Relativistic mean-field approach to nuclear surface properties in semi-infinite system

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In this report, we study the characteristic properties of the nuclear surface in the semi-infinite system within the relativistic mean field approximation. Especially we investigate the effects of the pion mean field on the nuclear suraface properties. In the framework of the relativistic mean field theory Boguta and Bodmer were the first to analyze semi-infinite nuclear matter with $\sigma - \omega$ Lagrangian [1] and Hofer and Stocker [2] analyzed again in more sophisticated way. But the effects of the finite pion mean field on the nuclear surface properties have been not studied.

We employ an original Walecka model Lagrangian density with self coupling cubic and quartic terms in the $\sigma-$ field, and $\pi-$ field which couples to the Dirac field in the pseudovector form. In the semi-infinite system we can write the Dirac field as

$$\phi_{\mathbf{k}}(\mathbf{x}) = \exp(i\mathbf{k}_\perp \cdot \mathbf{x}_\perp)\phi_{\mathbf{k}}(z) \tag{1}$$

because of translational invariance in the transverse direction $\mathbf{x}_\perp$. We get then the Dirac equation on $\phi_{\mathbf{k}}(z)$ as

$$\left\{-i\alpha_3\frac{d}{dz} + \vec{\alpha_\perp}\cdot\vec{k_\perp} + \beta(M + g_\sigma\sigma) + g_\omega V_0 + \lambda g_\pi \gamma_5 \alpha_3 \left(\frac{d\pi}{dz}\right)\right\}\phi_{\mathbf{k}}(z) = E\phi_{\mathbf{k}}(z) \quad . \tag{2}$$

The boundary conditions are

$$\phi_{\mathbf{k}}(z) \to 0 \qquad for \quad z \to \ +\infty \tag{3}$$

$$\phi_{\mathbf{k}}(z) \quad \to \exp(ik_z z) + B(k_\perp, k_z)\exp(-ik_z z) \quad for \quad z \to \ -\infty \tag{4}$$

where $B(k_\perp, k_z)$ are reflection coefficients. Using the calculated Dirac fields we get several densities and the relevant meson fields successively. The mean field approach for the semi-infinite nuclear matter are solved numerically by iteration to obtain satisfactory self-consistency. Nuclear surface properties characterized by two quantities : surface energy coefficient(a_s) and surface thickness (t), which empirical values are $a_s = 19 \pm 1[MeV]$ and $t = 2.2 \pm 0.1[fm]$. Our preliminary results are listed in the Table 1. In all parameter sets the effects of the pion mean field are very small because the nuclear puedovector density which couples to the pion field are small nevertheless the vector and scalar densities fluctuate near the nuclear surface. Accordingly it is difficult to find the suitable parameter set which reproduce the matter saturation properties and the nuclear surface properties within this framework.

Table 1: Results for the surface energy coefficient a_s and the surface thickness t

	a_s[MeV](with pion)	a_s[MeV](without)	t[fm] (with pion)	t [fm](without)
PW1	31.26	31.26	2.40	2.35
PW2	15.04	15.23	1.50	1.50
PB1	15.60	15.65	3.05	3.05
PB2	15.71	15.75	3.05	3.05

Table 2: Parameters sets used this report. $C_s = M(g_\sigma/m_\sigma)$, $C_v = M(g_\omega/m_\omega)$. b and c are the coefficients of cubic and quartic term in $\sigma-$ field respectively. K and E/A represent the compressibility coefficient and saturation energy calculated by using each parameter set respectively.

	C_s	C_v	b	c	M_σ[MeV]	K[MeV]	E/A[MeV]
PW1	16.36	14.01	0	0	450	544.8	-15.83
PW2	16.36	14.01	0	0	600	544.8	-15.83
PB1	8.0	0.0	0.482	10.164	200	90.37	-16.77
PB2	8.0	1.0	0.445	9.465	200	95.35	-15.78

References

[1] J. Boguta and A. R. Bodmer Nucl. Phys. **A292**, 413 (1977).
[2] D. Hofer and W. Stocker Nucl. Phys. **A492**,637 (1989).