Formation of anomalous isotopes of dark atoms under conditions of supernova explosion

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Introduction

This work considers a scenario of dark matter involving hypothetically stable particles X with a charge of -2n.

Main idea

The aim of this work is to study the structure of dark atoms, as well as the mechanism of formation of anomalous isotopes during the capture of heavy element nuclei in supernova explosions. Problems associated with the potentially strong interaction of X-Ne atoms with matter nuclei, which can disrupt the bound state of dark atoms and lead to the formation of anomalous isotopes.

Objectives:

- Learn about the quantum mechanical model of dark atoms
- Consider their behaviour under conditions of supernova explosion
- Investigate the possibility of forming abnormal isotopes.
- Calculate the flow of dark atoms from supernova

Theoretical part

One possible candidate for dark matter is a particle with an electric charge of -2n, which may form dark atoms that explain the hidden mass of the universe.
The system of dark atoms consists of -2n (n is any natural number) charged particles X(for n = 1, which corresponds to O–) and a nucleus ^{4}He, held together by the Coulomb force. This model can explain the paradoxes of the search for hidden mass particles in the underground experiments DAMA/NaI and DAMA/LIBRA.
n addition to the standard nucleosynthesis reactions, the dark atom model predicts the following processes:

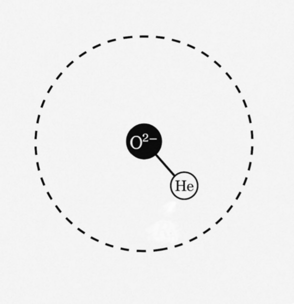
$$X + N \to XN + \gamma \tag{1}$$

According to the results obtained in the ATLAS experiment, the lower limit on the mass of particle X is approximately 1 TeV [1]. The specific configuration of the bound dark atom system is determined by the parameter:

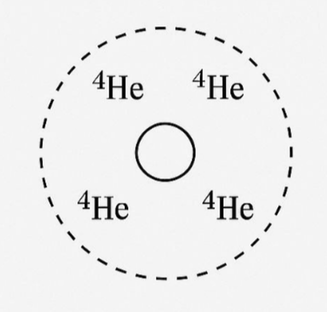
$$a \approx Z_\alpha Z_X \alpha \, A_\alpha m_p R_{n\mathrm{He}}$$

XHe and its structure

When $0 < a < 1$ the bound state looks like a Bohr atom with a negatively charged particle in the centre and an nHe nucleus moving in a Bohr orbit.
When $1 < a < \infty$, the state looks like a Thomson atom, in which nHe oscillates around a heavy negatively charged particle.



Bohr atom



Thomson atom

Structure of the XN

B—all isotopes form Bohr-like particles;
T—all isotopes form Thomson-like particles;
Number—the mass number of the lightest Thomson-like particle.

n	**A**					
	H	***He***	***Li***	***Be***	***B***	***C***
1	B	4	T	T	T	T
2	4	3	T	T	T	T
3	3	T	T	T	T	T
4	3	T	T	T	T	T
5	2	T	T	T	T	T

Table 1: Structure of the XN bound states.

Conditions for a supernova explosion

Under conditions of supernova explosion, dark X-nHe atoms can ionise and form a free multi-charged component X^{-2n}, which can be captured by other heavy element nuclei(like Fe, Ni, S) and form anomalous isotopes of these elements.

Bond energy for Bohr atoms(For the case of XHe):

$$W^{\text{Bohr}}_{X-N} = 2n^2 Z^2 \alpha^2 m_N = \frac{1}{2 m_N R_b^2}.$$

$$W_{XHe} \approx 1.6 MeV$$

For a simple assessment of the bond energy for Thompson atoms, we use a mechanical model:

$$\mathcal{H} = \begin{cases} \frac{P^2}{2m_N} - \frac{3nZ\alpha}{R_N} + \frac{nZ\alpha}{R_N}\left(\frac{r}{R_N}\right)^2, r < R_N \\ \frac{P^2}{2m_N} - \frac{2nZ\alpha}{R_N}, r > R_N \end{cases}$$

Шаги

$$W_{X-N}^{\text{Thomson-Glashow}} = 3\frac{nZ\alpha}{R_N}\left(1-\sqrt{\frac{1}{2nZ\alpha m_N R_N}}\right) = 3\frac{nZ\alpha}{R_N}\left(1-\sqrt{\frac{R_b}{R_N}}\right).$$

The calculation results show that the anomalous isotopes have high binding energy and are not ionized in the supernova explosion conditions, but are accelerated and form a flux of exotic isotopes.

n	^{56}Fe	^{59}Ni	^{28}Si	^{52}S	^{40}Ca	^{16}O
1	23,6	25,1	15,1	16,8	20	9,3
2	47,9	50,9	31,3	34,5	40,7	20
3	72,4	76,8	47,5	52,4	61,6	30,8
4	96,9	102,7	63,9	70,4	82,5	41,8
5	101,4	128,7	80,3	88,4	103,5	52,9

Table 2: Ionization energy of anomalous isotopes $X^{-2n}N$ (MeV)

Conclusion

The following tasks were completed in the course of this research work:

- The theoretical model of the dark atom, Bohr and Thomson type was introduced;
- Calculations for ionization energy for anomalous isotopes of dark atoms in case of their capture by nuclei of heavy elements were carried out.
- In the future, it is planned to calculate the flow of dark atoms from supernovae and construct a model of their distribution in space.

Result

Dark atoms are indeed ionised in supernova explosions and captured by the nuclei of heavy elements, forming anomalous isotopes of elements that are accelerated in supernovae.

Thank you for your attention!

References

- Beylin, V.A.; Bikbaev, T.E.; Khlopov, M.Y.; Mayorov, A.G.; Sopin, D.O. Universe 2024, 10, 368. Dark Atoms of Nuclear Interacting Dark Matter., Dark Atoms of Nuclear Interacting Dark Matter., 2024.
- Cahn, R.N.; Glashow, S.L., Chemical Signatures for Superheavy Elementary Particles. , Science, 607-611, (1981), DOI: 10.1088/2041-8205/790/2/L21.
- M. Khlopov, What comes after the Standard Model?, Progress in Particle and Nuclear Physics, Volume 116, (2021), ISSN 0146-641