PLASMA SHIELDING EFFECTS ON NUCLEAR SPECTRA: ^{18}NE APPLICATION

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INTRODUCTION

- The effects of the plasma environments on the nuclear structure of the nuclei have never been investigated theoretically or experimentally
- How atomic nuclei embedded in the plasma environment are affected by plasma
- The plasma effects on the change of nuclear energy levels are probed through computations performed within the nuclear shell-model framework
- The single-particle energy (spe) values to be used in the calculations are obtained by considering the modified Woods-Saxon (WS) potential
- The modification is executed on Coulomb Interaction Term in WS potential
- It is observed that proton spe values are sensitive to plasma shielding effect
- The ground-state binding energies are determined to be extremely sensitive to the plasma shielding parameters

MOTIVATION

- It is expected a screening for nucleon-nucleon or nucleon-core nucleus interactions
- The interaction between the core and the valance nucleons moving in an independent central potential well is contributed to the single-particle energy (spe)
- We have focused on the plasma-shielding of the interactions of the valence nucleons with the core nucleus in order to investigate plasma effects on the nuclear structure
- ^{18}Ne application WHY?
    - Even-even structure
    - In order to minimize the shielding contributions that can be arised from possible two-body interactions
    - Interaction only between protons is observable
- Due to the shielding effect of the plasma, the atomic systems exhibit quite different properties compared to the atomic systems without plasma
- The important nuclear processes take place in plasma environments such as the stars, and the plasma plays a dominant role in this process

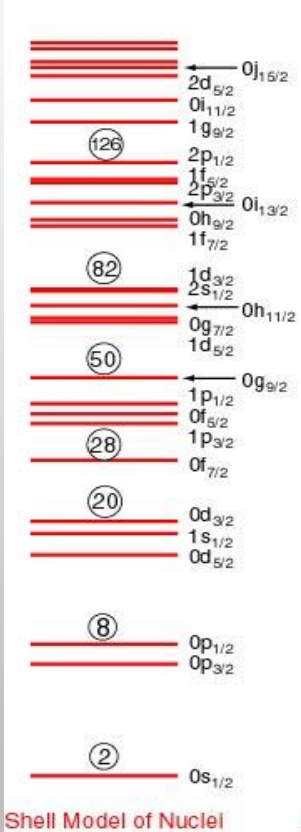
PLASMA EFFECT

- For the nucleus, the Coulomb Interaction in the effective potential model is modified due to plasma medium
- The More General Exponential Cosine Screened Coulomb (MGECSC) potential is considered
- The MGECSC potential is modeled the potential energy between two protons

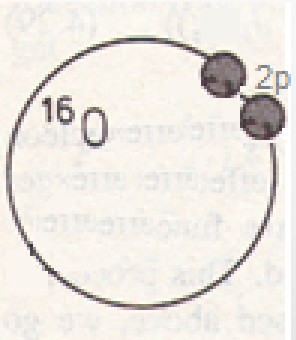
$$V_{mgecsc}(r)=\frac{e^2}{r}(1+br)\exp\left(-\frac{r}{\lambda}\right)\cos\left(\frac{ar}{\lambda}\right)$$

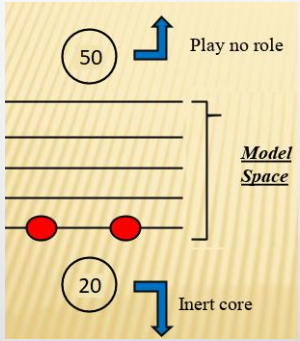
- A, b and λ are the plasma shielding parameters
- Proton spe levels obtained by using WS potential are sensitive to plasma shielding parameters (λ, a and b)
- The localizations of these spe levels that will be employed in SM calculations are shifted by changing plasma shielding effects

SHELL MODEL



- A powerful tool in calculating of the energy levels of nuclei with several valence nucleons outside of closed-shells
- Double magic nuclei : ${}^{16}_{8}O_{8}\ {}^{40}_{20}Ca_{20}\ {}^{208}_{82}Pb_{126}\cdots{}^{100}_{50}Sn_{50}\cdots$
- ^{16}O is assumed as an inert core nucleus
- Two valance protons
- USDB hamiltonian in SM calculations
- The energies of the levels can be divided into three parts
  - Binding energies of the closed-shells (which is ^{16}O)
  - Sum of the kinetic energies of the valance nucleons and single nucleon energies including interactions of core
  - Interaction between valance nucleons





$$H = \sum_{ij}^{A} \epsilon_i a_i^{+} a_j + \frac{1}{4}\sum_{ijkl}^{A} \langle ij|V|kl\rangle\, a_i^{+} a_j^{+} a_k a_l$$

SINGLE PARTICLE ENERGIES

- The spe's can be specified by allowing a central potential
  - Harmonic Oscillator
  - Wood-Saxon
  - Yukawa

$$H = \sum_{ij}^{A} \epsilon_i a_i^+ a_j + \frac{1}{4}\sum_{ijkl}^{A} \langle ij|V|kl\rangle\, a_i^+ a_j^+ a_k a_l$$

- In order to calculate proton spe's to be used in the SM calculations

$$V(r) = \frac{V_0}{1 + [\frac{\exp(r - R_0)}{a_0}]} + \frac{1}{r}\frac{d}{dr}\frac{V_{so}}{1 + [\frac{\exp(r - R_{s0})}{a_{s0}}]}\vec{l}.\vec{s} + V_C(r)$$

- Spin-independent central potential term

spin-orbit potential term

Coulomb potential term

$$V_C(r) = \frac{Ze^2}{r} \text{for } r \geq R_C$$

$$V_C(r) = \frac{Ze^2}{R_C}\left[\frac{3}{2} - \frac{r^2}{2R_C^2}\right] \text{for } r \leq R_C$$

SINGLE PARTICLE ENERGIES

- To compute the spe's, we have used WSPOT software By Brown
- WS parameters used to calculate the spe's have been adjusted to give spe's in USDB Hamiltonian as close as possible

V_0=-57.32 MeV, V_1= -22.30 MeV, V_{so}=18.765 MeV, r_0=r_{so}=1.2753 fm, a_0=a_{so}=1.0 fm ve r_c=1.275 fm

- The single particle energies obtained by using these parameters in the WS potential were calculated as 2.111, -3.207 and -3.927 Mev for $d_{3/2}$, $s_{1/2}$ and $d_{5/2}$ orbitals (which is almost the same as ones used in USDB)

```
! depmas=  0.30 lincom=  56 icntrl= 1 fgserr=  1.00
! 1=d3/2 2=d5/2 3=s1/2
! the first line has the three single-particle energies
! the - sign tells oxbash that the tbme have a mass dependence of the form
! [18/(16+n)]^0.3 where n is the number of valence particles
-63     2.1117   -3.9257   -3.2079   16.0000   18.0000 0.3000000
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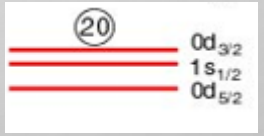


SINGLE PARTICLE ENERGIES

- When considering ^{18}Ne nucleus embedded in plasma environment, coulomb interaction in the system, due to plasma shielding effect, is modified as follows

$$V_C(r) = \frac{Ze^2}{r} \text{for } r \geq R_C$$

$$V_C(r) = \frac{Ze^2}{R_C}\left[\frac{3}{2} - \frac{r^2}{2R_C^2}\right] \text{for } r \leq R_C$$

$$V_{MGECSC}(r) = \begin{cases} \frac{Ze^2}{r}(1+br)\exp\left(-\frac{r}{\lambda}\right)\cos\left(\frac{ar}{\lambda}\right) & r > R_c \\ \frac{Ze^2}{r}\left(1-\frac{r^2}{{R_c}^2}\right) + \frac{Ze^2}{R_c}(1+bR_c)\exp\left(-\frac{R_c}{\lambda}\right)\cos\left(\frac{aR_c}{\lambda}\right) & r \leq R_c \end{cases}$$

$$V_{MGECSC}(r) = \frac{e^2}{r}(1+br)\exp\left(-\frac{r}{\lambda}\right)\cos\left(\frac{ar}{\lambda}\right)$$

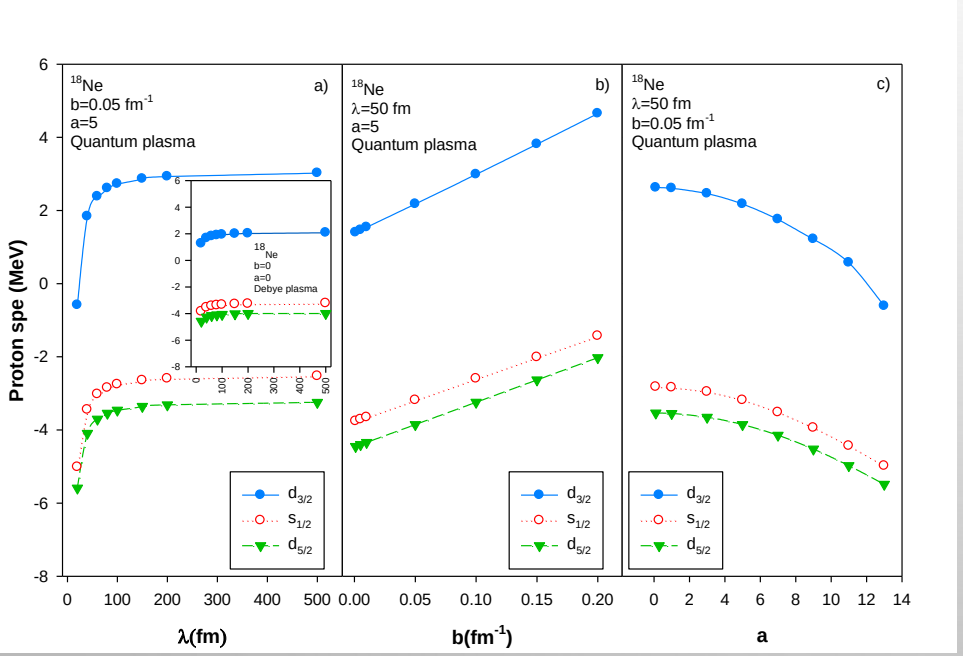
- THE TOTAL EFFECTIVE POTENTIAL FOR THE SYSTEM

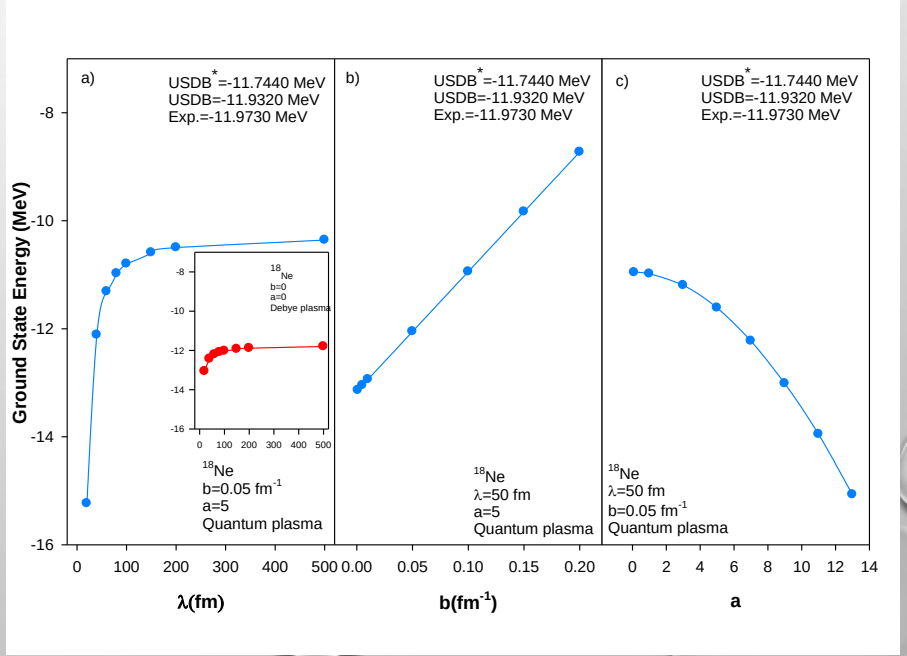
$$V(r) = \frac{V_0}{1+[\frac{\exp(r-R_0)}{a_0}]} + \frac{1}{r}\frac{d}{dr}\frac{V_{so}}{1+[\frac{\exp(r-R_{s0})}{a_{s0}}]}\vec{l}.\vec{s} + V_C(r)$$

$$U_{eff}(r) = \frac{V_0}{1+[\frac{\exp(r-R_0)}{a_0}]} + \frac{1}{r}\frac{d}{dr}\frac{V_{so}}{1+[\frac{\exp(r-R_{s0})}{a_{s0}}]}\vec{l}.\vec{s} + V_{MGECSC}(r)$$

PROTON SPE VE GROUND STATE

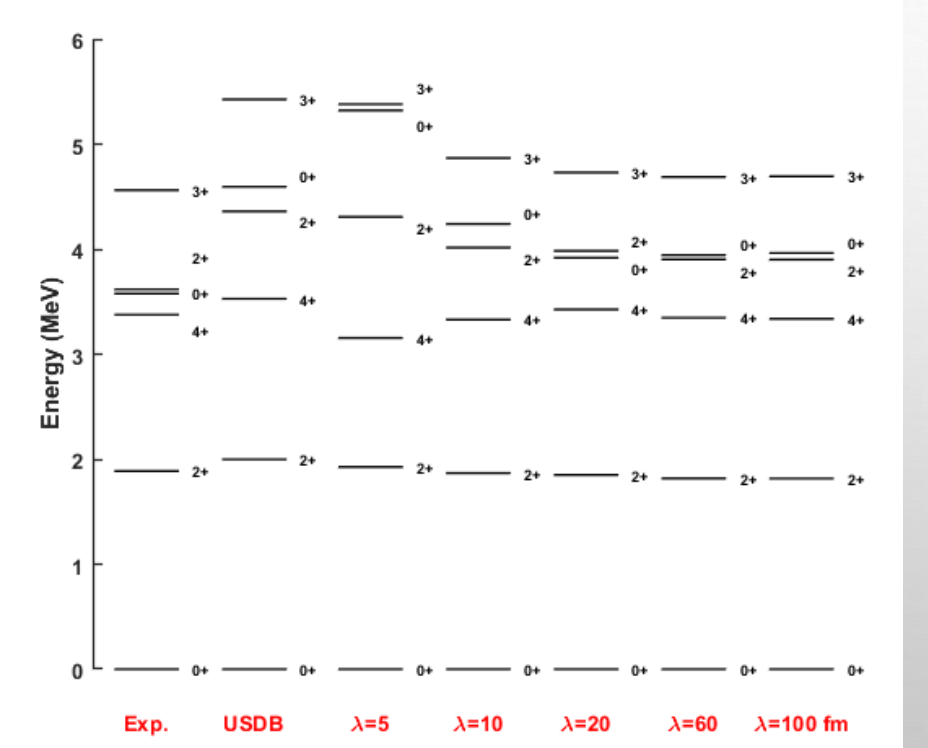
- In the calculations, certain ranges are used for the numerical values of these shielding parameters as
  - λ = 5-500 fm, b = 0.01-0.2 fm^{-1} a = 0.1-13.
- The change of $d_{5/2}$, $s_{1/2}$ and $d_{3/2}$ levels for the proton spe of ^{18}Ne nucleus
- The effects of plasma shielding parameters on the proton spe values will indirectly cause shifts in the ground state and excited states of the nucleus.





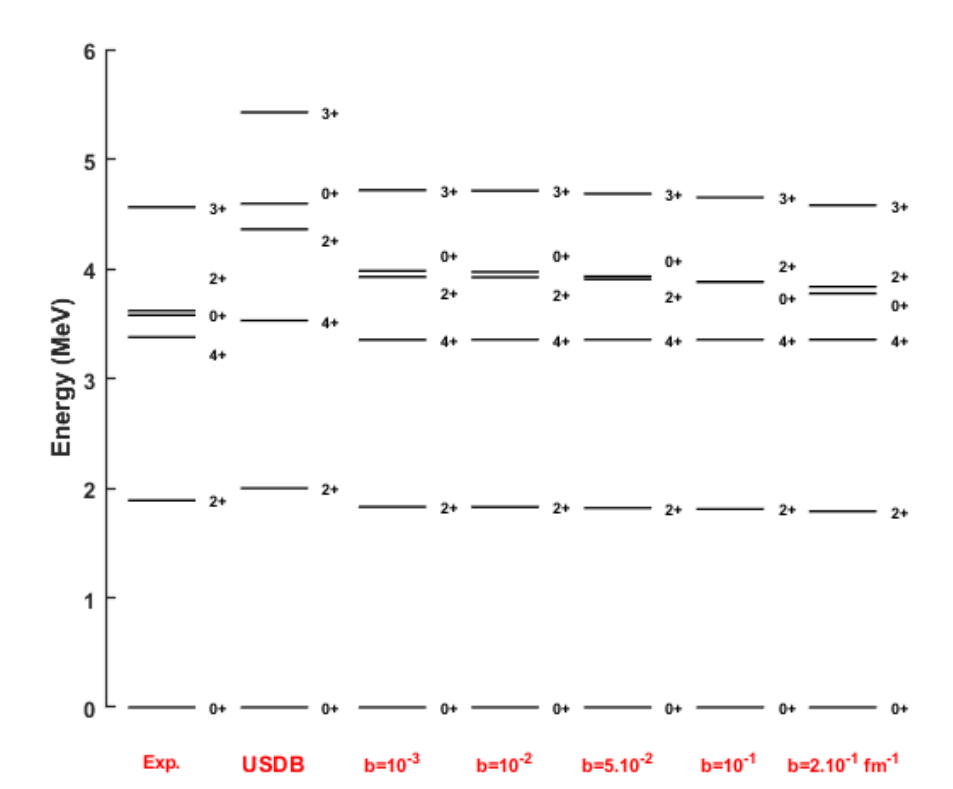
EXCITED STATES

- The excited state energies of ^{18}Ne nucleus embedded in quantum plasma depicted by MGECSC potential with a = 5 and b = 0.05 fm^{-1} are represented for different λ values
- Since λ = 50 fm case has spe-values close to proton spe-values of plasma-free environment, the increasing or decreasing of this value could be exhibited different behaviors on the energy spectra



EXCITED STATES

- The excited state energies of ^{18}Ne nucleus embedded in quantum plasma depicted by MGECSC potential with $\lambda = 50$ fm and $a = 5$ are represented for different b values



EXCITED STATES

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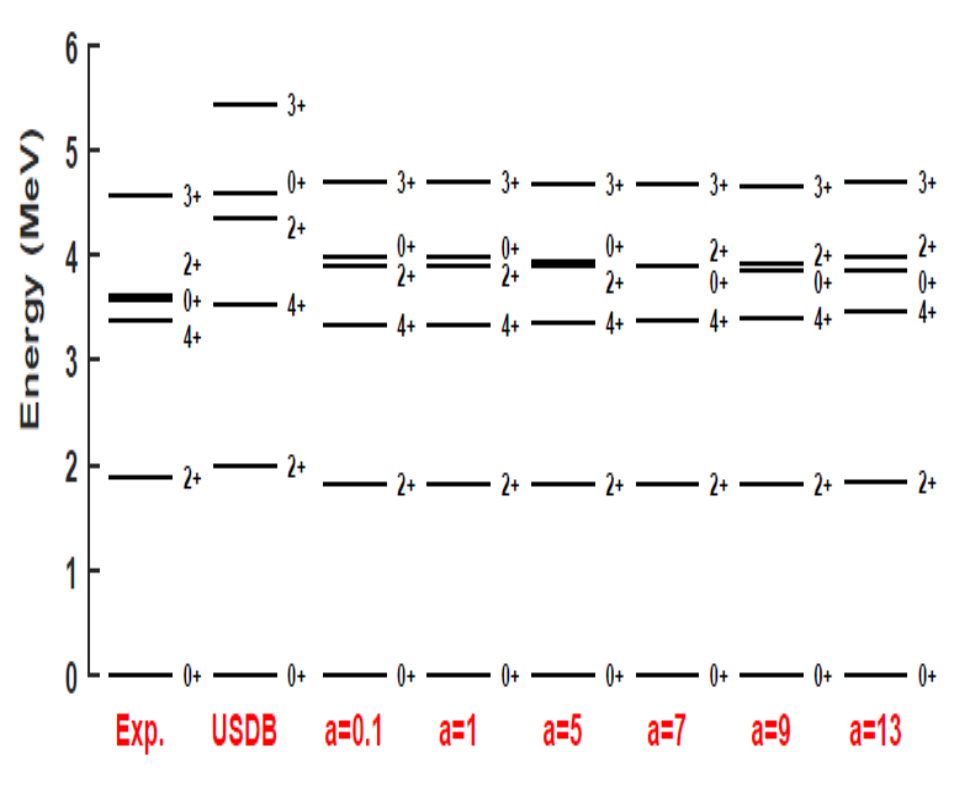

CONCLUSIONS

- In our investigations, the effect of change of spe levels used in SM calculations has been investigated
- The Coulomb interaction term in the WS potential has been modified due to the screening effect of the plasma environment
- The effects of plasmas on nuclear levels have been systematically investigated in SM calculations
- The Coulomb interaction between the ^{16}O core nucleus and the valance protons is shielded by the plasma environment
- It has been observed that proton spe values are sensitive to plasma shielding parameters
- The ground-state binding energies have been determined to be extremely sensitive to these parameters
- Plasma environments have affected the proton spe and the gse in the same way
- Although plasma shielding effect has an effect on all excited levels, it can be evaluated that it is more effective at high energy levels

THANK YOU VERY MUCH…

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