Atmospheres and Spectra of Magnetic Neutron Stars

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We construct atmosphere models for strongly magnetized neutron stars with surface fields $B \sim 10^{12} - 10^{15}$ G and effective temperatures $T_{\rm eff} \sim 10^6 - 10^7$ K. The atmospheres directly determine the characteristics of thermal emission from isolated neutron stars, including radio pulsars, soft gamma-ray repeaters, and anomalous X-ray pulsars. In our models, the atmosphere is composed of pure hydrogen or helium and is assumed to be fully ionized. The radiative opacities include free-free absorption and scattering by both electrons and ions computed for the two photon polarization modes in the magnetized electron-ion plasma. We describe a modified (due to the two photon modes) Unsöld-Lucy temperature correction method to establish radiative equilibrium and the resulting temperature profile. We discuss the effect of vacuum polarization, which modifies the dielectric property of the medium and gives rise to a resonance feature in the opacity; this feature is narrow and occurs at a photon energy that depends on the plasma density. Vacuum polarization can also induce resonant conversion of photon modes via a mechanism analogous to the MSW mechanism for neutrino oscillation. We discuss the subtleties in treating the vacuum polarization effects. We show that vacuum polarization produces a broad depression in the X-ray flux at high energies, which arises from the density dependence of the vacuum resonance feature and the large density gradient present in the atmosphere, and the depression of continuum flux strongly suppresses the equivalent width of the ion cyclotron line.