NOTIZEN

The Occurrence of Ultrastrong Magnetic Fields in Nuclear Shock Waves

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In fast heavy nucleus-nucleus collisions transient magnetic fields as high as $\sim 10^{18}$ Gauss are predicted. The occurrence of these superstrong magnetic fields may lead to the production of magnetic monopoles and to CP conservation with zero Cabibbo angle.

If large nuclei collide with a velocity large compared to the sound velocity in nuclear matter shock waves are predicted to develop [1]. Assuming for simplicity an ideal Fermi gas for the nuclear matter one would have to put for the specific heat ratio $\gamma = c_p/c_v = 5/3$. This would then lead to a density increase in the shock wave given by $n/n_0 = (\gamma+1)/(\gamma-1) = 4$, where $n_0 = r_0^{-3}$ is the equilibrium number density of the nucleons in nuclear matter, and $r_0 \cong 1.5 \times 10^{-13}$ cm.

Since the sound velocity in nuclear matter is of the order $\sim c/10$ (c velocity of light) heavy ions accelerated to several 100 MeV/nucleon would move with $v \cong c$, such that the Mach number would be of the order ~ 10.

If a heavy nucleus with radius R_0 is being shot onto another nucleus with radius R_1 such that $R_1 > R_0$, the penetration of the smaller nucleus into the larger one will result in a bow shock with the material in it moving at the velocity $v \cong c$ and with a density ~ 4 times nuclear density. This mass flow in the shock is accompanied by a proton current with a current density given by

$$j = n\,e\,v \cong 4\left(\frac{1}{2}\right) n_0\,e\,c = 2\,n_0\,e\,c\,, \qquad (1)$$

where the factor 1/2 takes into account that roughly only 1/2 of the nucleons in nuclear matter are protons. From Maxwell's equation

$$\left(\frac{4\pi}{c}\right)\boldsymbol{j} = \operatorname{curl}\boldsymbol{H} \qquad (2)$$

one then obtains for the magnetic field at the radial distance $r = R_0$ and which is the radius of the bow shock

$$H \cong 4\pi\,n_0\,e\,R_0\,. \qquad (3)$$

Putting $R_0 = r_0\,A^{1/3}$ and assuming $A \cong 200$ (atomic weight of nucleus with radius R_0) one obtains $H \cong 1.5 \times 10^{18}$ Gauss. This magnetic field is sustained for the time $\tau \sim 2\,R_0/c = 6 \times 10^{-23}$ sec.

It has been speculated by Schwinger [2] that the quarks are magnetic monopoles with a magnetic coupling constant $g^2/\hbar\,c = 137$. If this should be true then it may be difficult to separate the quarks by high energy collisions alone since there the kinetic energy for a minimal impact length r is determined by the uncertainty principle to be of the order $E_{\text{kin}} \cong \hbar\,c/r$ whereas the potential magnetic energy is given by $E_{\text{pot}} \cong g^2/r$, such that always $E_{\text{kin}}/E_{\text{pot}} = \hbar\,c/g^2 = 1/137 < 1$. However, bound monopoles with a mutual orbital radius r can be separated by a strong magnetic field $H \gtrsim g/r^2$. With $g^2/\hbar\,c = 137$ and $r = 1.5 \times 10^{-13}$ cm this field would be $H \gtrsim 2.9 \times 10^{18}$ Gauss and which is of the same order of magnitude as the magnetic field estimated above to be generated in a heavy nucleus-nucleus collision. In another speculation [3], where it was hypothesized that the quarks are magnetic monopoles endowed with negative mass, the required magnetic field for pulling the monopoles apart was estimated to be even less and of the order $\sim 10^{17}$ Gauss. If the quarks are bound magnetic monopoles their orbital velocity is of the order c and the characteristic orbital time given by $\tau_0 \cong 2\pi\,r/c \cong 2 \times 10^{-23}$ sec. It therefore follows that the duration of the magnetic field would be about three times longer than the orbital time and should be sufficiently long to separate the monopoles.

Finally we would like to call attention to a hypothesis by Salam and Strathdee [4] who showed that magnetic fields in excess of $\sim 10^{16}$ Gauss may affect a transition to CP conservation with zero Cabibbo angle.

In summary it can be stated that heavy ion accelerators open the prospect for the transient generation of ultrastrong magnetic fields in nuclear matter and which are otherwise unattainable. It is obvious that this may have other important consequences.

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