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PULSARS AS COSMIC RAY PARTICLE ACCELERATORS: Dynamics of Electrons

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ABSTRACT

The Lorentz-Dirac-equation with Landau-approximation has been solved numerically for electrons in the electromagnetic field of a magnetic dipole rotating with the angular velocity $\vec{\omega}$ perpendicular to its magnetic moment $\vec{\mu}$. Results are discussed with respect to electron orbits and energy development.

1. Introduction. Initial conditions are as in my preceding papers (Thielheim 1985 a,b). In the case of the perpendicular rotator, considered here, there is an additional symmetry for particles with opposite electric charge and equal rest mass. Although, of course, the rest mass of electrons and protons is different, this symmetry, nevertheless, may be helpful for comparisons between electron and proton orbits. By this symmetry, namely, corresponding orbits of particles with opposite charge and equal rest mass become identical through rotation of 180° around the axis of rotation (z-axis). The difference in rest mass between electrons and protons becomes irrelevant in the ultra relativistic regime as long as radiation reaction is negligible. In this context it is important to note that under the premises of model 1 and with the initial conditions applied here electrons as well as protons very rapidly become ultrarelativistic. Therefore in many cases corresponding electron and proton orbits respectively are quite similar in the initial stages of orbital motion. But then radiation reaction is, of course, much more important for electrons than for protons.

2. Electrons starting in the Distant Zone. The orbits of electrons starting in the distant zone are quite similar to the corresponding orbits of protons as can be seen from figure 1 showing electron orbits of initial radius $R_o = 3$ and initial latitude $\theta_o = 7^{\circ}$. The maximum energy of electrons originating from this initial radius $R_o = 3$ and different values of initial latitude ($\theta_o = 1^{\circ}, 2^{\circ}, 3^{\circ}, 4^{\circ}, 5^{\circ}, 6^{\circ}, 7^{\circ}$ and 8°) is shown as a function of initial longitude ϕ_o in figure 2. Electrons starting near the equator

of rotation (e.g. for $\theta_o = 70^o$ corresponding to the orbits in figure 1) show a larger maximum near $\phi_o = 180^o$ and a smaller maximum near $\phi_o = 45^o$. This asymmetry between the two maxima is much more pronounced in electron orbits than in proton orbits. Maximum energy may exceed 10^8 times the rest energy of electrons giving rise to spectecular radiation reaction effects when accelerating forces perpendicular to the velocity vector become important. This is illustrated clearly by figure 3 in which the energy development on some electron orbits with $R_o = 3$ and $\theta_o = 50^o$ is shown as a function of time. On any of these orbits there is a very strong increase of electron energy with time in the early stages of orbital motion. But then in certain ranges of initial longitude (e.g. for $\phi_o = 40^o, 120^o$ and 160^o) electron energy continues to increase further monotonically, while in other ranges of initial longitude (e.g. for $\phi_o = 300^o$ and 320^o) electron energy may even decrease depending of the field configurations these particles run into.

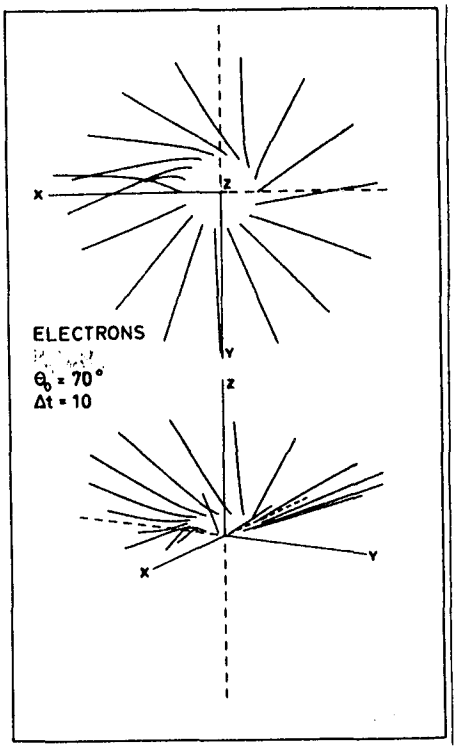

figure 1

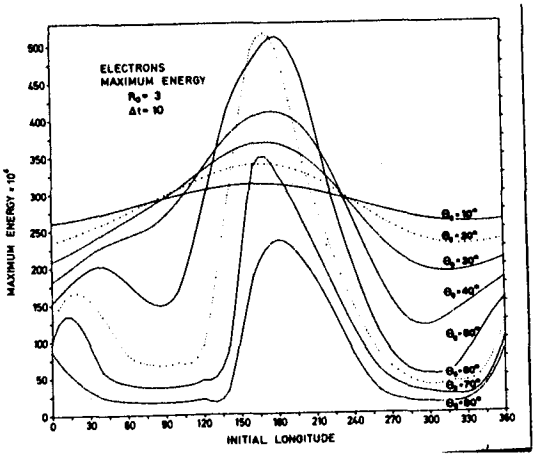

figure 2

3. Electrons starting in the Near Zone. The critical surface (separating initial points of orbits leading to the surface R_p=10km from

those leading to infinity) does not seen to be very different for electrons than for protons (after rotation by 180° around the z-axis, of course). Maximum energy R_o=2.2 and R_o=1.8 leads to values well above 10 times the rest energy. In those examples for particles starting in the equatorial zone (with respect to rotation) there is a larger maximum around ϕ_o =27° and a smaller maximum around ϕ_o =7°. For R_o=1.8 there are electrons running inwardly as can be seen for Θ_o=7° in figure 6. These orbits appear to be more curled than the corresponding ones of protons. The double maximum structure of electron energy resembling the double maximum structure observed in pulsar radiation appears to be an interesting feature of the pre - sent calculations. Finally it should be mentioned that considerably higher particle energies can be expected for other parameters concerning the rotating dipole.

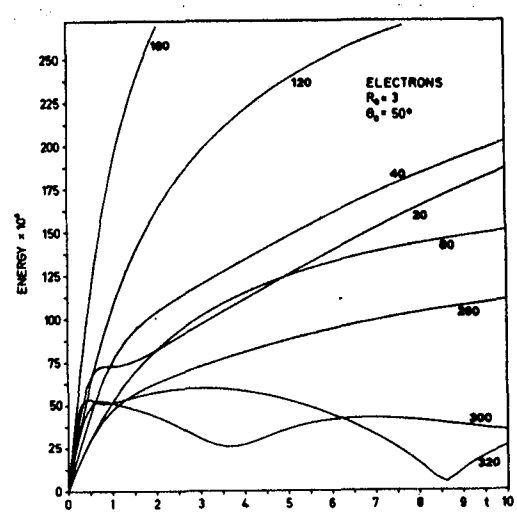

figure 3

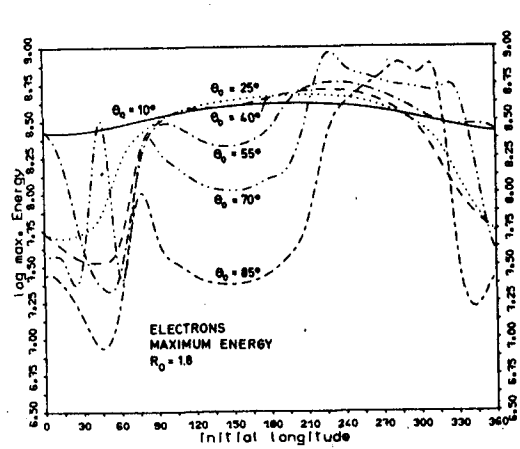

figure 4

References.
K.O.Thielheim (1985a) oG 8.2-21 this conference. (1985b) oG 8.2-22 this conference.

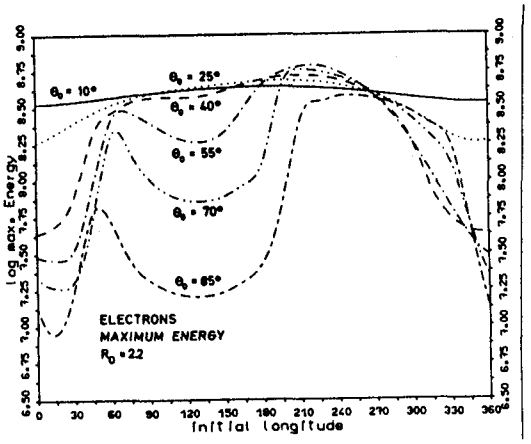

figure 5

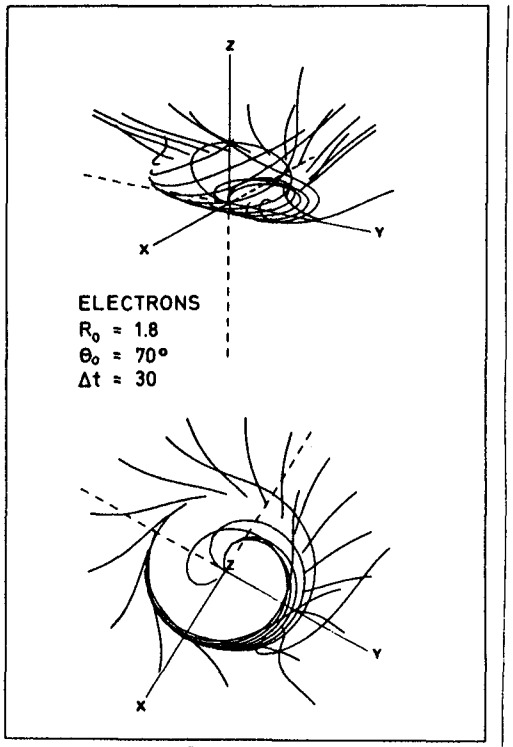

figure 6