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Neutrino-nucleon interactions in magnetized neutron-star matter: The effects of parity violation. Phil Arras and Dong Lai, *Center for Radiophysics and Space Research, Space Sciences Building, Cornell University, Ithaca, New York 14853*. (Received 24 November 1998; published 22 July 1999)

We study neutrino-nucleon scattering and absorption in a dense, magnetized nuclear medium. These are the most important sources of neutrino opacity governing the cooling of a proto-neutron star in the first tens of seconds after its formation. Because the weak interaction is parity violating, the absorption and scattering cross sections depend asymmetrically on the directions of the neutrino momenta with respect to the magnetic field. We develop the moment formalism of neutrino transport in the presence of such asymmetric opacities and derive explicit expressions for the neutrino flux and other angular moments of the Boltzmann transport equation. For a given neutrino species, there is a drift flux of neutrinos along the magnetic field in addition to the usual diffusive flux. This drift flux depends on the deviation of the neutrino distribution function from thermal equilibrium. Hence, despite the fact that the neutrino cross sections are asymmetric throughout the star, the asymmetric neutrino flux can be generated only in the outer region of the proto-neutron star where the neutrino distribution deviates significantly from thermal equilibrium. The deviation from equilibrium is similarly altered by the asymmetric scattering and absorption, although its magnitude will still be quite small in the interior of the star. We clarify two reasons why previous studies have led to misleading results. First, inelasticity must be included in the phase space integrals in order to satisfy detail balance. Second, nucleon recoil must be included in order to find the leading order asymmetric cross sections correctly, even though it can be ignored to leading order to get the zero field opacities. In addition to the asymmetric absorption opacity arising from nucleon polarization, we also derive the contribution of the electron (or positron) ground state Landau level. For neutrinos of energy less than a few times the temperature, this is the dominant source of asymmetric opacity. Last, we discuss the implication of our result to the origin of pulsar kicks: in order to generate kick velocity of a few hundred km s^{-1} from asymmetric neutrino emission using the parity violation effect, the proto-neutron star must have a dipole magnetic field of at least 10^{15} – 10^{16} G. [S0556-2821(99)02616-8] [Phys. Rev. D **60**, 043001 (1999)]

Angular distribution of neutron inverse beta decay, $\bar{\nu}_e + p \rightarrow e^+ + n$. P. Vogel and J. F. Beacom, *Physics Department 161-33, California Institute of Technology, Pasadena, California 91125*. (Received 1 April 1999; published 27 July 1999)

The reaction $\bar{\nu}_e + p \rightarrow e^+ + n$ is very important for low-energy ($E_\nu \lesssim 60$ MeV) antineutrino experiments. In this paper we calculate the positron angular distribution, which at low energies is slightly backward. We show that weak magnetism and recoil corrections have a large effect on the angular distribution, making it

isotropic at about 15 MeV and slightly forward at higher energies. We also show that the behavior of the cross section and the angular distribution can be well understood analytically for $E_\nu \lesssim 60$ MeV by calculating to $\mathcal{O}(1/M)$, where M is the nucleon mass. The correct angular distribution is useful for separating $\bar{\nu}_e + p \rightarrow e^+ + n$ events from other reactions and detector backgrounds, as well as for possible localization of the source (e.g., a supernova) direction. We comment on how similar corrections appear for the lepton angular distributions in the deuteron breakup reactions $\bar{\nu}_e + d \rightarrow e^+ + n + n$ and $\nu_e + d \rightarrow e^- + p + p$. Finally, in the reaction $\bar{\nu}_e + p \rightarrow e^+ + n$, the angular distribution of the outgoing neutrons is strongly forward peaked, leading to a measurable separation in positron and neutron detection points, also potentially useful for rejecting backgrounds or locating the source direction. [S0556-2821(99)04015-1] [Phys. Rev. D **60**, 053003 (1999)]

Testing violations of special and general relativity through the energy dependence of $\nu_\mu \leftrightarrow \nu_\tau$ oscillations in the Super-Kamiokande atmospheric neutrino experiment. G. L. Fogli, E. Lisi, A. Marrone, and G. Scioscia, *Dipartimento di Fisica and Sezione INFN di Bari, Via Amendola 173, I-70126 Bari, Italy*. (Received 6 April 1999; published 28 July 1999)

The atmospheric neutrino data collected by the Super-Kamiokande experiment span about four decades in neutrino energy E , and are thus appropriate to probe the energy dependence of the oscillation wavelength λ associated with $\nu_\mu \leftrightarrow \nu_\tau$ flavor transitions, when these are assumed to explain the data. Such a dependence takes the form $\lambda^{-1} \propto E^n$ in a wide class of theoretical models, including “standard” oscillations due to neutrino mass and mixing ($n = -1$), energy-independent oscillations ($n = 0$), and violations of the equivalence principle or of Lorentz invariance ($n = 1$). We study first how the theoretical zenith distributions of sub-GeV, multi-GeV, and upward-going muon events change for different integer values of n . Then we perform a detailed analysis of the Super-Kamiokande data by treating the energy exponent n as a free parameter, with unconstrained scale factors for both the amplitude and the phase of $\nu_\mu \leftrightarrow \nu_\tau$ oscillations. We find a best-fit range $n = -0.9 \pm 0.4$ at 90% C.L., which confirms the standard scenario ($n = -1$) as the dominant oscillation mechanism, and strongly constrains possible concurrent exotic processes ($n \neq -1$). In particular, we work out the interesting case of leading standard oscillations plus subleading terms induced by violations of special or general relativity principles, and obtain extremely stringent upper bounds on the amplitude of such violations in the (ν_μ, ν_τ) sector. [S0556-2821(99)03115-X] [Phys. Rev. D **60**, 053006 (1999)]

Free energy of bubbles and droplets in the quark-hadron phase transition. Gregers Neergaard and Jes Madsen, *Institute of Physics and Astronomy, University of Aarhus, DK-8000 Århus C, Denmark*. (Received 8 March 1999; published 28 July 1999)

Using the MIT bag model, we calculate the free energy of droplets of a quark-gluon plasma in a bulk hadronic medium, and of hadronic bubbles in a bulk quark-gluon plasma, under the assumption of vanishing chemical potentials. We investigate the validity of the multiple reflection expansion approximation, and we devise a novel procedure for calculating finite-size corrections to the free energy of hadronic bubbles in a bulk quark-gluon plasma. While our results agree largely with earlier calculations, we show that the usual multiple reflection expansion should be used with caution, and we propose a modification of the multiple reflection expansion, which makes this approximation agree nicely with direct numerical calculations. The results should be of relevance in connection with the cosmological quark-hadron transition as well as for ultrarelativistic heavy ion collisions. [S0556-2821(99)03815-1] [Phys. Rev. D **60**, 054011 (1999)]

Beyond the adiabatic approximation: The impact of thresholds on the hadronic spectrum. Nathan Isgur, *Jefferson Lab, 12000 Jefferson Avenue, Newport News, Virginia 23606.* (Received 14 January 1999; revised manuscript received 12 May 1999; published 28 July 1999)

In the adiabatic approximation, most of the effects of $q\bar{q}$ loops on spectroscopy can be absorbed into a static interquark potential. I develop a formalism which can be used to treat the residual non-adiabatic effects associated with the presence of nearby hadronic thresholds for heavy quarks. I then define a potential which includes additional high energy corrections to the adiabatic limit which would be present for finite quark masses. This “improved” potential allows a systematic low energy expansion of the impact of thresholds on hadronic spectra. [S0556-2821(99)06315-8] [Phys. Rev. D **60**, 054013 (1999)]

Chiral symmetry and the delta-nucleon transition form factors. G. C. Gellas,¹ T. R. Hemmert,² C. N. Ktorides,¹ and G. I. Poulis,^{1,3}
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The three complex form factors entering the $\Delta \rightarrow N\gamma^*$ vertex are calculated to $\mathcal{O}(\epsilon^3)$ in the framework of a chiral effective theory with explicit $\Delta(1232)$ degrees of freedom included. It is shown that the low q^2 behavior of the form factors is governed by πN , $\pi\Delta$ loop effects. Predictions are given for the q^2 dependence of the three transition multipoles $M1(q^2)$, $E2(q^2)$, $C2(q^2)$. Furthermore, the role of the presently unknown low energy constants that affect the values of the multipole ratios $\text{EMR}(q^2)$ and $\text{CMR}(q^2)$ is elucidated. [S0556-2821(99)04215-0] [Phys. Rev. D **60**, 054022 (1999)]

Diffraction structure function in a quasiclassical approximation. Yuri V. Kovchegov and Larry McLerran, *School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455.* (Received 4 March 1999; published 9 August 1999)

We derive an expression for the diffractive F_2 structure function which should be valid at small x for quasielastic scattering on a

hadron and for quasielastic scattering on a large nucleus. This expression includes multiple rescatterings of the quark-antiquark pair produced by the virtual photon off the sources of color charge in a quasiclassical approximation. We find that there is a relation between such diffractive production and inclusive processes. In the former, one averages over all colors of sources before squaring the amplitude, and in the latter one first squares the amplitude and then averages it in the hadron or nuclear wave function. We show that in the limit of a large virtuality of the photon Q^2 the diffractive structure function becomes linearly proportional to the gluon distribution of the hadron or nucleus, therefore proving that in this sense diffraction is a leading twist effect. [S0556-2821(99)02915-X] [Phys. Rev. D **60**, 054025 (1999)]

Dynamical renormalization group resummation of finite temperature infrared divergences. D. Boyanovsky,^{1,2} H. J. de Vega,^{2,1} R. Holman,³ and M. Simonato,^{2,4}
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We introduce the method of dynamical renormalization group to study relaxation and damping out of equilibrium directly in real time and apply it to the study of infrared divergences in scalar QED. This method allows a consistent resummation of infrared effects associated with the exchange of quasistatic transverse photons and leads to anomalous logarithmic relaxation of the form $e^{-\alpha T t \ln[t/t_0]}$ for hard momentum charged excitations. This is in contrast with the usual quasiparticle interpretation of charged collective excitations at finite temperature in the sense of exponential relaxation of a narrow width resonance for which the width is the imaginary part of the self-energy on shell. In the case of narrow resonances away from thresholds, this approach leads to the usual exponential relaxation. The hard thermal loop resummation program is incorporated consistently into the dynamical renormalization group yielding a picture of relaxation and damping phenomena in a plasma in real time that transcends the conceptual limitations of the quasiparticle picture and other types of resummation schemes. [S0556-2821(99)02516-3] [Phys. Rev. D **60**, 065003 (1999)]

⁸B-neutrino spectrum. Veríssimo M. de Aquino and Moacyr Canaves, Jr., *Departamento de Física, Universidade Estadual de Londrina, 86051-970 Londrina-Pr., Brazil.* (Received 11 December 1998; published 24 August 1999)

Motivated by the possibility of new and more accurate data about the flux of solar neutrinos and the neutrino spectrum in future SuperKamiokande experiments, we present in this paper the deformations produced in the spectrum of ⁸B neutrinos when oscillations have been taken into account. The results are presented for mixing angles ω in the range $0.0006 < \sin^2 \omega < 0.347$, the differences of the squared masses $4.4 \times 10^{-5} \text{ eV}^2 > \Delta = m_2^2 - m_1^2 > 7 \times 10^{-8} \text{ eV}^2$, and for some values of the mixing angle ϕ and the squared mass m_3^2 . The degenerate case is analyzed as the two-neutrino case. [S0556-2821(99)06413-9] [Phys. Rev. D **60**, 073001 (1999)]