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Heat and charge transport in envelopes of weakly and strongly magnetized neutron stars

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Abstract. Thermal and electrical electron conductivities are calculated for a broad range of physical parameters typical for envelopes of neutron stars. An appropriate effective electron-ion scattering potential is used, based on calculations involving modified ion structure factors suggested recently for the treatment of the transport problems in dense Coulomb plasmas. These results are applied to calculation of the thermal structure of neutron-star envelopes.

Electron conduction is the most important process that determines thermal structure and magnetic evolution of neutron stars. In dense, strongly coupled Coulomb plasmas, typical of neutron-star envelopes, the conduction depends mainly on electron scattering off ions (off phonons in the crystalline phase). Recently, its treatment has been considerably improved, and appropriate ionic structure factors have been derived (Baiko et al. 1998).

This breakthrough in the theory has been used in our numerical calculations of the electron conduction in neutron-star envelopes and white-dwarf interiors. In the non-magnetic case, we have devised an effective scatering potential which, when used in the relaxation-time approximation, yields analytic expressions that accurately fit our numerical results (Potekhin et al. 1999). Furthermore, this effective potential has been used at arbitrary magnetic fields in order to derive practical expressions for evaluation of electrical and thermal conductivities and thermopower of degenerate electrons in magnetized neutron-star envelopes. All tensor components of the kinetic coefficients in magnetic fields have been calculated and fitted by analytic formulas (Potekhin 1999).

Here these results are applied to a study of the thermal structure of a neutron-star envelope composed of iron. We use the mean-ion approximation for both the conductive and radiative opacities. The mean ion charge is estimated from the equation of state (EOS) following Potekhin, Chabrier, & Yakovlev (1997). In the magnetic case, the EOS by Thorolfsson et al. (1998) is employed. The figure shows temperature profiles obtained for *surface* temperature T_s fixed at 5×10^5 K and 2×10^6 K, for several values of magnetic field strength B and inclination angle θ. Unlike a very simplified analytic model by Heyl & Hernquist (1998), the present treatment is not restricted to the outermost layers $\rho < \rho_B$ where the field is strongly quantizing: the temperature profiles are traced up to the true isothermal region. In the non-magnetic case, more accurate profiles (shown by dotted lines on the left panel) have been obtained with using the OPAL radiative opacities (Iglesias & Rogers 1996) instead of the mean-ion ones. In spite of the considerable divergence at low density, the inner temperature T_i turns out to be nearly independent of radiative opacities used.

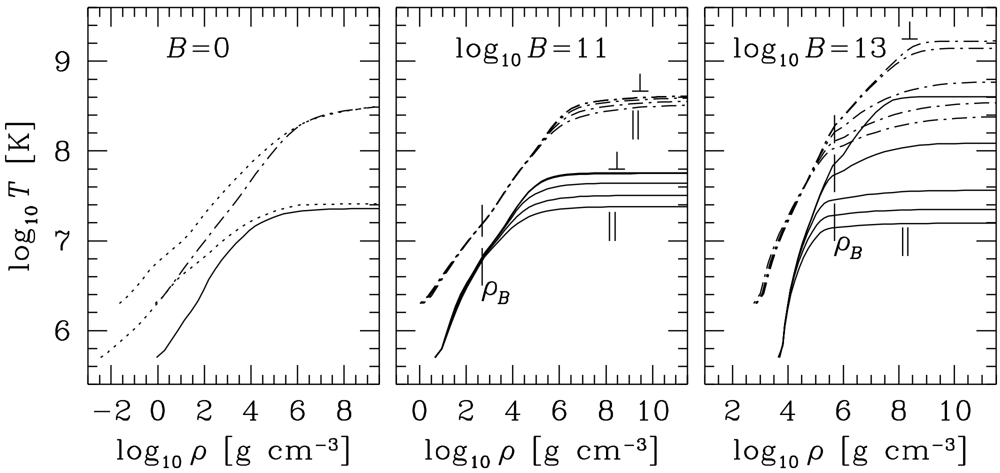

Figure 1. Temperature profiles through an iron envelope of a neutron star with surface gravity $g_s = 10^{14}$ cm s^{-2}, effective surface temperature $T_s = 5 \times 10^5$ K (solid lines) and 2×10^6 K (dot-dashed lines), and magnetic field strength $B = 0$ (left), 10^{11} G (middle), or 10^{13} G (right) in the mean-ion approximation. Dotted lines on the left panel result from replacing the mean-ion radiative opacities by the OPAL ones. On the middle and right panels, different lines in each bunch show different magnetic field inclinations: $\cos\theta = 0$ ($\perp$) 0.1, 0.4, 0.7, and 1 ($\|$). The vertical dashes mark the density ρ_B at which the first Landau level starts to be populated.

While modeling neutron-star evolution, one needs to know T_s as a function of T_i. At $B = 0$, this function has been obtained by Potekhin et al. (1997) for non-accreted (iron) and accreted neutron-star envelopes. For a non-accreted envelope and arbitrary B and θ, a simple analytic fit to the ratio $T_s(T_i, B, \theta)/T_s(T_i, B = 0)$ is now available by e-mail: palex@astro.ioffe.rssi.ru.

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