Geoneutrino oscillations approach to discriminate distributions of HPE in the Earth's mantle using the Monte Carlo Technique.

Monography for Geoscientist degree [1]

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Dedicated to Calvin and Hobbes.

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Introduction

> *"This is a quote and I don't know who said this."*
>
> – Author's name, *Source of this quote*

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Distribution of Radioactive Elements

3.1 Relative Abundances

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Radioactivity

Radioactivity is the phenomenon in which a parent isotope turn into a daughter isotope, with different characteristics, through the emmission of a particle.
The history of radioactivity goes back to 1896, when H. Becquerel discovered that a uranium sample emmited some kind of penetrating radiation similar to the X rays (discovered earlier that year). In the following years, three different types of emissions were identified: alpha (α), beta (β) and gamma (γ). The nature of each of these emissions was identified through the years, concluding that α-particles correspond to ^4He nuclei, $\beta^{\pm}$-particles correspond to $e^{\pm}$ (electrons or positrons) and γ-particles are nothing but high energy photons.
Rutherford discovered that radioactive phenomena was linked directly with the nucleus ($\sim 1fm$) of a given isotope, thus, it is an entirely quantum phenomenon.
The overall radioactive phenomena are described by a rather simple mathematical approach given the statistical behavior of the phenomena (which is a result, and evidence of how "quantum"it is). Given N parent isotopes in a sample at a given time t and assuming no more are added, the rate of decay (dN/dt) is proportional to N [1]

$$\frac{dN}{dt} = -\lambda N \tag{4.1}$$

That, upon integration becomes

$$N(t) = N_0 \exp(-\lambda t) \tag{4.2}$$

Where N_0 corresponds to the number of parent isotopes at time $t = 0$ and λ is called the decay constant and is unique for every isotope.
This simple model has been key to the use of the radioactive isotopes to, for example, date rocks or organisms.

4.1 Types of radioactive decay

Let us now go deeper into the theory of the radioactivity.

4.1.1 Alpha decay

The theory of the alpha decay is rather simple. α-particles are confined in a finite potential well (the nucleus X) and will, as expected, have a certain probability of tunneling said barrier. When this happens, the α-particle will escape and leave a "new" (daughter) nucleus X' [1]. The process may be written as

$$ {}^{A}_{Z}X_N \rightarrow^{A-4}_{Z-2} X'_{N-2} + \alpha \tag{4.3} $$

Where A is the atomic mass number, Z is the atomic number and N is the charge.
This decay involves both strong (nuclear) interactions and electromagnetic interactions since the potential well is given by confinement due to strong interaction between nucleons and the barrier has a decaying-exponential side, given by the Coulomb potential.

4.1.2 Gamma decay

Gamma decay is similar to the common electromagnetic emission due to atomic transitions, in fact, it is produced when a metastable state of an isotope decays into a more stable state through the emission of high energy photons. It should be noted that, in this case, no change in A or N is produced. These metastable states are common daughter isotopes to α and β decays.
Lifetimes for this kind of process is generally short, taking only fractions of a second to decay while some α-decaying isotopes may have half-lives of the order of $10^3 yr$.

4.1.3 Beta decay

This type of decay can be considered to be more complex than the other two, as it responds to more complicated undelying physics: the weak interaction. It consists in a set of semileptonic processes (that involve both leptons and hadrons) that will be described below.

- **Positive Beta decay:**

$$ p \rightarrow n + e^{+} + \nu_e \tag{4.4} $$

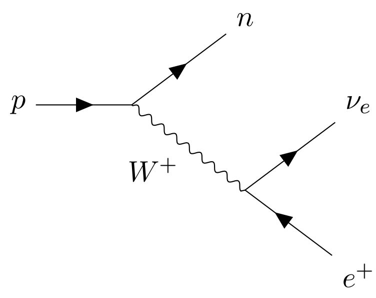

Figure 4.1: Feynman diagram for β^+ process.

- **Negative Beta decay:**

$$n \to p + e^- + \bar{\nu}_e \tag{4.5}$$

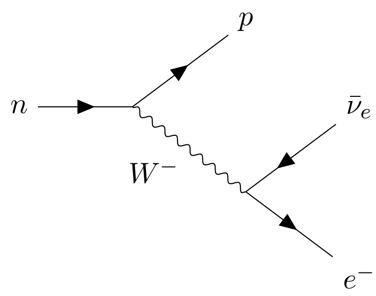

Figure 4.2: Feynman diagram for β^- process.

- **Electron capture:**

$$p + e^- \to n + \nu_e \tag{4.6}$$

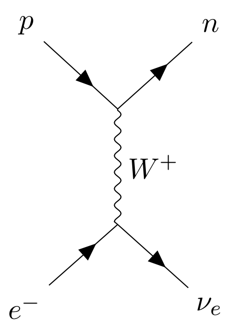

Figure 4.3: Feynman diagram for electron capture.

Note that in all these processes new particles are created in the nucleus, which is a consequence of the weak interaction that rules them.
The particles labelled with ν_e are electron neutrinos and were proposed by Pauli in order to solve the conundrum concerning the apparently continuous energy spectra of β-decay which is against the core of quantum mechanics, the inclusion of these particles in the energy spectrum of the decay made it discrete, thus, giving a solution to the problem.
For this project, we are strictly interested in the β^--decay since it is the one that produces antineutrinos.

4.2 Decay Chains

Different isotopes in the Earth have decay chains involve $\beta-$-decay at some point, but there are a few ones that dominate the antineutrino production.

4.3 (Anti)Neutrino emission

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Neutrino Physics

Neutrinos are neutral leptons that interact weakly and are always produced in a given flavor eigenstate $|\nu_\alpha\rangle$ with $\alpha = e, \mu, \tau$.

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The Model

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Results

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Analysis

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Further Problems

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Conclusions

Bibliography

[1] Kenneth S. Krane. *Introductory Nuclear Physics*. Wiley, 1988.