MAGNETIC FIELD GENERATION WITHIN MOLECULAR CLOUDS

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Abstract. Magnetic field generation in molecular (atomic) clouds at the early stages of galactic evolution is considered. It is shown that if there is no internal motions immersed the cloud, battery mechanisms (Lazarian 1992a) can account for the generation of thin magnetic shells around clouds insides in plasma with temperature gradients. If turbulent motions are present, the dynamo can be essential. The operation of $\alpha-\omega$, α^2 and turbulent dynamos within molecular clouds is discussed. It is shown that the turbulent dynamo leads to generation of magnetic fields in the trace behind the cloud. These magnetic fields within the molecular clouds and in their vicinity are important for the solution of the galactic seed field problem (see Lazarian 1992b) and the formation of structures in clumpy molecular complexes.

Key words: dynamo – molecular clouds – turbulence

1. Battery and dynamo mechanisms

Diffusion generated e.m.f. In the absence of turbulent motions, the magnetic field generated by diffusion *e.m.f.* (see Lazarian 19921a) is concentrated in the border area of plasma–molecular cloud. This magnetic field can be important for intergalactic clouds (Rees 1987). Such clouds are subjected to evaporation being in contact with a much hotter intercloud media (Sargent *et al.* 1980). As was pointed out by M. Rees, magnetic field that "brings the gyroradius ($\sim B^{-1}T^{-\frac{1}{2}}\ldots$) below the Coulomb collision length ($\sim n^{-1}T^{2}$)" can substantially inhibit thermal conductivity, resulting in the formation of cloud structures elongated along the direction of the field. The battery can be responsible for the generation of such a magnetic field, provided the temperature gradients of the order of 10^7 K exist in the hot media along the border with the intergalactic cloud.

$\alpha-\omega$ dynamo. A model of a clumpy flat molecular cloud is adopted here. In this model, cold clumps, supported by external pressure, move within a hot rarefied medium. As magnetic field lines cross clumps and the hot medium between them, they form a complex system. Therefore, as the clumps under the gravitational pool come closer to each other, they squeeze hot media in between. This results in inflating magnetic lines frozen in the hot medium over the plane of the cloud. Due to the fact that the magnetic field lines serve as a net for molecular material, the lines cannot escape the cloud altogether. The action of shear due to the differential rotation and the Coriolis force results in the exponential magnetic field amplification. A typical time of magnetic field generation, τ, is of order $3\cdot10^7$ years. In this model, dynamo numbers D_M are negative, and $|D_M|$ is greater than a threshold value ($5\div 10$).

If squeezing velocities v_s are greater than turbulent velocities v_t, then the maximum value of the magnetic field can be estimated as $\frac{B^2_{\max}}{8\pi}\sim \varrho v_s a_0\left(\frac{1}{f}\right)^{1/3}\omega$, where ϱ is the density of hot gas, a_0 is the size of a clump, f is the filling factor of the molecular cloud ($f\ll 1$)(see Elmegreen *et al.* 1992), and ω is an angular velocity.

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At some stage of the molecular cloud contraction the random velocity v_t increases. The more traditional $\alpha - \omega$ mechanism will also be active in a differentially rotating molecular cloud, as its density varies along the angular velocity direction (a pressure gradient in the hot phase is preserved because of magnetic field), and thus the turbulence is helical.

α^2 dynamo. Rough estimates show that the dynamo number for this mechanism is $\sim \frac{L}{l_T}$, where L is the characteristic scale associated with the cloud and l_T is the turbulence characteristic scale. This ratio is likely to be greater than a threshold value (≥ 5), and magnetic field generation is possible.

Turbulent dynamo. As a high speed clump moves through the ambient medium the turbulence velocity u decreases as $x^{-\frac{2}{3}}$ in its wake (from near the velocity of the clump u to $u \cdot \left(\frac{1}{f}\right)^{-6/15}$). Nonetheless in the vicinity of the clump and/or when the magnetic field is low, the magnetic Reynolds number $R_m \sim \frac{u a_0}{\nu_m}$ can be greater than a threshold value $\sim 20 \div 100$ (Kriolin *et al.* 1986) (ν_m is a magnetic diffusivity which for partially ionised media is $\sim 10^{20} \left(\frac{B}{1\mu\mathrm{G}}\right)^2 \frac{\mathrm{cm}^2}{\mathrm{s}}$, B is the magnetic field, while $au \sim 10^{22} \div 10^{23} \frac{\mathrm{cm}^2}{\mathrm{s}}$). Note that the ratio of the characteristic time of the collision t_s to the period t_p, in which the turbulent traces fill the volume inside the molecular cloud, is given by $\frac{t_p}{t_s} \sim \left(\frac{1}{f}\right)^{-2/5} \ll 1$).

Turbulent magnetic fields tend to form magnetic intermittent ropes on which then smaller clumps may condense forming filaments. Indeed, due to ambipolar diffusion a clump with a velocity component normal to the flux tube will let magnetic field inside, and also loose its normal velocity component. As a result clumps can stream along the direction of the flux tube visualising it.

Reconnection of magnetic fields. The mechanisms discussed above tend to form magnetic fields close to the equipartition value. If the reconnection happens, the appropriate temperature, T, is given by: $T \sim \frac{B^2}{nk} \sim 10^7 K \left(\frac{B}{10\mu\mathrm{G}}\right)^2 \left(\frac{10^{-2}\mathrm{cm}^{-3}}{n}\right)$. This can be an important heating mechanism for the rarefied media between the clumps.

Conclusions Processes of the magnetic field generation in molecular clouds are important at earlier stages of galactic evolution. Magnetic fields are generated at the time comparable with the free-fall time and help to solve the angular momentum problem for the molecular cloud (Bisnovatyi-Kogan *et al.* 1976) and solve seed field problem (Lazarian 1992b).

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