Ball lightning as a possible manifestation of high-temperature superconductivity in Nature

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Abstract

In the superconducting medium the circular current supported by its own magnetic field can exist giving rise to the possible underlying mechanism for the ball lightning.

The example of such self-supporting object is provided by superconducting circular current around the tube of the torus as shown in Fig.1. The current consists of charged particles moving in a circle of radius \( r \). It is worth mentioning that such a motion is two-dimensional the necessary condition for the superconductivity \([1]\) thus being satisfied. The centrifugal force is balanced by the Lorentz one so

\[
\frac{m\gamma v^2}{r} = \mu \frac{e}{c} v H , \quad \gamma = (1 - \beta^2)^{-1/2}, \quad \beta = \frac{v}{c} ,
\]

where \( \mu \) is the magnetic permeability of the medium, \( m \) is the rest mass of the particle, \( e \) is its charge, and \( \gamma \) is the Lorentz factor. It must be taken into account because the ball lightning is luminous object the particle velocity \( v \) thus being close to the light one \( c \) (the radiation is synchrotronic in the case under consideration). The magnetic field within the tube of the torus is \([2]\)

\[
H = \frac{2I}{cR} .
\]

It is practically homogeneous when \( r \ll R \) thus ensuring the circular motion of the particles. The current strength \( I \) is

\[
I = \frac{Qv}{2\pi r} = \frac{ev}{2\pi r} N , \quad Q = Ne .
\]

\( Q \) and \( N \) being the total moving charge and the number of charged particles respectively.
Putting Eqs. (2) and (3) into Eq.(1) we obtain the following connection between the particle number \( N \) and the radius of the torus

\[ N = \frac{\pi mc^2 \gamma}{\mu e^2} R \tag{4} \]

and the following expression for the magnetic field

\[ H = \frac{mc^2 \gamma \beta}{e r} \tag{5} \]

The energy of the object under consideration is the sum of the magnetic field one

\[ E_m = 2\pi^2 r^2 R \frac{\mu}{8\pi} H^2 = \frac{\pi (\gamma - 1)(\gamma + 1)(mc^2)^2}{4\mu e^2} R \tag{6} \]

and the kinetic energy of the moving charges

\[ E_k = (\gamma - 1)mc^2 N = \frac{\pi \gamma (\gamma - 1)(mc^2)^2}{\mu e^2} R \tag{7} \]

the total energy thus being

\[ E = E_m + E_k = \frac{\pi (\gamma - 1)(5\gamma + 1)(mc^2)^2}{4\mu e^2} R \tag{8} \]

To get the expression (6) we used the relation \( \gamma^2 \beta^2 = \gamma^2 - 1 \), see Eq.(1).

The Lorentz factor \( \gamma \) can be determined from the observed angular frequency of the synchrotron radiation \[2\]

\[ \omega = \frac{2\pi c}{\lambda} = \frac{eH}{mc} \gamma^2 = \frac{\beta \gamma^3 c}{\mu r} = \frac{\gamma^2(\gamma^2 - 1)^{1/2} c}{\mu r} \tag{9} \]

In this way we get

\[ \gamma^2(\gamma^2 - 1)^{1/2} = \frac{2\pi r}{\lambda} \mu \tag{10} \]

where \( \lambda \) is the wavelength of the radiation. The intensity of the radiation is \[2\]

\[ S = \frac{2ce^4(\gamma^2 - 1)}{3(mc^2)^2} H^2 = \frac{2ce^2(\gamma^2 - 1)^2}{3\mu^2 r^2} \tag{11} \]

The calculations are performed assuming the charged particles to be electrons and putting \( \mu = 1 \). The average observed diameter of the ball lightning (hereafter BL’s) is 24 cm \[3\] \[4\], but twice as large diameters are also observed rather often \[4\] \[7\]. For this reason the results are obtained for both the \( R = 12 \text{ cm} \) and \( R = 24 \text{ cm} \) values of the
torus radius. The tube radii are quite arbitrarily chosen as $r = (1, 2, 3)\text{cm}$. It is worth mentioning in this connection that the sphere is not the only observed form of the BL’s: many different forms including the torus are also observed \[5\]. The intervals of the Lorentz factor values are determined for the visible light region running from $\lambda = 7 \cdot 10^{-5}\text{cm}$ (red) to $\lambda = 3.8 \cdot 10^{-5}\text{cm}$ (violet) because the observed BL colours cover all this region \[3\].

The results are shown in Table 1. Two features are important.

| $r$, cm | $\gamma$ | $E \cdot 10^3$, J | $S \cdot 10^{-9}$W |
|---------|----------|-----------------|-------------------|
| 1       | 44.8 ÷ 54.9 | 29 ÷ 43         | 58 ÷ 86           | 1.85 ÷ 4.18 |
| 2       | 56.4 ÷ 69.2 | 46 ÷ 69         | 92 ÷ 138          | 1.16 ÷ 2.64 |
| 3       | 64.6 ÷ 79.2 | 60 ÷ 91         | 120 ÷ 182         | 0.89 ÷ 2.01 |

a. The energies are rather large, being practically the same as the average value of 100 kJ for the outdoors observations of BL’s \[3\].

b. At the same time the intensity of the radiation is rather small. Both these features are characteristic for the exploding BL’s \[5\].

In this way we showed that the object with the similar properties to those of the exploding BL’s can exist in the superconducting medium (the superconductivity must be high-temperature since there is no reasons to assume the temperatures of BL’s to be low). We do not know whether such a medium arises in the atmospheric processes leading to the BL’s (this problem is out of the scope of the present work), but the above results suggest that the exploding BL’s may be a possible evidence of this phenomenon.

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Figure 1: The torus of radius $R$ and the tube radius $r$. The superconducting surface current is shown by arrows.