ΔU done by a monopole of magnetic charge q_m along such a potential would hence be

$$\Delta U = q_m V_B. \tag{2}$$

Tipler and Mosca have provided an expression for the component of the magnetic field along the axis of a solenoid [3] of radius R (which need not necessarily be the same as the radius of the detector) and length L. Written in a co-ordinate system whereby the monopole enters the coil at $z = 0$, this is

$$B(z) = \frac{1}{2}\mu_0 n I \left(\frac{z}{\sqrt{(z^2 + R^2)}} + \frac{L - z}{\sqrt{((L - z)^2 + R^2)}} \right). \tag{3}$$

In this expression, μ_0 is the vacuum permeability; n is the number of turns per unit length of the coil; I is the current passing through the solenoid. The total work done by a monopole passing through the coil is hence

$$\Delta U = \frac{1}{2}\mu_0 n I \int_0^L \frac{z}{\sqrt{(z^2 + R^2)}} + \frac{L - z}{\sqrt{((L - z)^2 + R^2)}}\, dz. \tag{4}$$

There are two assumptions implicit in this calculation. Firstly, that the monopole is moving along the axis of the retarder. Secondly, that the magnetic field is only experienced by the monopole when it is inside the coil. The latter assumption can be justified by making the assumption that $L >> R$ so that the work done by the monopole while in the retarder is much more than that while it is approaching; the first is unimportant in a toy model where generalising the result would likely not elucidate the result and further.

When the integral in Eq. (4) is performed, the result is

$$\Delta U = q_m \mu_0 n L I. \tag{5}$$

The function of this device is to slow down relativistic monopoles so that they are travelling at a non-relativistic speed, which would improve the resolution of a detector. Work is done traversing the magnetic field, and this will result in a loss of kinetic energy. If the initial monopole is relativistic, it will have a kinetic energy similar to its rest mass m_m. This will be much larger than the final kinetic energy and so, as a first order approximation, $\Delta U = m_m c^2$ with c the speed of light. Rearranging Eq. (5), we require a current given by

$$I = \frac{m_m c^2}{q_m \mu_0 n L}. \tag{6}$$

We now require numerical values of the parameters in this result to get an approximate I. Firstly, we note that finding the minimum diameter copper wire for the coil will minimise the current required, as this will maximise the number of loops that the monopole travels through. The thinnest wire commercially available is 50 gauge copper wire which has a diameter of 0.025 mm [4] and so $n = 1/0.025\text{ mm} = 40000\text{ m}^{-1}$. We choose $L = 10$ m ; there is a balance between maximising L to minimise the current and the practicality of such a large structure. q_m is given by the Dirac quantisation condition - for more details on this see Rajante [1] or our first paper [2]. Numerically, the value of this is $q_m = 3.29 \times 10^-9\,\text{Am}$.

The most interesting quantity is the monopole mass - given that they are theoretical entities, there is no data on this value. However, we can take two possibilities as limiting case. The worst case scenario is that predicted by Hoof't and Polyakov, of $m_m = 10^{17}$ GeV . This is the Planck energy, for which our conventional understanding of physics breaks down. Experimentally, a lower limit on the mass is $m_m = 1$ TeV - this is the energy scale which we have probed up to without creating any monopoles [1].

For the upper mass limit, we find $I = 1.1 \times 10^{16}$ A and for the lower mass limit we find 110 A. Clearly the first of these is unfeasible and searching for such monopoles would require rethinking the detection mechanism. Initially, the second of these seems also to be impractical. However with the rise in supermaterials, it may be possible that ultrathin wire with diameters in the nanometre region will exist in the near future. Such wires would reduce the current required by a factor of 100, meaning that the proposed device may become viable. It should all be noted that the model proposed requires reducing the particle's entire momentum and this may not be required, so the result found is an overestimate.

To conclude, across two papers in this issue we have developed a model for detecting a single magnetic charge. In the first paper, the current induced in a copper loop by such a detector was calculated and it was remarked that decelerating the monopole would allow more confident detection to occur. Here, we proposed a mechanism for such a function, however found that it is would not be viable given current technological constraints. This simply highlights the difficulty in such searches which have been unsuccessful for around 70 years.

References

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[4] http://www.coilcraft.com/awg.cfm. Accessed: 28/10/14