Department of Physics, Indiana University (HOM, January 2000)

Beta Spectrum

Goal: to investigate the spectrum of β rays emitted by a ^{137}Cs source. The instrument used is a so-called 180° magnetic spectrometer that separates β rays of different momenta by the fact that they follow different paths in a magnetic field.

1. Introduction

The continuous spectrum of β rays emitted from a radioactive source has been explained by Fermi[1] [FER34]. Introductions into the theory of β decay can be found in many texts [2, 3, 4, 5]. Aside from the Fermi decay, there exists also a process called 'Internal Conversion' (of nuclear excitation energy) which leads to *discrete* lines in the β spectrum (ref. 2, p.396, ref. 5, p.362). A lot of interesting information on internal conversion is contained in a PhD thesis[6] of a former IU student. Here, it is assumed that you have learned enough about β decay to be able to answer the following questions: What determines the shape of the continuous spectrum? What is a Kurie plot? Can you explain the Internal Conversion process?

In this experiment we study the β decay of the ^{137}Cs nucleus that includes both, the Fermi decay and the internal conversion. You can find a lot of detailed information on this decay in ref. 7. Try to answer the following: What is the half-life of ^{137}Cs? What is the highest energy β rays that are emitted from ^{137}Cs? What role does the nucleus ^{137}Ba play in all of this? What are the expected energies of the conversion lines? Draw a decay scheme with the relevant details using information from ref. 7.

2. Equipment

The principle of operation of magnetic β spectrometers is explained in ref.2, p. 52-63. Some important relations between the parameters of the instrument and the quantities to be measured are also given there.

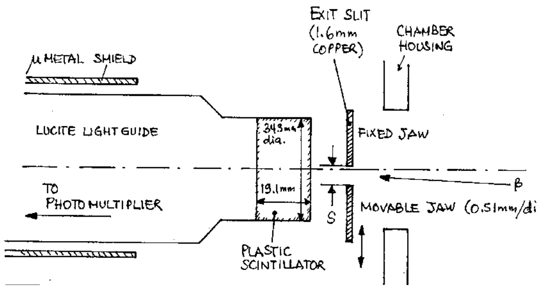
In the 1950's the measurement of β activity in nuclei was an important part of the nuclear research in the IU Physics Department, and a group headed by L.M. Langer (†2000) made many important contributions to the field. The spectrometer used in our lab is a piece of history of physics at IU. It is a somewhat smaller version of the original device [8, 9], built in 1948. Cook's thesis [9] contains a detailed description of the apparatus and many experimental details, and you should definitely read it. The smaller, newer device is also described in the literature[10]. A copy of ref. 10 is enclosed.

In the magnetic field of the spectrometer β rays from a source are guided on a semi-circular path to a slit in front of a detector. The pole pieces are cleverly shaped, providing a radial field dependence such that about 8% of the β rays emitted by the source are focused onto the exit slit. At a given magnetic field *B* (in Gauss), β rays of a certain momentum *p* (in keV/c) are transported around the semi-circular path with a mean bending radius ρ (in cm). In our instrument, ρ=15cm. The three quantities are related by the Lorentz force:

$$p = 0.3 \cdot B \cdot \rho \qquad (1)$$

The range of accepted momenta is defined by a slit of variable opening *s* (see fig.1). The slit width governs the momentum resolution Δp of the spectrometer. Using a typical slit witdh of s = 1 mm, you should estimate Δp as the difference in momentum between two β particles with bending radii ρ and $\rho + s/2$. In measuring a spectrum, it is clearly important that the magnetic field strength is known well[11]. Instead of using eq.1, it is more accurate to calibrate the relation between momentum and field by observing β's of a known momentum, e.g., from the K conversion line in ^{137}Ba (see ref.12).

Fig. 1 DETECTOR AND SLIT ASSEMBLY



The detector consists of a piece of plastic scintillator (fig.1) glued to a light guide that is coupled to a RCA 8575 photomultiplier. Pulses from the photomultiplier are sent to a discriminator which selects only pulses above an adjustable threshold for counting. This is needed in order to discriminate against the small, but frequent noise pulses. Since the pulse height also depends on the energy of the β particles, it is important to set the threshold carefully.

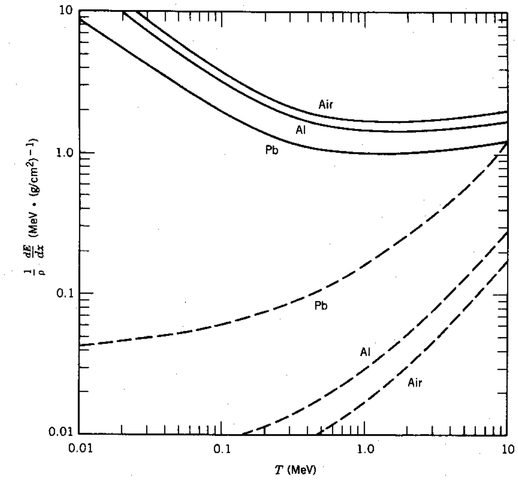


Figure 2 Energy loss by electrons in air, Al, and Pb. To suppress the large variation in *dE/dx* arising from the number of electrons of the material, the quantity $\rho^{-1}(dE/dx)$ is plotted. Solid lines are for collisions; dashed lines are for radiation. For additional tabulated data on energy losses, see L. Pages et al., *Atomic Data* **4**, 1 (1972).

The inside of the spectrometer is evacuated and a thermocouple gauge measures the pressure in the spectrometer chamber. The question arises: how good does the vacuum have to be? In order to answer this, you should calculate the energy loss along the semi-circular path of β's with momenta between 0.1 and 1.0 MeV/c and compare this figure to the momentum resolution Δp. The energy loss for β particles in various materials is given in fig.2.

3. Measurements

- the performance of photomultipliers is affected by magnetic fields: does the fringe field from the spectrometer have an effect on your measurement?
- how to set the threshold of the discriminator?
- measure the magnetic field B with the Hall probe and the flip coil.

- the magnet current I can be varied (useful range is from 20mA to 100mA): establish the connection between I and B; are there hysteresis effects?.
- calibrate the magnetic field using the known rigidity of the K conversion line ref. 2, p.227.
- measure the continuous part of the spectrum; construct a Kurie plot; determine the endpoint energy.
- how many conversion lines are visible? determine their energies.
- determine the conversion coefficient $_K$ of the K line.
- determine the intensity ratios between conversion lines.

4. References

[1] E. Fermi, Z.f.Physik **88** (1934) 161

[2] K. Siegbahn, Beta- and Gamma-Ray Spectroscopy, North-Holland, Amsterdam 1955. (QC771.S57)

[3] W.E. Burcham, Elements of Nuclear Physics, Longman, London 1979, p.295ff. (QC776.B85)

[4] H. Frauenfelder and E.M. Henley, Subatomic Physics, Prentice-Hall, Englewood 1974, p.273ff. (QC776.F845)

[5] E. Segré, Nuclei and Particles, Benjamin, Reading 1977, p.410ff. (QC776.S4)

[6] G.A. Graves, PhD thesis, Physics Department, Indiana University, 1952 (QC1000.G776)

[7] C.M. Lederer and V.S. Shirley, Table of Isotopes, Wiley, New York 1978.

[8] L.M. Langer and C.S. Cook, Rev. Sci. Instr. **19**, 257 (1948)

[9] C.S. Cook, PhD thesis, Physics Department, Indiana University, 1948 (QC1000.C77)

[10] J.A. Bruner and F.R. Scott, A High-Resolution Beta-Ray Spectrometer, Rev. Sci. Instr. **21,** 545 (1950).

[11] L.M. Langer and F.R. Scott, Rev. Sci. Instr. **21**, 522 (1950)

[12] L.M. Langer and R.D. Moffat, Phys. Rev. **78**, 74 (1950)