

Beta decay blackbody model

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Abstract

The energy beta spectrum of radioactive beta emitters is similar to the continuous spectra of thermal radiation, thermionic emission and bremsstrahlung. A useful and universal way of describing such spectra is the blackbody model.

Introduction

Figure 1 shows a typical spectrum of a radioactive beta emitter. Beta decay is the main decay channel of ^{210}Bi isotope, the contribution of alpha decay does not exceed $10^{-4}\%$. The half-life of 5 days.

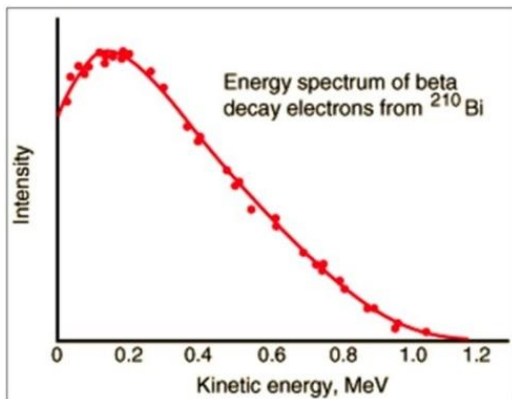


Fig. 1. Energy Spectrum of ^{210}Bi Beta Decay Electrons from G.J. Neary.

Model

Let's say a beta emitter is a black body with a nuclear Fermi gas. Gas quasiparticles have a charge, not necessarily a whole, and obey Fermi-Dirac statistics. The presence of a charge allows the kinetic energy to be expressed in electrical units. The following is a fragment of a mathcad file with the simplest blackbody formula for ^{210}Bi beta power density depending on the kinetic energy of the beta particles:

$\text{fm} := 10^{-15} \text{ m}$	$\text{AMU} := 1.66053886 \cdot 10^{-27} \cdot \text{kg}$
$h := 6.6260693 \cdot 10^{-34} \cdot \text{J} \cdot \text{s}$	$k_b := 1.3806505 \cdot 10^{-23} \cdot \frac{\text{J}}{\text{K}}$
$\text{eV} := 1.602176565 \cdot 10^{-19} \cdot \text{J}$	$\text{MeV} := 10^6 \cdot \text{eV}$
$m_{\text{Bi}} := 210 \text{ AMU}$	$r_{\text{Bi}} := 1.23 \text{ fm} \cdot \sqrt[3]{210}$
$r_{\text{Bi}} = 7.311 \text{ fm}$	
$n_{\text{fg}} := \frac{1}{r_{\text{Bi}}^3}$	$n_{\text{fg}} = 2.559 \times 10^{42} \cdot \frac{1}{\text{m}^3}$
fermi-gas concentration in ^{210}Bi	
$E_{\text{peak}} := 0.23 \text{ MeV}$	$T_K := 0.80 \cdot 10^9 \cdot \text{K}$
$PD(E, T_K) := \frac{E^2 \cdot n_{\text{fg}}}{h} \cdot \frac{1}{e^{\frac{2 \cdot E}{3 \cdot k_b \cdot T_K}} + 1}$	black body formula for beta spectrum ^{210}Bi
$PD(E_{\text{peak}}, T_K) = 5.118 \times 10^{47} \cdot \frac{\text{W}}{\text{m}^3}$	$PDa(E, T_K) := \frac{PD(E, T_K)}{PD(E_{\text{peak}}, T_K)}$

Figures 2-3 allow you to visually compare the beta spectrum of ^{210}Bi according to the blackbody formula with the experimental spectrum from G.J. Neary's article and pioneering work of C.D. Ellis and W.A. Wooster.

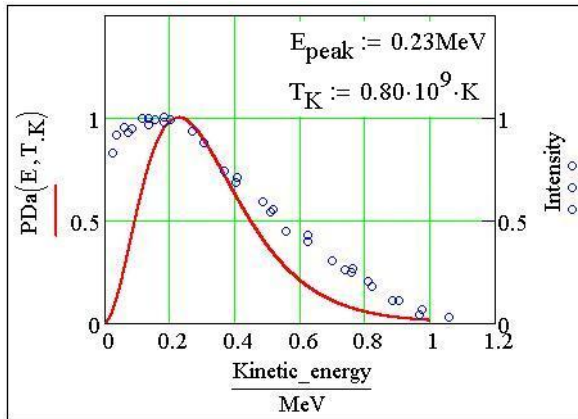


Fig. 2. The energy spectrum of ^{210}Bi beta decay electrons according to the blackbody formula (red line) and the experimental spectrum from G.J. Neary's article (blue circles).

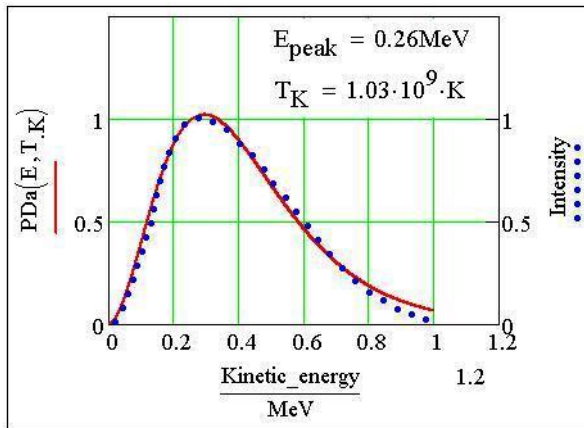


Fig. 3. The energy spectrum of ^{210}Bi beta decay electrons according to the blackbody formula (red line) and the experimental spectrum from pioneering work of C.D. Ellis and W.A. Wooster (blue dots).

Figure 4 from the article by G.A. Gamov demonstrates the difference in the shape of the spectra of neighboring beta emitters in the uranium series - ^{214}Pb (RaB), ^{210}Bi (RaE), ^{214}Bi (RaC). Within the framework of the blackbody model, the difference in the spectra may be associated with different temperatures of the nuclear fermi-gas.

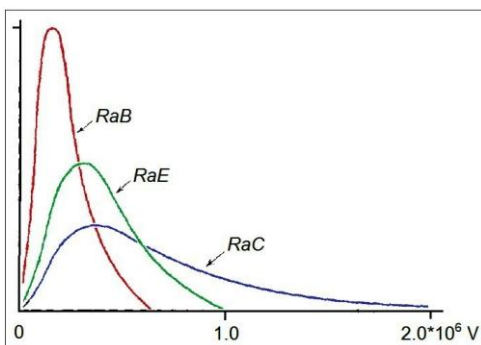


Fig.4 . The shape of the spectra of neighboring beta emitters in the uranium series - ^{214}Pb (RaB), ^{210}Bi (RaE), ^{214}Bi (RaC).

Conclusions

It seems that it is possible to search neutrino of beta decay in details of the shape of experimental spectrum that distinguish it from blackbody model.

A curious prediction of the model is the very high temperature of the nuclear Fermi gas. If this is true, then experimentally detecting the dependence of beta decay on temperature will not be a very simple task.

References

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