Axion-Photon Conversion Probabilty

PHYS 462 Independent Research Report

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I. Context and Motivation

The axion is a hypothetical elementary particle that is a candidate for what comprises cold dark matter. Due to the axion's weak interaction with forces other than gravity, it has been difficult to observe. However, the magnetosphere and plasma around neutron stars prove to form an extreme environment conducive to the resonant conversion of axions into detectable radio photons. In particular, we expect the axion-photon conversion to occur when the plasma frequency of the neutron star equals the axion mass. By taking advantage of the coupling between the axion and electromagnetism, we can effectively uncover the existence of the axion through indirect detection.

Plans to simulate the neutron star environment in future research necessitates the determination of the probability of the axion-photon conversion as well as how this probability varies with the alteration of three parameters. Thus, the goal of this project is to calculate the probability of conversion.

II. Research Methods

In the beginning of the semester, I obtained prerequisite knowledge for the planned project, particularly focusing on how the Schrödinger equation predicts the dynamics of single particles in a potential barrier or well. I continued to investigate how we can solve for the wavefunctions of particles through methods like the WKB approximation. Learning soon shifted to two-particle interactions which required the use of the Klein-Gordon equation, the time-independent one-dimensional form of which are

$$-\phi_\alpha''(x) + m(x)^2\phi_\gamma(x) = E^2\phi_\alpha(x)$$
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where ϕ is the "scalar particle wavefunction", α denotes the axion, γ denotes the photon, $m(x)$ is the mass parameter (assumed to be a constant μ when non-zero), and E is the energy of the particles. We assume that the energy of the incident axion and emitted photon are equal. We also require boundary conditions to be satisfied in that the wavefunction and its first derivative are continuous where the mass parameter region of width a begins and ends. Such conditions are formulated, and then we employ Mathematica to numerically solve the above equations.

III. Quantitative Results

Preliminary calculations of the axion and photon wavefunctions in Mathematica yielded the general form of solutions for $E > \mu$ displayed in Figure 1.

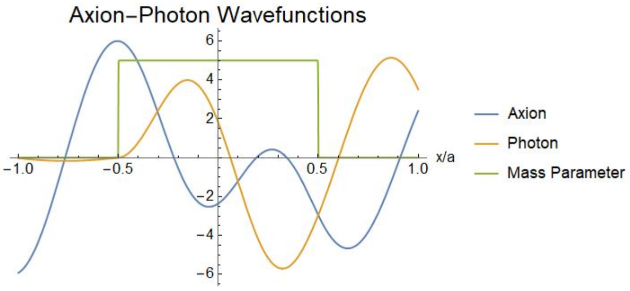

Figure 1. Numerically solved axion and photon wavefunctions for $\mu = 5$

Boundary conditions to the scenario in Figure 1 give nine coefficients to solve for and eight equations. Normalizing all amplitudes to the incident axion amplitude reduces this to eight coefficients, so solving for the transmitted photon amplitude yields the transmission coefficient t which is a function of the mass parameter, particle energy, and mass parameter width. We then find the probability of this transmission, that is, the probability of the axion converting into a photon, by making a 3D plot of $|t|^2$ in Figure 2.

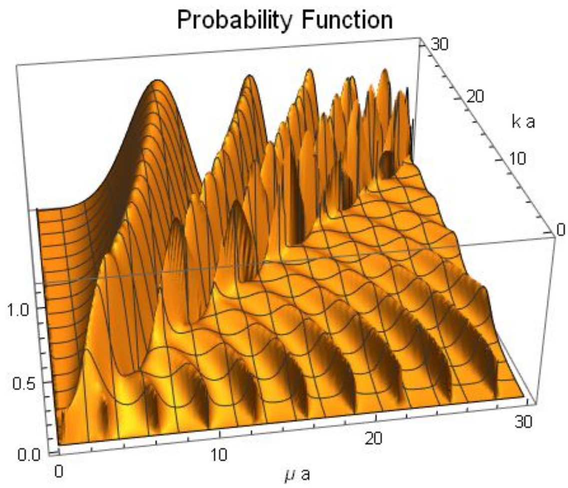

Figure 2. Conversion probabilty function for $a = 1$

As with the Schrödinger equation, we find there are two distinct regimes: $k > \mu$ and $k < \mu$. The probability oscillates between zero and one along a line of constant k for $k > \mu$, with peaks of increasing sharpness as k and μ grow. That is, for large μ, the conversion probability is more sensitive to the mass parameter.

IV. Further Studies and Conclusions

After this semester's research, we obtained the probability of the axion-photon conversion as a function of μ, a, and E. This probability function neglects time dependence and the mixing parameters of the axion and photon, the latter of which must be considered for the resonant conversion probability. Thus, we can extend this semester's work under these new considerations, resulting in a useful tool for the eventual creation of computer models of the axion-photon conversion process in neutron star environments.