Zjazd CAMK
Sprawozdanie za 2023 rok

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CAMK
1 lutego 2024

NS crust

- Nuclei - outer crust - up to density $\rho \sim 10^{11}$ g/cm^3 , pressure $P \sim 10^{29}$ erg/cm^3- experimentally available (measured).
  Mass $\Delta M < 10^{-5} M_\odot$, thickness $\Delta R \sim 400$ m.
- NS -inner part of the outer crust, inner crust, core - based on the theory of dense matter and extrapolation of nuclear properties measurements
- Catalyzed crust - global minimum of energy, all reactions leading to a lower energy of the system allowed
- Accreted crust - temperature too low to reach global equilibrium (thermonuclear reactions blocked) local equilibrium at fixed number of nuclei - local energy minimum (additional constraints in thermodynamic equilibrium)

Compression of the crust

- Minimising of energy - assuming very fast reactions
- At any moment matter is in (local) equilibrium.
- Single nucleus approximation

$$\Downarrow$$

- Reaction layer defined by
  - macroscopic processes (accretion, compresion)
  - microscopic processes (reaction rate)
- How large is reaction layer ?

Layers of electron captures in the crust of accreting neutron stars

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Reaction layer

$$(A, Z) + e^- \to (A, Z-1) + \nu \quad \text{slow} \ ,$$
$$(A, Z-1) + e^- \to (A, Z-2) + \nu \quad \text{fast}$$

Continuity equation

$$\partial_\tau (nX) + \ \partial_z (vnX) = -nX\mathscr{R}_{\rm ec} \ .$$

$\tau_{\rm acc}$ the accretion timescale

$$\tau_{\rm acc}(t) = \frac{4\pi R^4 P_{\rm th}}{GM\dot{M}(t)} \ ;$$

$$\frac{\partial}{\partial t} \ln \left(n \ X\right) + \frac{1}{\tau_{\rm acc}(t)} \frac{\partial \ln X}{\partial \tilde{P}} = -\mathscr{R}_{\rm ec}$$

Mixture of two nuclides (isobars)

Parent nuclei $N_0 \quad (A, Z)$

Grand-daughter nuclei $N_2 \quad (A, Z-2)$

$$X = \frac{N_0}{N_0 + N_2}$$

Linear mixing rule:

$$P_{\rm lat} = -0.3 \left(\frac{4\pi}{3}\right)^{1/3} n_e^{4/3} \ e^2 \ \mathcal{F}(X)$$

$$\mathcal{F}(X) = \frac{(Z_0-2)^{5/3} + X\left[Z_0^{5/3} - (Z_0-2)^{5/3}\right]}{Z_0 + 2 \ (X-1)}$$

$$n(P, X) = \frac{n_e(P, X) \ A}{X Z_0 + (1-X)(Z_0-2)}$$

Evolution of the reaction layer

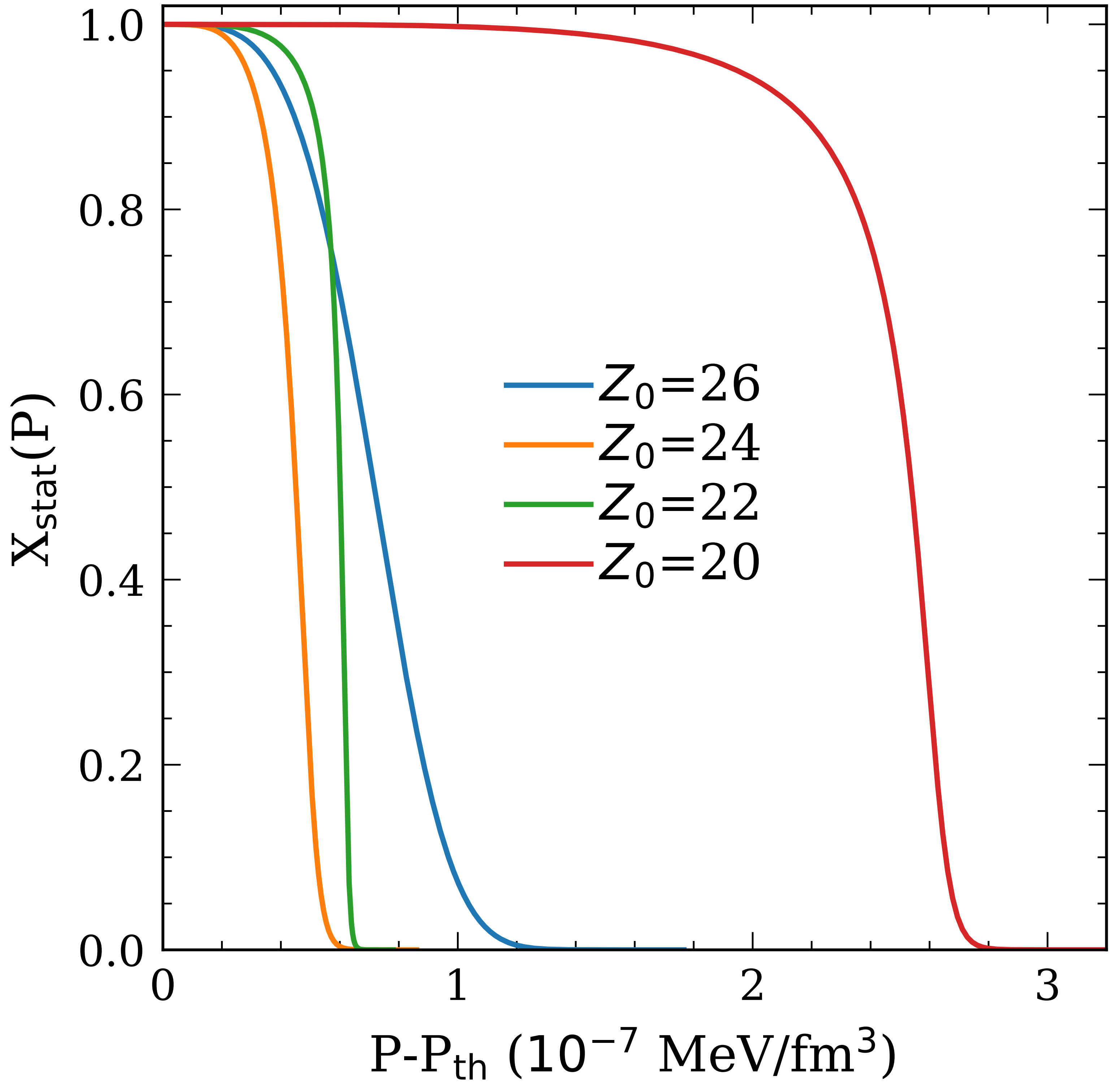
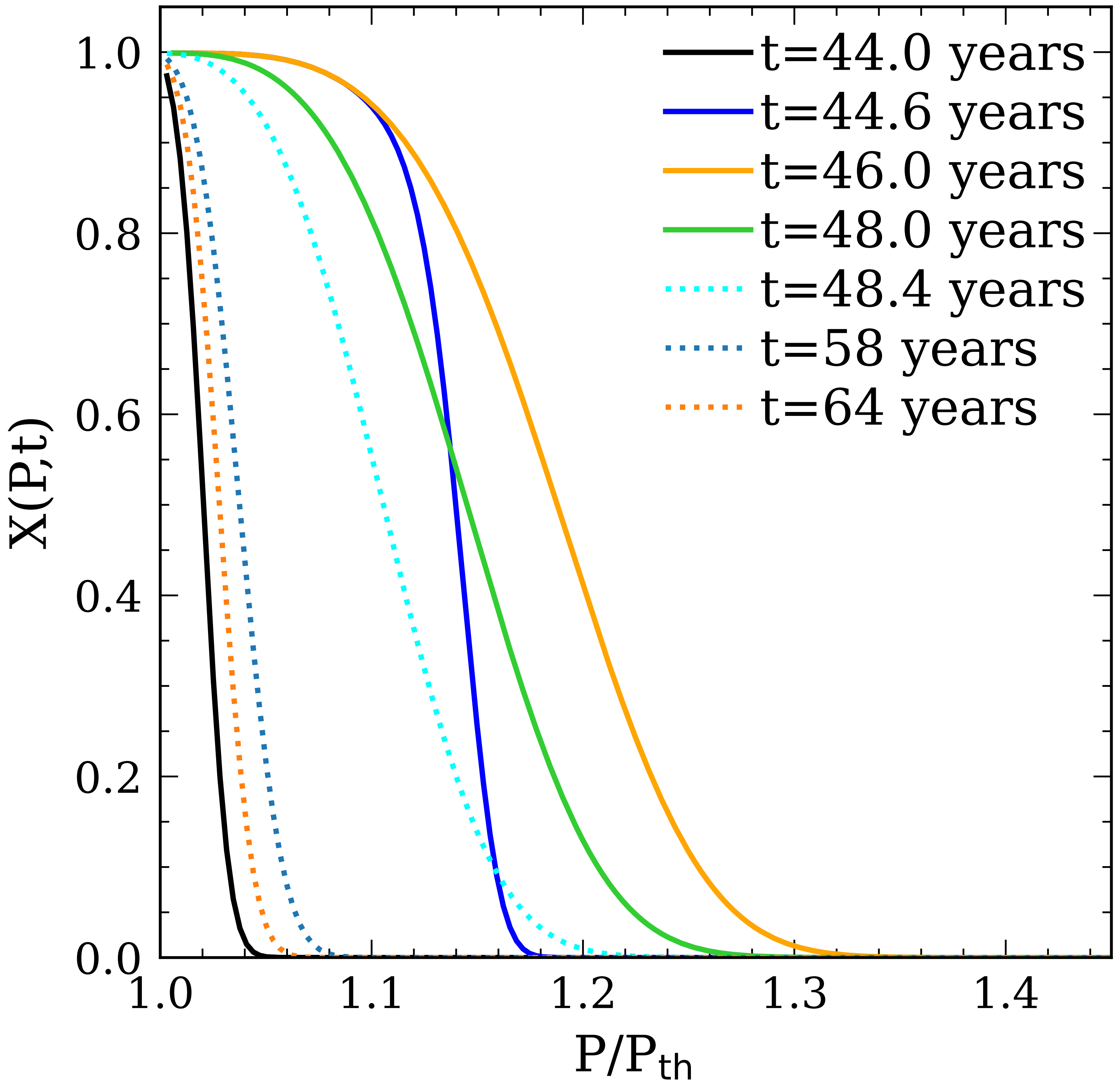


Fig. 1: Stationary solution for the parent nucleus abundance X as a function of the pressure for the four reactions in the outer crust.



(a) $\dot{M}_{max} = 10^{-8}$ $M_\odot$ per year.

Reaction layer

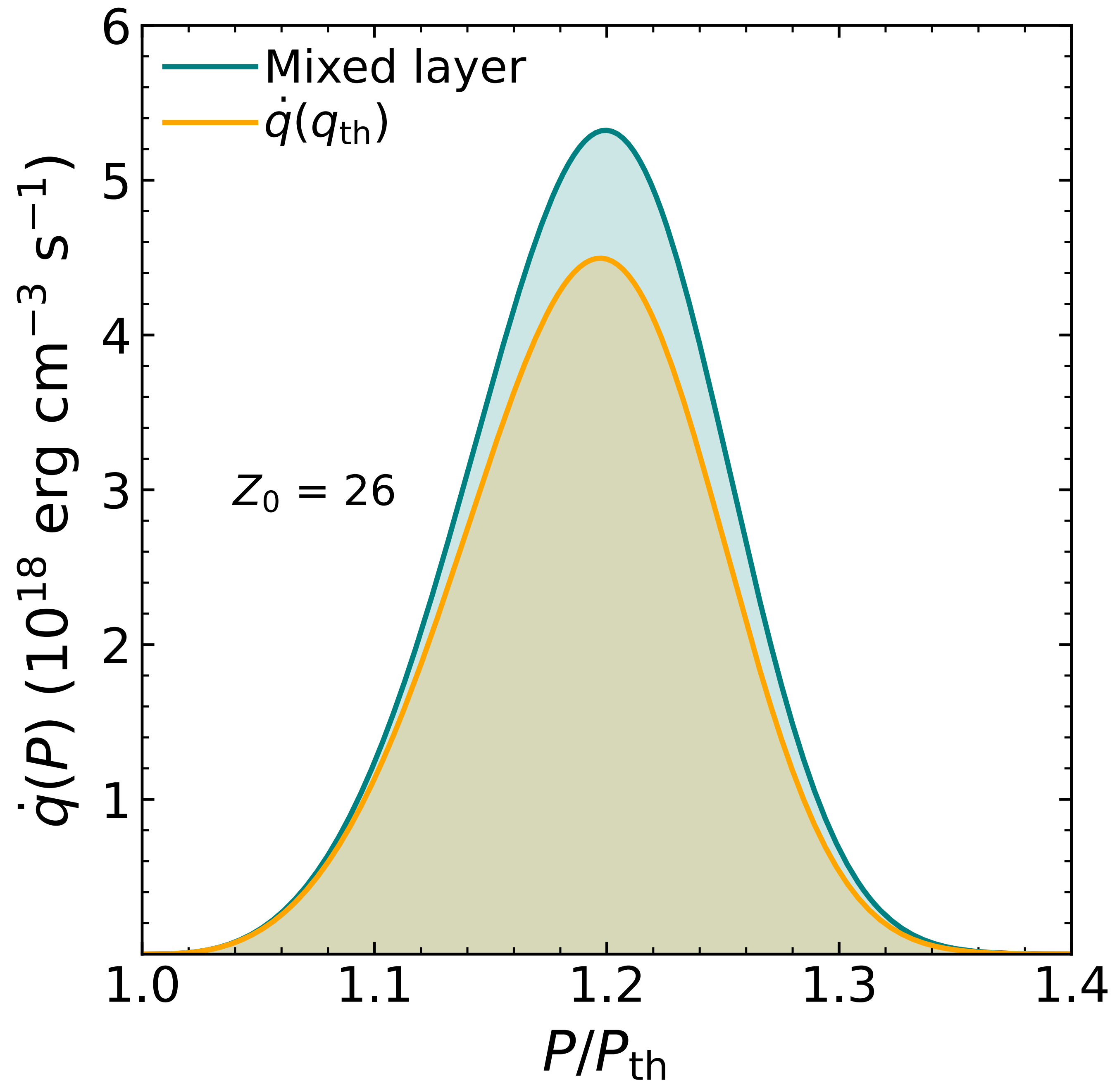


Fig. 3: Heating rate per unit volume $\dot{q}$ in the shell with proton number $Z_0 = 26$ as a function of the pressure during active accretion. This quantity is given for the mixed layer approach in blue, and compared to the quasi-instantaneous approach in orange.

- The size of the reaction layer much smaller than the size of the shell below
- Thickness of the reaction layers:

  $\delta P = 10^{-7}\ \mathrm{MeV/fm^3}$
- Shell thickness (between reaction layers)

  $\Delta P \sim 10^{-5} - 10^{-4}\ \mathrm{MeV/fm^3}$
- Energy release larger than in the case of instantaneous reaction (by $\sim 20\,\%$)

The Astrophysical Journal, 950:185 (9pp), 2023 June 20 https://doi.org/10.3847/1538-4357/acd759

Crustal Failure as a Tool to Probe Hybrid Stars

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Received 2022 October 31; revised 2023 May 3; accepted 2023 May 18; published 2023 June 26