Modeling the interaction of “dark” OHe atoms with nuclei of baryonic matter.

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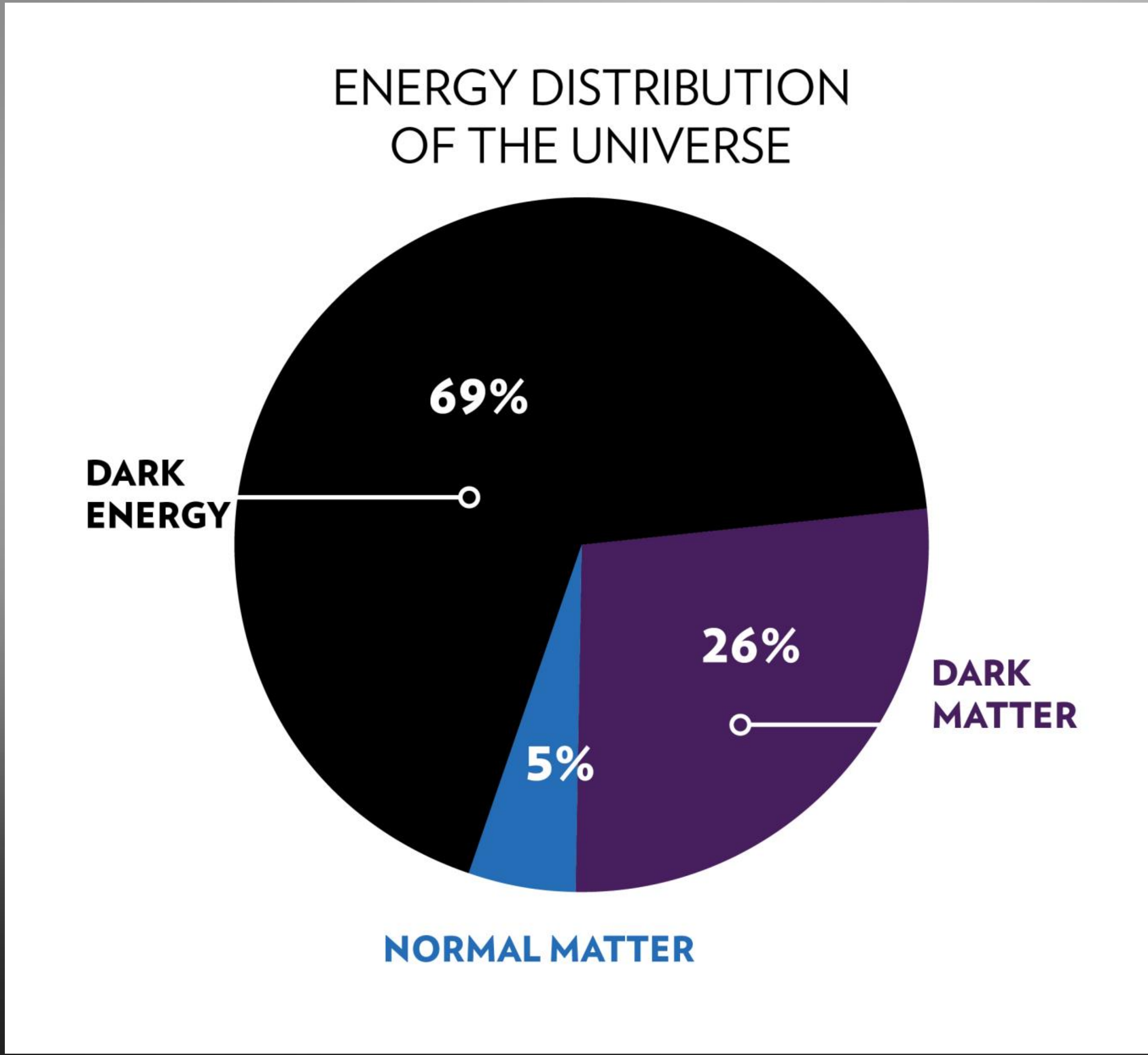
“What comes beyond the Standard models?”

The problem of the dark matter



Scenarios of hypothetical, stable, electrically charged particles.

In this paper, we consider a scenario of a composite dark matter, in which hypothetical stable particles O^{--} form neutral atomic states of OHe with primordial helium, having nuclear interaction with baryonic matter and called “dark” atoms.

The OHe model assumes the existence of relict, stable, lepton-like, massive (~ TeV) particles with a charge of -2, bound by the Coulomb interaction with primordial helium nuclei into "dark atoms" of dark matter.

The OHe hypothesis includes only one parameter of the "new" physics – mass of O-particles.

The "dark" OHe atoms dominate in the modern density of nonrelativistic matter and play the role of a nontrivial form of a strongly interacting dark matter.

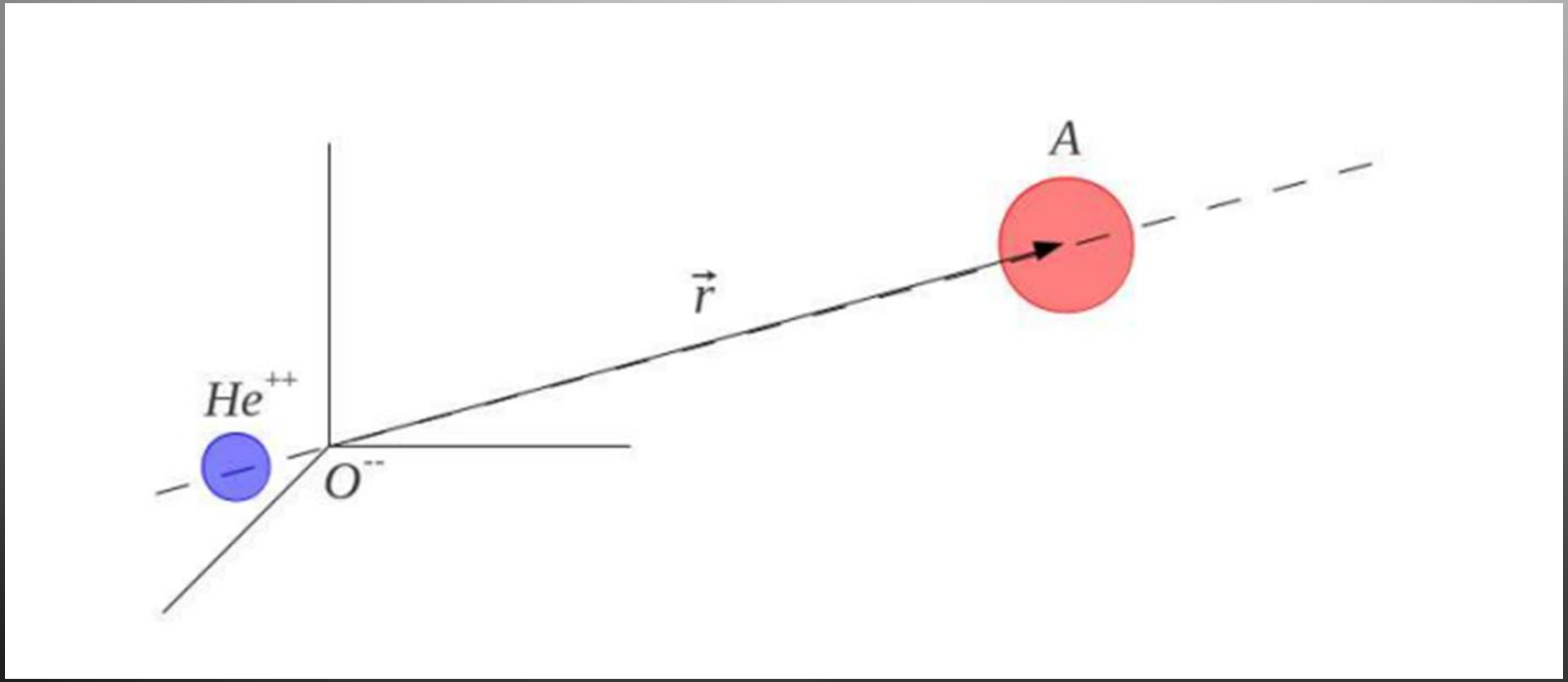


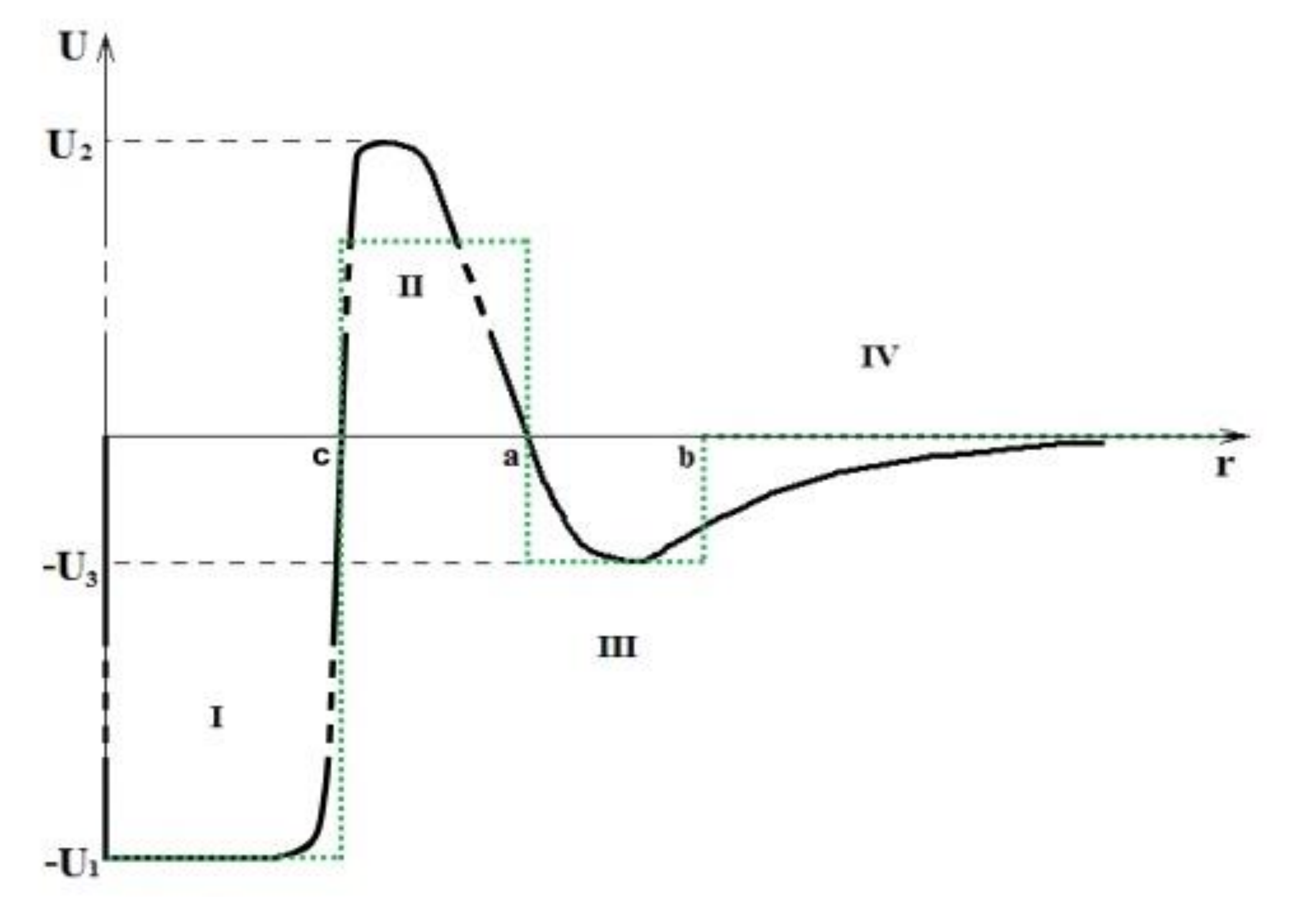
Illustration of the "dark" OHe atom and the outer core of substance A

Search results for "dark" matter

The results of the DAMA / NaI and DAMA / LIBRA experiments can be explained by annual modulations of energy release during the formation of the low-energy bound state of OHe with nuclei.

Detector	Cores	A	Z	Temperature	Detection
DAMA (/NaI +/LIBRA)	Na I Tl	23 127 205	11 53 81	300 K	8.9 σ
CoGeNT	Ge	70-74	32	70 K	2.8 σ
CDMS	Ge (Si)	70-74 (28-30)	32 (14)	Cryogenic	–
XENON100	Xe	124-134	54	Cryogenic	–

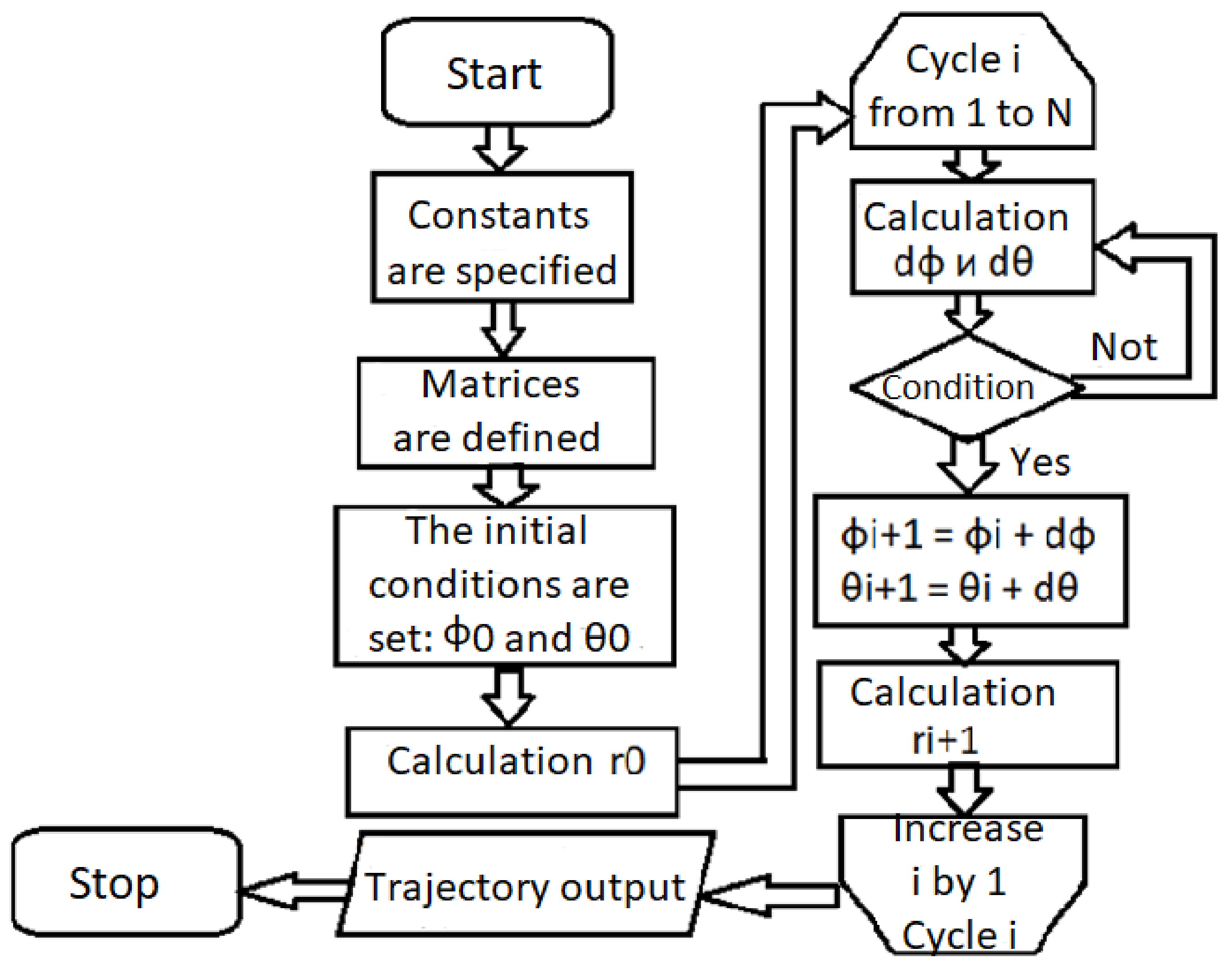
The existence of a low-energy bound state of OHe with nuclei and the dominance of elastic processes in the OHe scenario are based on the hypothesis of the presence of a dipole potential barrier in the interaction of OHe with nuclei, which requires a correct quantum-mechanical description.



The effective interaction potential between OHe and nucleus

The aim of the work is to build a numerical model of the interaction of the "dark" OHe atom with the atomic nuclei. In the framework of the proposed approach to such modeling, to reveal the essence of the processes of interaction of OHe with nuclei, a classical model is used, in which the effects of quantum physics are successively added.

Modeling OHe

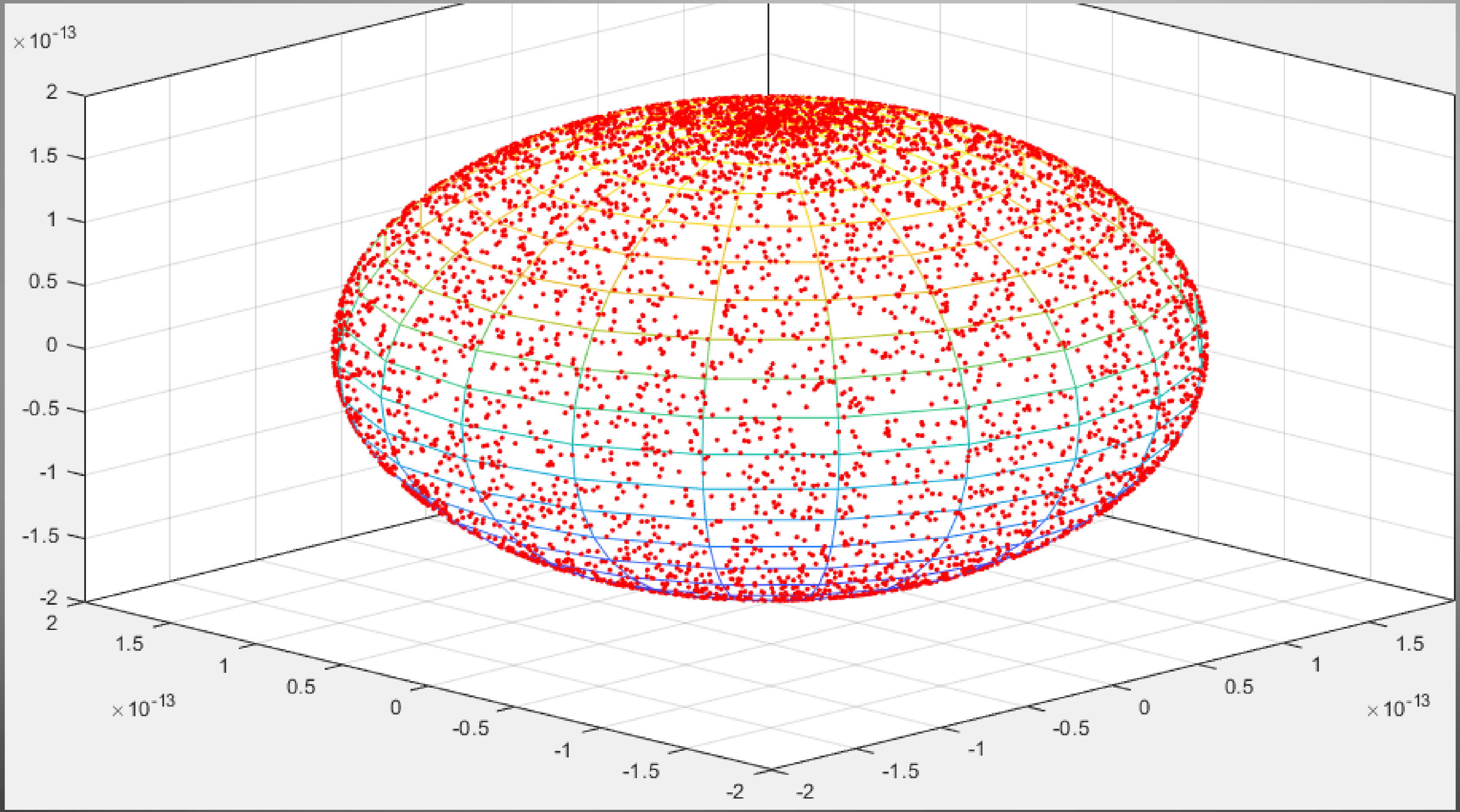


Block diagram of an OHe system simulation

$$d\theta = \left(\frac{V_\alpha dt}{R_b}\right)\left(2rand - 1\right)$$

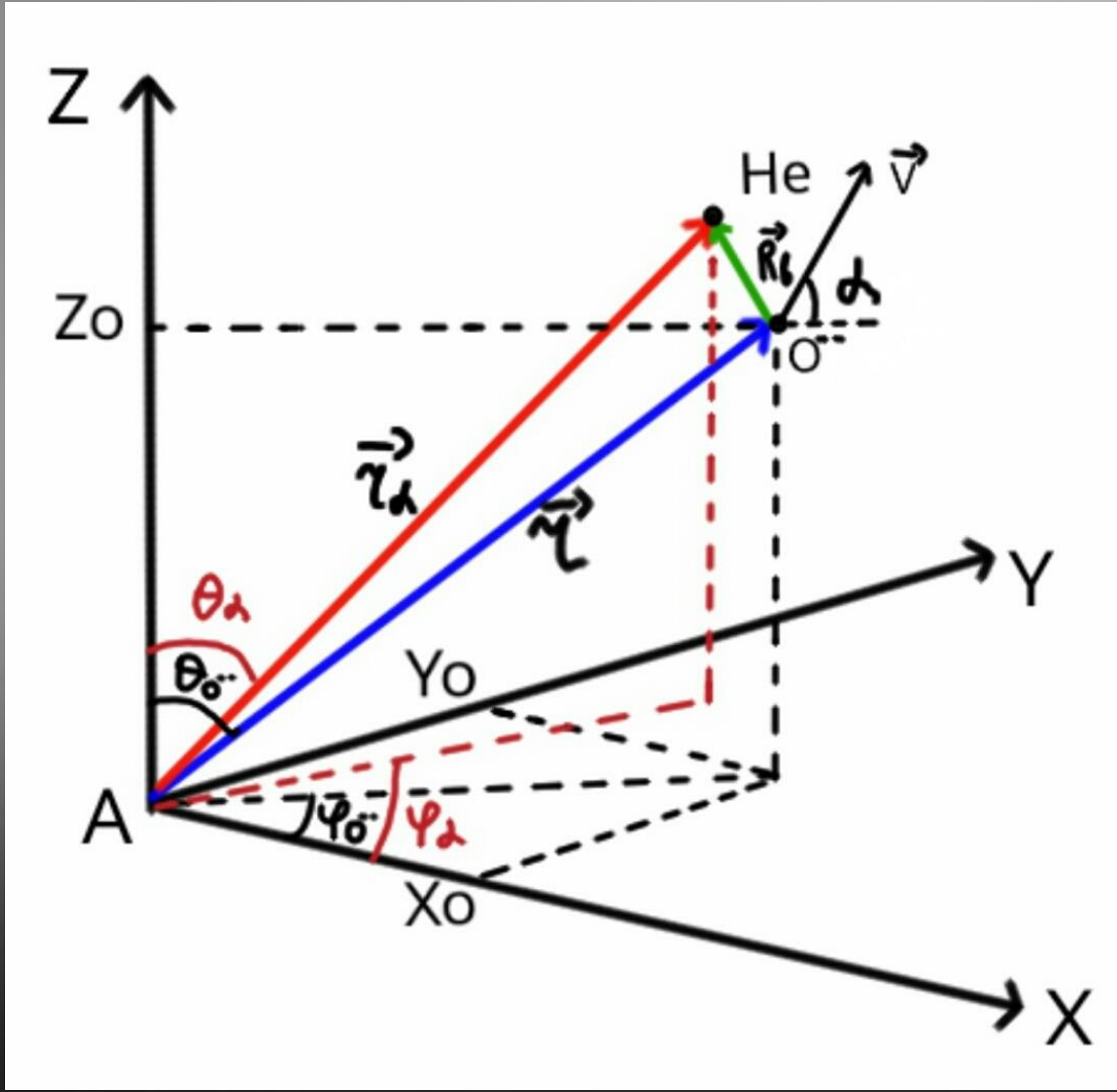
$$d\phi = \frac{\sqrt{\left(\frac{V_\alpha dt}{R_b}\right)^2 - \left(d\theta\right)^2}}{\cos(\theta)}\left(2rand - 1\right)$$

$$\left(d\theta\right)^2 + \left(\cos\theta d\phi\right)^2 \leq \left(\frac{V_\alpha dt}{R_b}\right)^2$$



The density distribution of the coordinates of the alpha particle on the surface of a sphere of the Bohr radius Rb

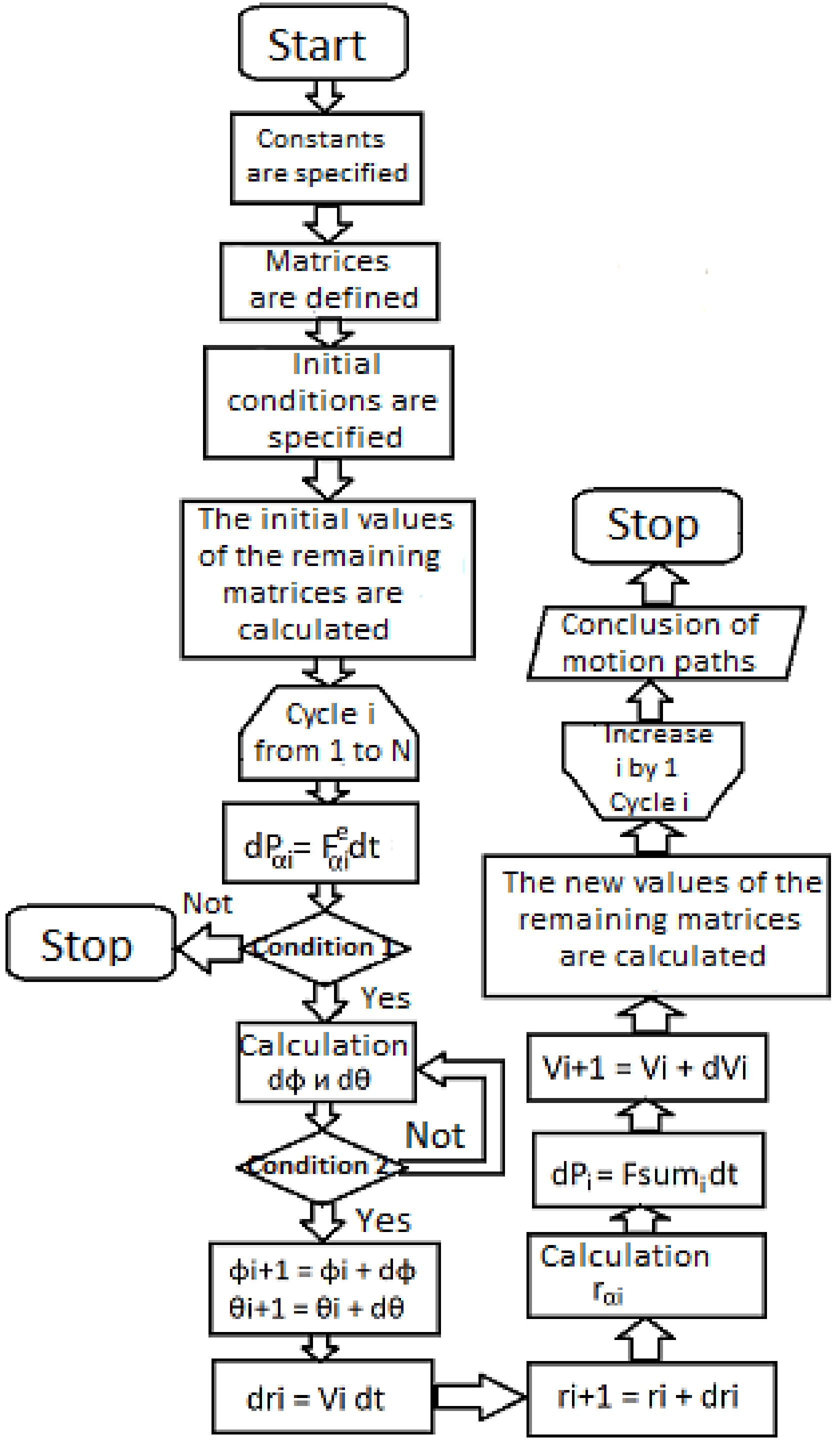
OHe – nucleus coordinate system



Coulomb interaction in the OHe – nucleus system

$$\vec{F}^e_\alpha = \vec{F}^e_\alpha(\vec{r}_\alpha) = \frac{ZZ_\alpha e^2 \vec{r}_\alpha}{r^3_\alpha}$$

$$\vec{F}^e_{ZO} = \vec{F}^e_{ZO}(\vec{r}) = \frac{ZZ_O e^2 \vec{r}}{r^3},$$

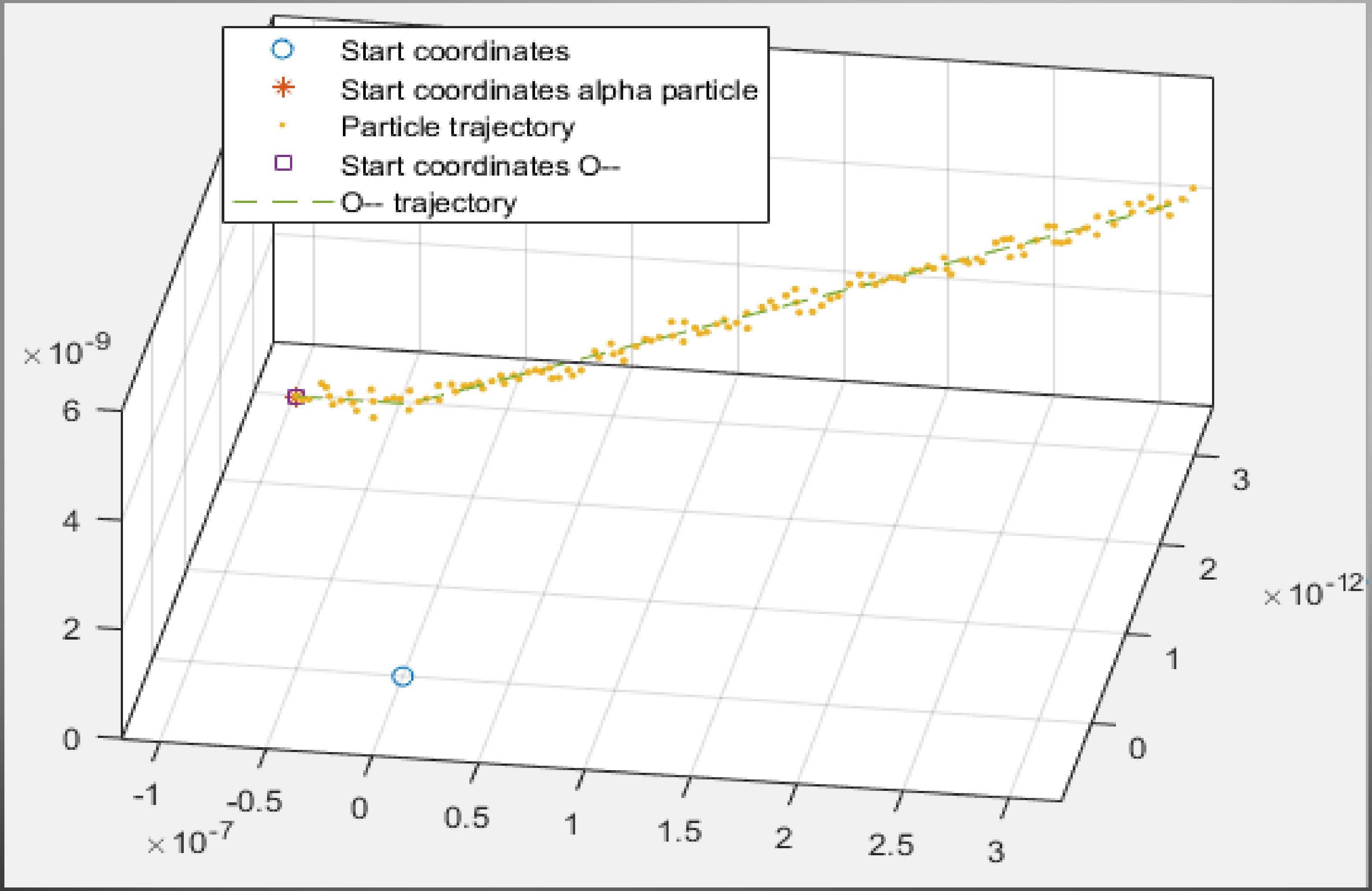


The block diagram of the simulation of the Coulomb interaction in the OHe – core system

$$dT < I \approx 1.6MeV$$

$$dT = \frac{dP_{\alpha_i}^2}{2m_\alpha}$$

Condition 1



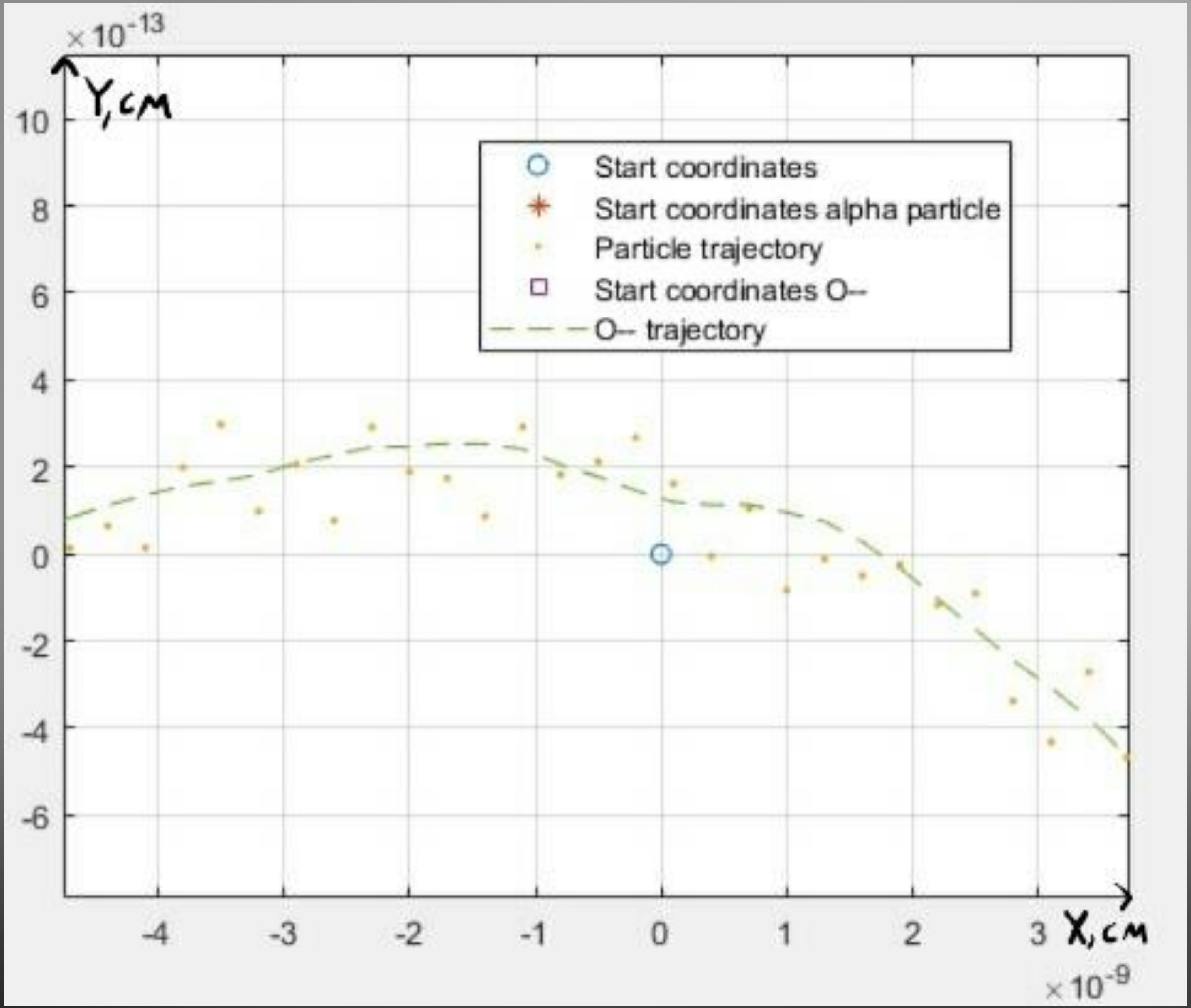
Alpha particle and O^{--} particle trajectories

Nuclear interaction in the OHe – core system

$$\vec{F}_\alpha^N = -\frac{\frac{V_0}{a}\exp\left(\frac{r_\alpha - R_Z}{a}\right)\frac{\vec{r}_\alpha}{r_\alpha}}{\left(1+\exp\left(\frac{r_\alpha - R_Z}{a}\right)\right)^2}$$

$$\vec{F}_{Sum} = \vec{F}^e_{ZO} + \vec{F}_\alpha$$

$$\vec{F}_\alpha = \vec{F}^e_\alpha + \vec{F}^N_\alpha$$



The trajectory of the alpha particle and the particle O^{--} in the XY plane

Further modeling perspectives.

1) Accounting for the final size of the nuclei.
2) Quantum-mechanical tunneling effect.

$$B_k = \frac{Zze^2}{R}$$

$$D \approx \exp\left(-\frac{2}{\hbar}\int_R^{r_2}\sqrt{2\mu(V-T)}dr\right)$$

$$V = \frac{Zze^2}{r}$$

$$r_2 = \frac{Zze^2}{T}$$

Conclusion

The result of this work is a numerical model describing the OHe-nucleus system with self-consistent consideration of nuclear and electromagnetic interactions. In the future, the obtained model can be used to interpret the results of experiments on a direct search for dark matter particles.

However, the process of numerical simulation has not yet been fully completed and its improvement is planned in the future by introducing the final sizes of nuclei, taking into account the distribution of nucleon density and proton density within nucleus, and introducing the quantum-mechanical effect of tunneling of the He nucleus into the nucleus.

$$\rho_{p,n} = \rho_{o_{p,n}} \left(1 + \exp\left(\frac{r - R^{rms}_{p,n}}{a_{p,n}}\right)\right)^{-1}$$

где a_p, a_n и $R^{rms}_{p,n}$ вычисляются следующим образом:

$$a_p = 0.449 + 0.071\frac{Z}{N}$$

$$a_n = 0.446 + 0.072\frac{N}{Z}$$

$$R^{rms}_{p,n} = \left(\frac{3}{5}R^2_{o_{p,n}} + \frac{7\pi^2}{5}a^2_{p,n}\right)^{\frac{1}{2}}\left(1 + \frac{5}{4\pi}\beta_2^2\right)^{\frac{1}{2}}$$

где R_{o_p} и R_{o_n} также вычисляются используя формулы:

$$R_{o_p} = 1.322Z^{\frac{1}{3}} + 0.007N + 0.022$$

$$R_{o_n} = 0.953N^{\frac{1}{3}} + 0.015Z + 0.774$$

где $N = A - Z$ это число нейтронов в ядре.

$$I_0 = \frac{Z^2_{O^{--}} Z^2_{He}\alpha^2 m_{He}}{2} \approx 1.6 \text{ МэВ}$$

$$R_b = \frac{\hbar c}{Z_{O^{--}} Z_{He} m_{He}\alpha} \approx 2 \cdot 10^{-13} \text{ см}$$

$$V_\alpha = \frac{\hbar c^2}{m_{He} R_b} \approx 3.02 \cdot 10^4 \frac{\text{см}}{\text{с}}$$