Spectroscopy of Beta Particles

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1 Introduction

In this experiment, the β^- and β^+ emission of ^{90}Sr and ^{22}Na will be investigated through the kinetic energy of the spectrum of the particles using the Geiger counter.

2 Theory

The emission of energetic electrons or positrons from a nucleus is called β decay. The electron emission from the nucleus is called β^- decay and the positron emission from the nucleus is called β^+ decay. And the capture of an electron by the nucleus is called a capture.

In all of these procedures, the charge of the system and the energy is preserved. Generally, β^- decay occurs when there are more neutrons than the protons. In this process, a neutron is turned into a proton and by the charge conservation, there should be an emission of an electron. Similarly, β^+ decay generally occurs when the nucleus contains more protons than the neutron. In this case, the nucleus becomes more stable by increasing the number of neutrons[1]. Again there must be an emission of a positively charged particle, with the same charge as the proton. Schematically these decays can be represented as follows

$$ {}^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e} \tag{1} $$
$$ {}^{1}_{1}\mathrm{p} \rightarrow {}^{1}_{0}\mathrm{n} + {}^{0}_{+1}\mathrm{e} \tag{2} $$

Therefore the β^- decay of an atom can be represented as

$$ {}^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X} \rightarrow {}^{\mathrm{A}}_{\mathrm{Z+1}}\mathrm{X} + {}^{0}_{-1}\mathrm{e} \tag{3} $$

Where ${}^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X}$ represents mother nucleus,${}^{\mathrm{A}}_{\mathrm{Z+1}}\mathrm{X}$ represents daughter nucleus and ${}^{0}_{-1}\mathrm{e}$ represents β^- particle. Following the energy conservation principle, one can obtain

$$ m_x c^2 = m_y c^2 + K_y + m_c c^2 + K_e \tag{4} $$

Defining Q, the disintegration energy of this as

$$ Q = K_y + K_e = (m_x - m_y - m_c)^2 \tag{5} $$

Since the created particles, namely the daughter nucleus, kinetic energy, and the β^- particle's kinetic energies are positive, the disintegration energy is also positive which corresponds to the energy equivalence of the missing mass in this process. It can be considered that the recoil energy or the kinetic energy of the daughter nucleus is negligible. Considering $K_y \approx 0$

$$ Q \approx K_e \tag{6} $$

So it can be said that all the energy is spent on the kinetic energies of the β^- particles. This requires the discreet appearance of the kinetic energy vs particle count spectrum, i.e the spectrum of β^- particles. As can be seen from the figure (4.1) and (4.2) this is not the case. Since the energy conservation principle seems valid, this violation of energy conservation points out that the $\beta^\pm$ process creates a new particle called the neutrino. This particle must satisfy the requirements, that the conservation laws impose. Those are the following

1. The particle must have no mass or a small fraction of the electron's mass to satisfy the energy conservation principle.
2. It must have quantum number $\frac{1}{2}$ to satisfy the angular momentum conservation principle.
3. It must have no charge to satisfy the charge conservation principle.

So the equations (1)-(3) must be revised accordingly. They become

$$ {}^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e} + \bar{\nu} \tag{7} $$
$$ {}^{1}_{1}\mathrm{p} \rightarrow {}^{1}_{0}\mathrm{n} + {}^{0}_{+1}\mathrm{e} + \nu \tag{8} $$
$$ {}^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X} \rightarrow {}^{\mathrm{A}}_{\mathrm{Z+1}}\mathrm{X} + {}^{0}_{-1}\mathrm{e} + \bar{\nu} \tag{9} $$

Where ν and $\bar{\nu}$ is neutrino and anti-neutrino respectively. They are identical except for their spin directions. Now also the equation (6) must be also changed as following

$$ Q \approx K_e + E_\nu \tag{10} $$

So the disintegration energy is shared by the electron and the neutrino.

In the experiment, the samples of ^{90}Sr and ^{22}Na samples are placed and a counter will determine the radioactivity (see Experimental Setup). The β particles have different kinetic energies and to measure the particles with exact kinetic energies, the path of the particle is manipulated with the magnetic field. Since the magnetic field applies force perpendicular to the particle's path, the particle does not gain or lose energy. So setting the different magnetic field strengths would allow the measurement of the β particles with specific kinetic energies. The relationship between the applied magnetic field strength and the particle's kinetic energy can be derived easily. Since the Lorenz force and the centripetal acceleration is equal one can get

$$ evB = \frac{mv^2}{r} \tag{11} $$

Where v is the speed of the particle, B is the applied magnetic field in Tesla, and r is the radius of the circular path of the particle. This yields the momentum of the particle

$$ p = mv = eBr \tag{12} $$

Total relativistic energy of the particles is then

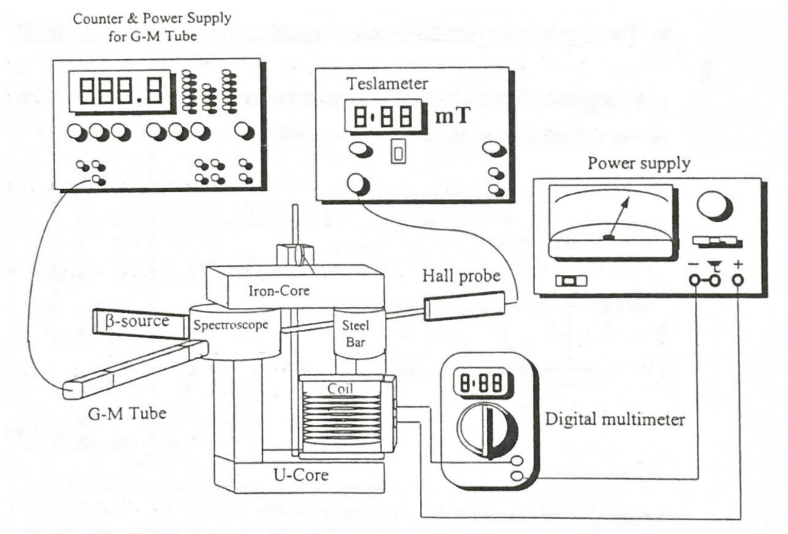
$$ E = \sqrt{p^2c^2 + m_0^2c^4} \tag{13} $$

The kinetic energy K of the particle is then

$$ K = \sqrt{(eBrc)^2 + m_0^2 + c^4} - m_0c^2 \tag{14} $$

3 Experimental Setup

Experimental setup consist of the radioactive sample, spectroscope, solenoid coil, Tesla-meter, power supply and a Geiger-Müller counter. Schematically it is as following



The beta source emits energetic electrons particles or β particles and in the spectroscope, their path is manipulated with a magnetic field, i.e solenoid. They send to the Geiger-Müller tube. It must be pointed out that the radius of the path is equal to $5cm$.

Geiger-Müller tube consists of low-pressure gas (helium, neon, or argon) which applied high potential difference. The potential difference allows an electric current when an energetic particle or photon strikes upon it. The voltage must be arranged such that it does not allow a continuous flow of electric current so that it can not damage the equipment, and also it must not be too low otherwise no electric current would yield no information of radiation. The counter does not differentiate the radiation since it just measures the electric number of electric flow. But since the particles are being manipulated with the solenoid, the kinetic energies of the particle are determined using the equation (14).

Power supply determines the supplied ampere for the solenoid, increasing it would result in an increase in the magnetic field in the solenoid. The desired magnetic field strength is read from the Tesla meter.

4 Measurements

4.1 β^- Decay of Na Sample

Background Counts	Trial I	Trial II	Average Count
	30	14	22

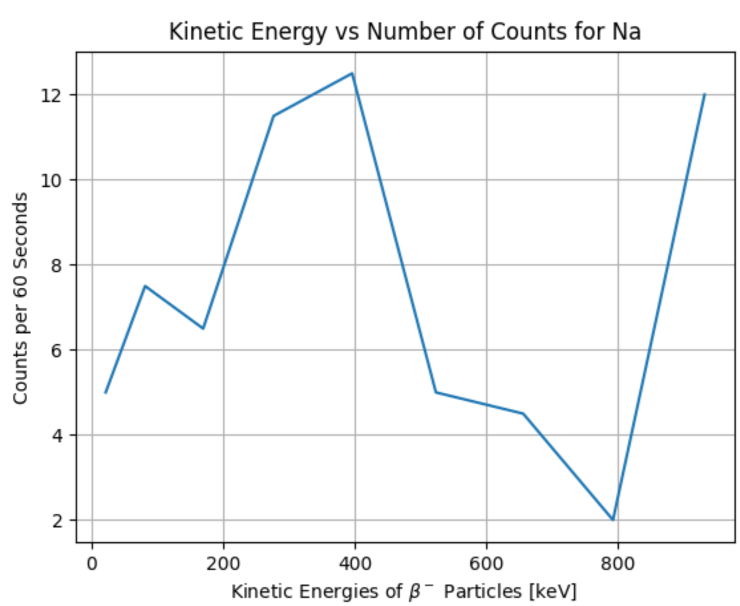
Table 1: Background Radiation Count

Counts at B=0	Trial I	Trial II	Average Count
	24	32	33

Table 2: Counts at zero magnetic field strength for Na

Number of β^- Particles					
B[mT]	Trial I	Trial II	Average	Corrected Avarage	Energy [keV]
10	28	38	33	5	21.53
20	43	28	35.5	7.5	81.45
30	33	36	34.5	6.5	169.72
40	37	42	39.5	11.5	276.86
50	43	40	41.5	12.5	396.22
60	38	26	32	5	523.59
70	29	34	31.5	4.5	656.34
80	30	30	30	2	792.84
90	38	42	40	12	932.01

Table 3: Counts of beta β^- particles for different values of magnetic field strength



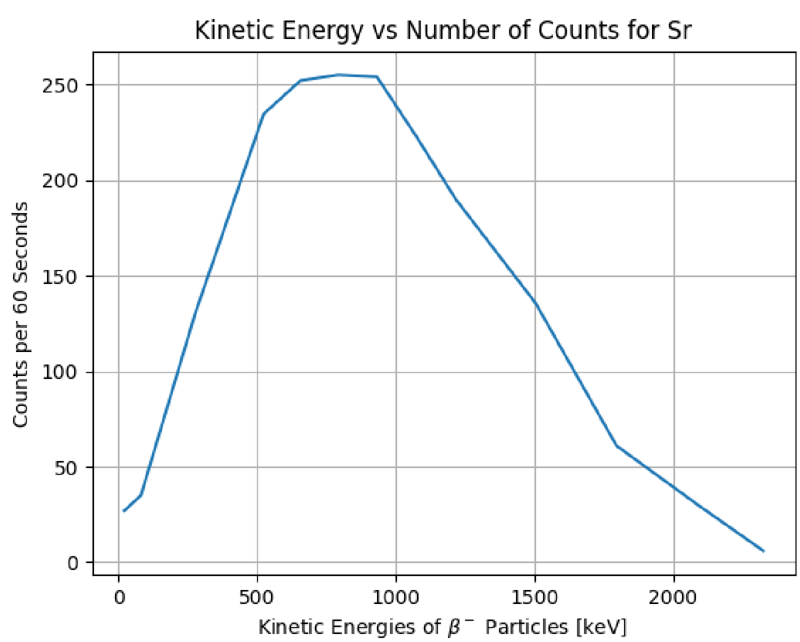
4.2 β^- Decay of Sr Sample

Counts at B=0	Trial I	Trial II	Average Count
	41	36	38.5

Table 4: Counts at zero magnetic field for Sr

Number of β^- Particles					
B[mT]	Trial I	Trial II	Average	Corrected Average	Energy [keV]
10	50	48	49	27	21.53
20	58	56	57	35	81.45
40	168	156	152	130	276.86
60	264	249	256.5	234.5	523.59
70	265	283	274	252	656.34
80	277	277	297	255	792.84
90	285	267	276	254	932.01
100	263	227	245	223	1073.17
110	207	217	212	190	1215.81
130	159	152	155.5	135.5	1504.31
150	90	76	83	61	1795.74
170	50	54	52	30	2089.12
186	22	34	28	6	2324.83

Table 5: Counts of beta β^- particles for different values of magnetic field strength



5 Results and Discussion

The kinetic energies of the particles have been calculated according to the equation (14) using python (see appendix). The endpoint kinetic energy of the ^{90}Sr can be taken as the last data since the count nearly drops down to the background radiation count.

For the ^{90}Sr there are two different beta decays with different maximum kinetic energies. It decays emitting an electron with a maximum energy of 546 keV into yttrium (^{90}Y). The latter decays through β^- decay with a maximum energy of 2274 keV into ^{90}Zr with a half-life of 64.1 hours. Since the half-life of the latter beta decay is much shorter, the expected end point energy is also the latter.

It can be seen from the graph (4.2) and the table (5) that the measured end point energy is $2324.83 keV$. Accepted value of the end point energy is $2273 keV$[2], so therefor

$$\left|\frac{h_{experimental} - h_{excepted}}{h_{excepted}}\right| \times 100 = \left|\frac{2324.83 - 2273}{2273}\right| \times 100 = 2.28\% \tag{15}$$

Since every device in this experiment has a confidence interval, the error propagates through the equation (14). To decrease this random error the measurements can be repeated. Also, the counts were per sixty seconds, making the counts in a longer interval would result in reduction of the random error.

6 References

1- https://en.wikipedia.org/wiki/Betadecay

2- https://www.ld-didactic.de/software/524221en/Content/Appendix/Sr90.htm