Beta Decay Theory: What it means to Quantum Mechanics

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Abstract

This paper goes into depth about explaining the beta decay theory and goes over the history it took for Fermi to discovered the beta decay theory. Then, the objective of this experiment is to investigate if the beta decay theory aligns with observed data. To do this, eighty experiments are done where the decay time is recorded, forty experiments for H-3 to He-3 and the other forty experiments for C-14 to N-14. Then, it is found that H-3 to He-3 have an average decay time of 16.72 years and C-14 to N-14 have an average decay time of 6686 years. Finally, this paper uses the radioactive decay law to calculate theoretical values, and it is found that the calculated values align similarly to the theoretical values, thus proving that the beta decay theory does align with observed data.

I. Introduction

The goal of beta decay theory is to determine the time it takes for an atom to decay by finding the favorable ratio of neutron/proton. Therefore, there are two ways to approach beta decay theory: beta-minus decay (β^-) and beta-plus decay (β^+) which only occurs if the mother nucleus is less stable than the daughter nucleus. During beta-minus decay, the atom's atomic number increases as the neutron is converted to a proton. As a result, for conservation of charge to remain in the atom, the nucleus produces an electron (beta particle) along with an antineutrino. Meanwhile, during beta-plus decay, the atom's atomic number decreases as the proton is converted to a neutron. As a result, for conservation of charge to remain in the atom, the nucleus produces a positron (beta particle and is an electron's antimatter equivalent) and a neutrino.

A key quantitative prediction of beta decay (and all radioactive decay) is that nuclei decay probabilistically but with a well-defined average lifetime. For a large ensemble of nuclei, the number remaining undecayed after time t follows the radioactive decay law

$$N(t) = N_0 e^{-\lambda t}, \tag{1}$$

where N_0 is the initial number of nuclei and λ is the decay constant. The half-life $T_{1/2}$ is related to λ by

$$\lambda = \frac{0.693}{T_{1/2}}, \tag{2}$$

so each isotope is theoretically characterized by a unique half-life and decay constant.

II. History

The journey of discovering the beta decay theory started when Soddy and Rutherford proposed that transforming an element's atoms into another resulted in alpha and beta decay. However, an issue arose as the law of conversation of energy contradicted with the the energy that was being produced by the radioactive decay. Then, in 1905 Einstein proposed his theory of relativity which provided a partial solution as with energy and mass being equivalent, it could cause the energy that occurred during radioactive decay. Then, in 1931 Pauli proposed that during beta decay, it involved electrons and neutral particles where their shared energy equaled the difference between the parent and product nuclei's mass-energy. Finally, Fermi discovered a weak force that possessed a range that was less than the gravitational and electromagnetic forces by proposing that during beta decay both an electron and antineutrino were produced when the neutron converted to a proton. As a result, Fermi discovered a coupling constant that came from looking at his data of beta decays and his derivation of beta emissions, and sent his findings by the end of 1933.

III. Experiment

TEXT HERE

IV. Measurements

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V. Theory vs. Results

To have a proper comparison of the beta decay theory results and the experimental results, the average decay time of H-3 to He-3 and the average decay time C-14 to N-14 need to be found. Therefore the following formula will be used:

$$t_{\text{avg}} = \frac{1}{N}\sum_{i=1}^{N} t_i, \tag{3}$$

With N representing the amount of experiments, then $N = 40$ as there are forty experiments for H-3 to He-3 and forty separate experiments for C-14 to N-14. Therefore, using the equation above, the decay time average for H-3 to He-3 is 16.72 years and the decay time average for C-14 to N-14 is 6686 years.

Next, to find the theoretical results of H-3 to He-3 and C-14 to N-14, the lifetime, $\overline{T}$, needs to be found. This can be done taking the inverse of equation (2):

$$\overline{T} = (\lambda)^{-1} = \frac{T_{1/2}}{0.693} \tag{4}$$

From here, the half-life of H-3 to He-3 is defined to be around 12 years and the half-life of C-14 to N-14 is defined to be around 5600 years. As a result, when using equation above, the lifetime of H-3 to He-3 is 17.32 years and the lifetime of C-14 to N-14 is 8081 years. Finally, percent difference will be used to compare the experiments to the theoretical which is defined as the following:

$$\%_{difference} = \frac{|t_{avg} - \overline{T}|}{\overline{T}} * 100 \tag{5}$$

As a result, when using the defined equation above, for H-3 to He-3 there's a percent difference of 3.464% and for C-14 to N-14 a percent difference of 17.26%. Therefore, the percent difference for both experiments shows that the experimental results tend to align with the predicted results that comes from the beta decay theory. Thus, what can be concluded about the system is that beta decay theory is occuring and that since beta-plus decay can only happen if the mother nucleus is less stable than the daughter nucleus, then it can also be concluded that a beta-minus decay is occurring. It can further be concluded that a beta-minus decay is occurring because it results in the atom's atomic number to increase, which happens for H-3 to He-3 as H-3 has an atomic number of 1 and then goes to He-3 with an atomic number of 2, showing an increase. This also happens for C-14 to N-14 as well since C-14 has an atomic number of 6 and then goes to N-14 with an atomic number of 7, showing an increase.

VI. Conclusion

This paper proved that the beta decay theory does align with observed data. To start, the beta decay theory is defined as having two decays: beta-minus decay and beta-plus decay. For the beta-minus decay, it results in the atom's atomic number to increase since the neutron is converted to a proton. Then, eighty experiments occurred where each experiment records a decay time, forty experiments are performed for H-3 to He-3 and another forty experiments are performed for C-14 to N-14. Afterwards, the averages of each set of forty experiments are taken into account, resulting in H-3 to He-3 to have an average decay time of 16.72 years and C-14 to N-14 to have an average decay time of 6686 years. Next, to calculate theoretical values the radioactive law is used to derive the general formula for the decay constant (λ). From here, the general formula of λ is inversed to find the general formula for the lifetime ($\overline{T}$). This then results for the estimated half-lives of H-3 to He-3 and C-14 to N-14 to be used in the general formula for $\overline{T}$ to calculate the theoretical decay times. Finally, the percent difference is taken with the experimental and theoretical decay times for H-3 to He-3 where it has a 3.464% difference and for C-14 to N-14 where it has a 17.26% difference. As a result, this shows that the calculated values align similarly to the theoretical values, thus proving the beta decay theory since it's defined that for beta-minus decay, the atomic number increases (which happens for both H-3 to He-3 and C-14 to N-14).

VII. References

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