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Increased penetration of the Coulomb Barrier in a strong Electromagnetic Field

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Path to Clean Energy

Physicist and Engineers have been researching and innovating in the field of nuclear fusion power for decades. Powerful new lasers have been theoretically shown to lower the repulsion between positively charged nuclei. We examine these results further, working towards a more predictive *ab-initio* description of the Deuterium-Tritium (DT) fusion reaction. If the effect can be demonstrated, this could greatly enhance the fusion cross-section.

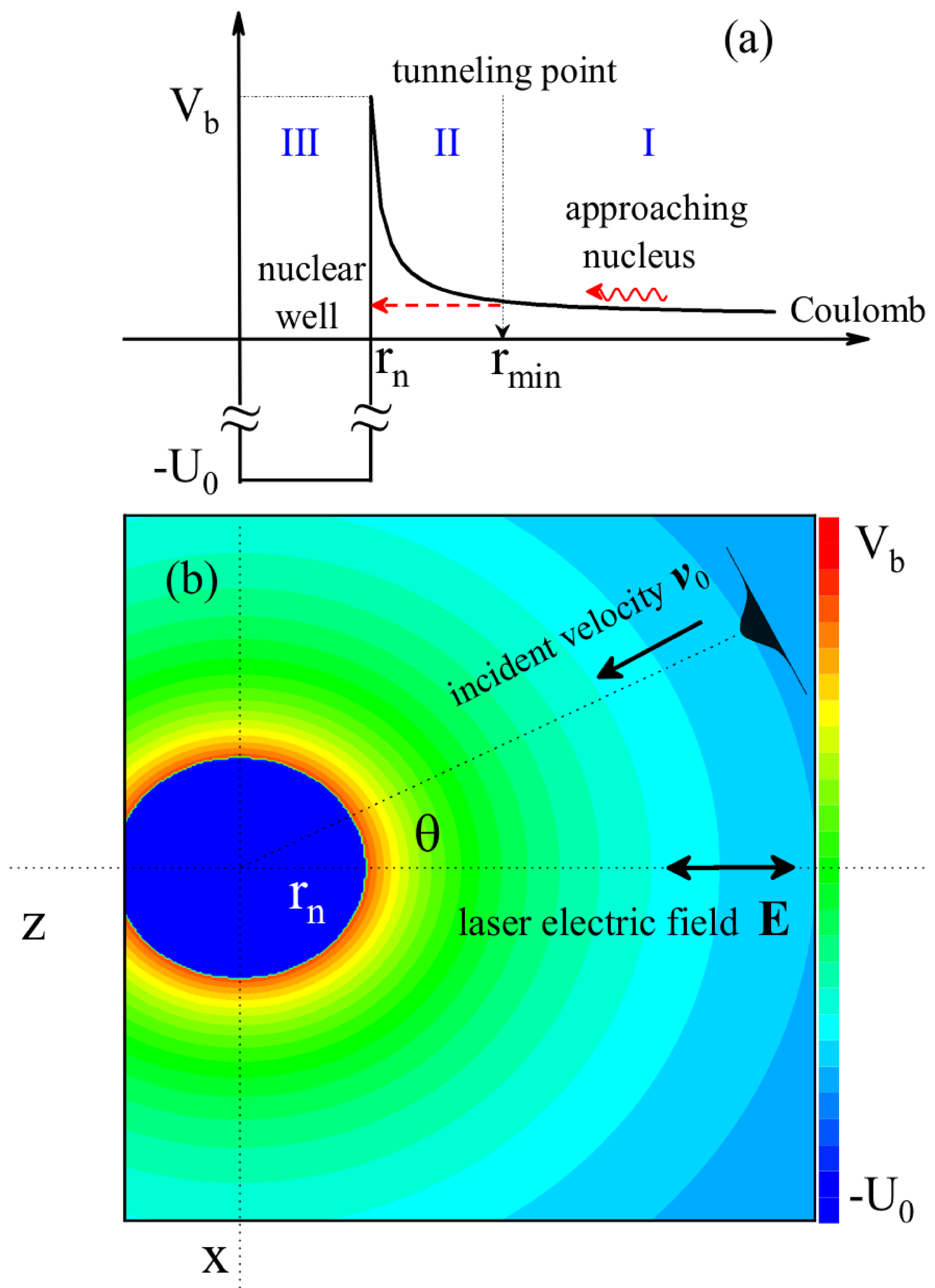

Figure 1: (a) The key regions of the fusion reaction: I: the approach; II: quantum tunneling; III: nuclear fusion. (b) An incident wave function approaches the nuclear well at an angle θ to the laser electric field. [4]

The Setup

We begin with a simple potential consisting of a nuclear well inside of the nuclear radius r_n and a Coulomb repulsion outside *(eq. 1) (fig. 1a)*.

$$V_{coul} = \begin{cases} -U_0 & \text{if } r \leq r_n \\ \frac{\hbar\alpha}{4\pi\epsilon_0 r} & \text{if } r > r_n \end{cases} \quad (1)$$

We then "switch on" an external electric field polarized along the z-axis *(eq. 2) (fig. 1b)*.

$$\vec{E}(t) = \hat{e}_z E_0 sin\omega t \quad (2)$$

Our final potential is a simplified, time averaged model of two-body spinless DT fusion in an electric field *(eq. 3)*.[1]

$$V_{eff} = \begin{cases} -U_0 & \text{if } r \in Din \\ \frac{V_0}{n_d}\sum_{l \in even} P_l(Cos\theta)V_l & \text{if } r \in D_{out} \end{cases} \quad (3)$$

The region outside of the nuclear well is now also a function of n_d, a dimensionless parameter that varies directly with the wavelength and square root of the intensity of the laser.

The R-matrix Solution Method

The calculable R-matrix method is a technique to solve the Schrödinger equation for scattering and reactions, which is particularly efficient for coupled channel systems.

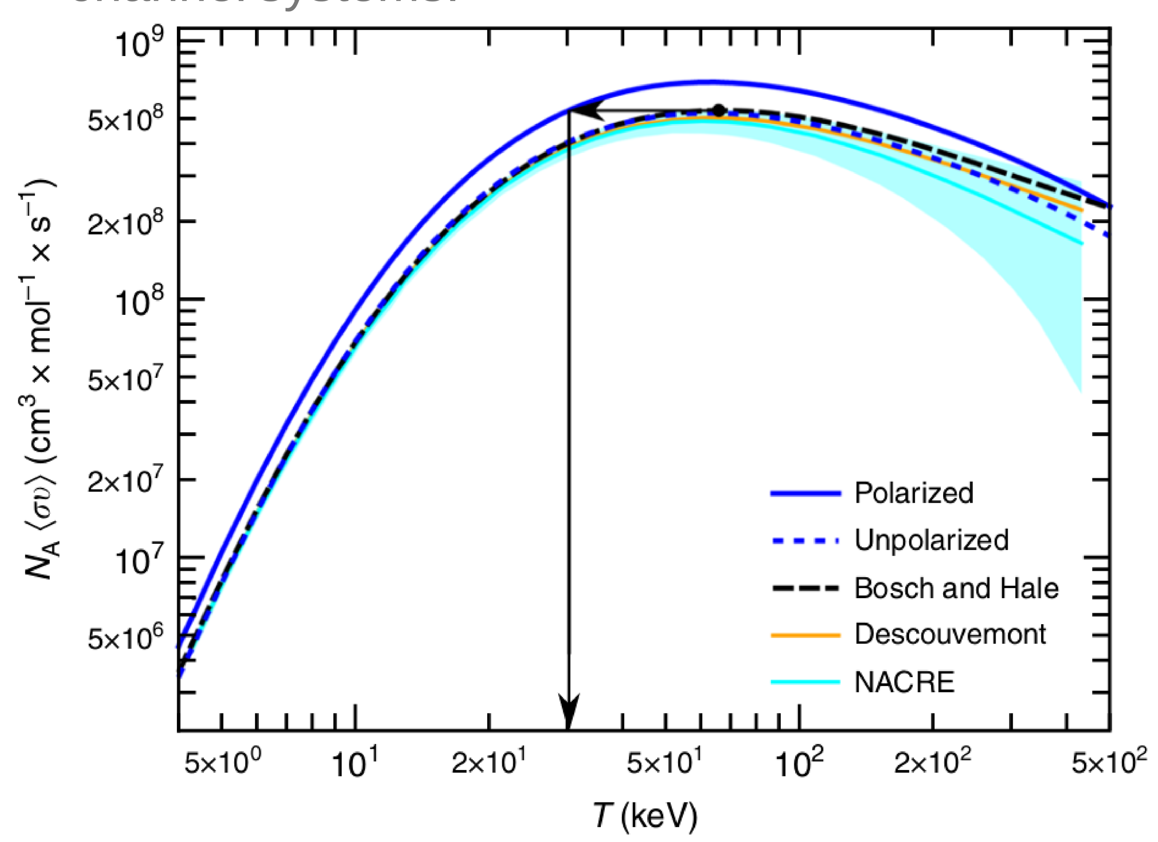

Figure 2: Computed DT reaction rate N_A<σv> for unpolarized and polarized fuel as a function of the Temperature *T*. Polarized fuel is shown to reach equal cross sections at a lower temperature, with a higher overall peak. [5]

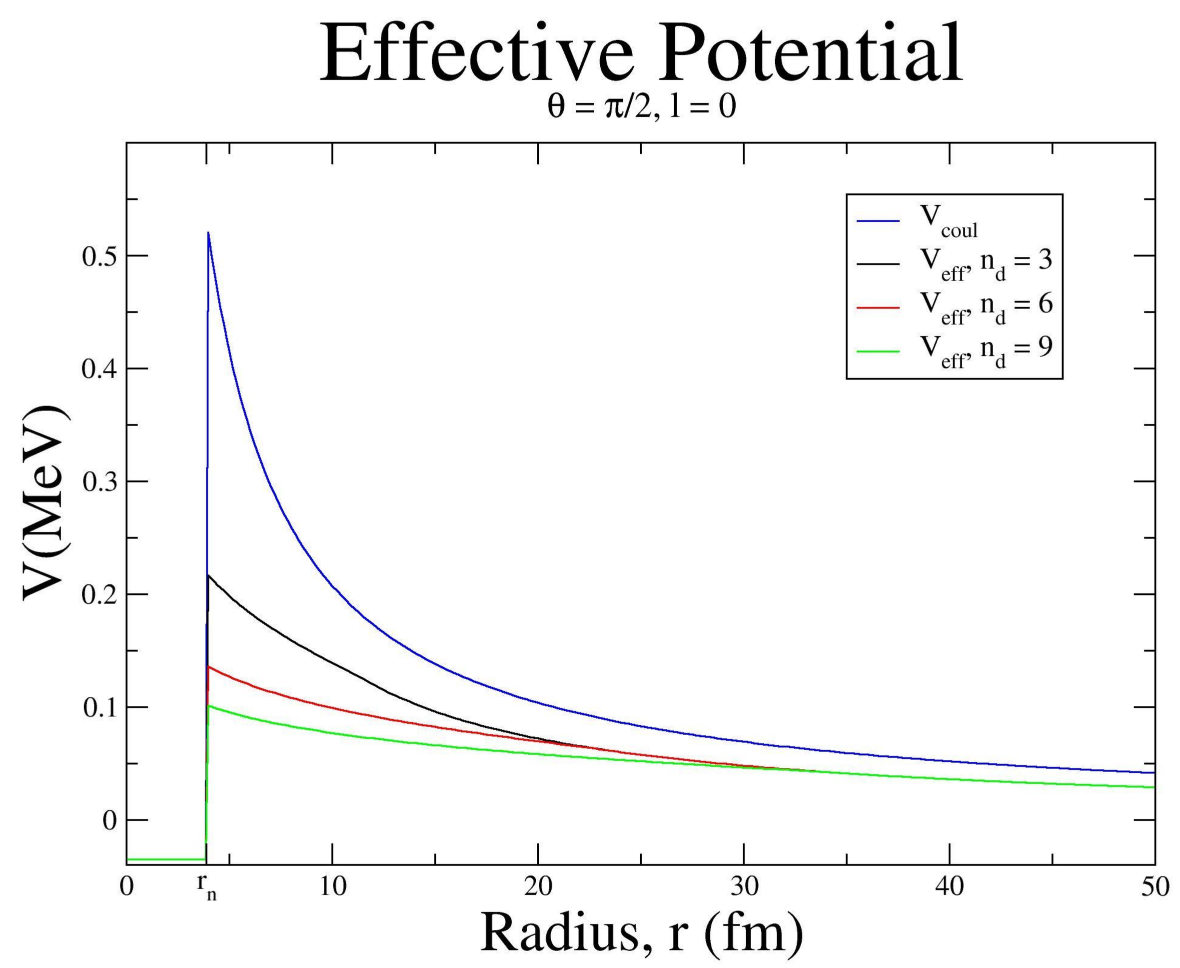

Figure 3: Potential energy plots comparing the Coulomb barrier with no external electric field *(eq. 1)* to an external field with increasing n_d values *(eq. 3)*.

Discussion of Results

The potentials in fig. (3), reveal that the Coulomb barrier is lowered as the power of the laser is increased. This corresponds to a higher amplitude of the wave functions in the internal region *(fig. 4)*. The square magnitude of the wave functions corresponds to the probability of finding the particle in a particular region; this indicates there may be a greater chance of fusion.

What Comes Next?

Currently we are generalizing to the coupled-channel case[3], where the incoming and outgoing wave functions may have a different angular momentum. Once completed, we will proceed with a realistic *ab-initio* calculation that accounts for the internal nucleon-nucleon interactions. Such calculations have already shown higher reaction cross sections for polarized fuel *(fig. 2)* [5]; the electromagnetic field from the laser may enhance this further.

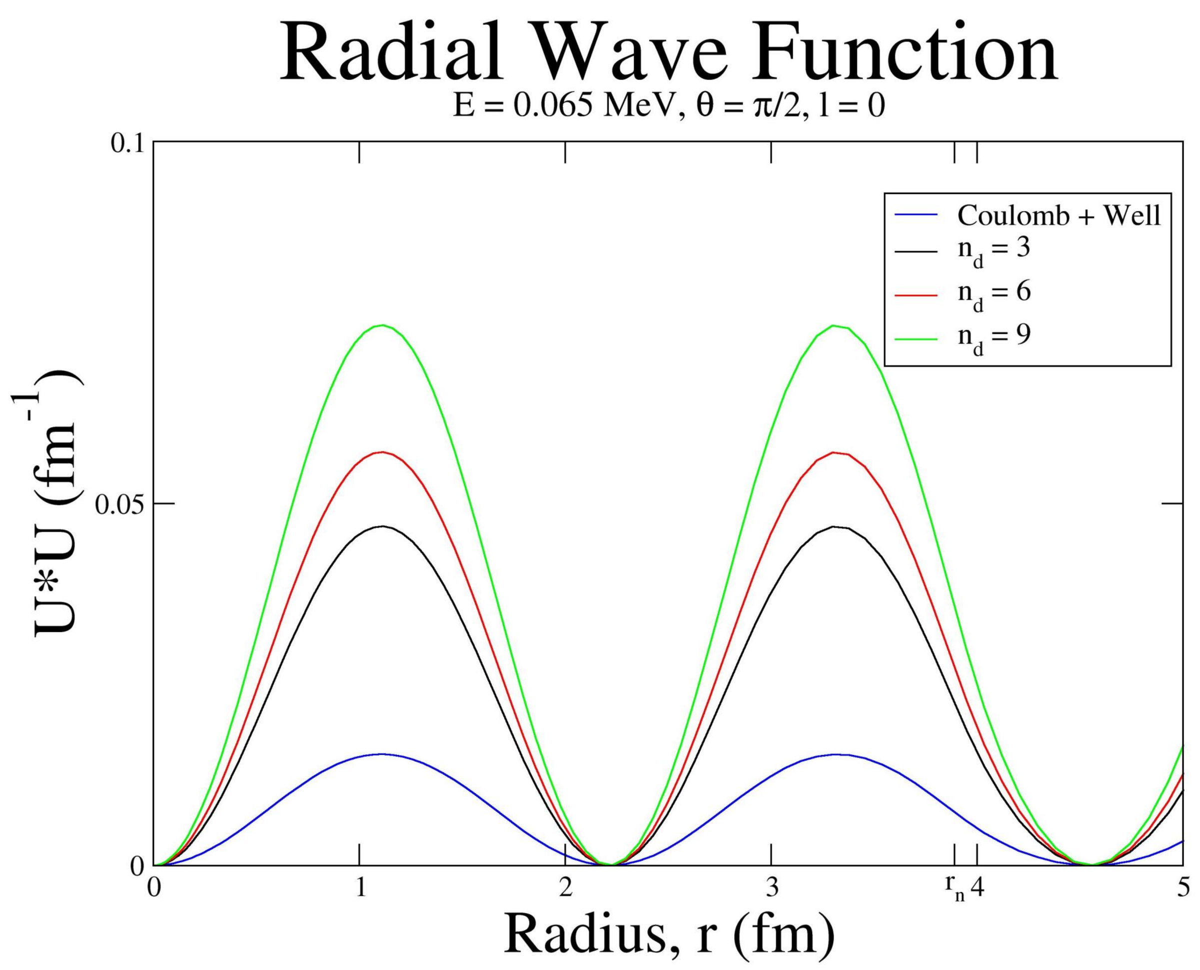

Figure 4: The wave functions generated using the R-matrix method. Higher amplitude waves inside of the nuclear radius r_n correspond to higher probability that the particle will be found in that region.

Conclusion

The addition of strong lasers to a fusion apparatus may lower the necessary input energy. We are analyzing this claim using R-matrix methods to solve a Hamiltonian representing a Coulomb barrier interacting with a strong external electromagnetic field outside of a nuclear well. Our results so far are consistent with the hypothesis.

References

[1] W Lv, H Duan, J Liu, Phys. Rev. C. 100, 064610 (2019)

[2] P Descouvemont, D Baye, Rep. Prog. Phys. 73, 036301 (2010)

[3] D. Baye, P.-H. Heenen, M. Libert-Heinemann, Nucl. Phys. A291 (1977) 230-240

[4] S Liu, H Duan, D Ye, J Lie, ArXiv. 2103, 14391v1 (2021)

[5] G Hupin, S Quaglioni, P Navrátil, Nat. Commun. 10, 351 (2019)

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Discovery, accelerated