Radioactivity Physics Fundamentals

Will Schmidt

The purpose of this article on radioactivity is to explain and describe the following subjects:

- What radioactivity is
- How radioactive decay processes work
- When radioactive decay is initiated

Radioactivity is like the atomic nucleus speaking.

This article is really about the neutrino. How can such a small particle with no electric charge and very little mass (if any) control the destiny of the world and all living things?

Listen, the radioactive nuclear atom will tell you. This article will explain how the neutrino works and what it does. What the neutrino really is, has not yet been discovered.

There are three types of neutrinos: the electron neutrino, the muon neutrino, and the tau neutrino. They will be mentioned in examples below.

There are three major classes of radioactivity processes:

- Radioactive beta decay
- Alpha particle decay
- Decay of proton particles

These radioactivity processes will be described below and include:

- Radioactivity decay of the free neutron.
- Radioactivity decay of the proton (if any)
- Pion particle decay
- Muon particle decay.

By these radioactivity processes, nuclear structure is unfolding.

H. Becquerel discovered the ionizing effects of radioactivity radiation in 1899, and Rutherford showed that alpha particles were emitted as well as beta electrons.

What Radioactivity Is

Radioactivity is the spontaneous decay, or change, of one atom into another. The excitation energy of the radioactive atom must exceed the binding energy of the emitted particle. The decay process is regarded as a statistical process for which decay constants can be calculated to indicate the number of atoms that will decay per unit of time. Radioactive decay series are well known for uranium, actinium, and thorium. The nuclear reactions for the formation of daughter atoms resulting from the emission of decay particles are well known. These are given by the Bateman differential equations[(1)].

The specific process for ejection of the decay particle from the radioactive atom, and the process to determine the lifetimes of radioactive atoms, have not previously been known or published. This article will describe and explain them.

The Bohr Atom Model

The Bohr atom[(2)] is used here as an analogy to explain the radioactivity decay processes. Niels Bohr was awarded the Nobel Prize in physics in 1922 for his concept of the atom. The Bohr atom has a positively charged proton for a central nucleus with an orbiting negatively charged electron. There is a balance between the centrifugal force of the orbiting electron and the attractive electrostatic force between the electron and the proton nucleus.

The Bohr-like model is used in this article to present the physics that is assumed to take place within radioactive parent nucleons. In this way a great deal can be learned about the radioactivity decay process and nuclear structure that may not be obvious from observable measurements alone.

The neutron model is assumed to consist of a proton, an orbiting electron, and an anti-neutrino. These are exhibited following neutron decay.

Similarly, the proton is assumed to consist of a neutron, an orbiting positron, and a neutrino. These are exhibited following proton decay.

These radioactive nucleon models are used to describe the decay processes, and to incorporate a timing system to tell the radioactive nucleon when to initiate the decay process.

The very important role of neutrinos and anti-neutrinos in radioactivity decay is highlighted, and described for the first time.

All of this is explained below. The physics for every radioactivity decay process for all atoms, isotopes, and nuclear particles can be described and calculated using the Bohr-like models.

Free Neutron Beta Decay

Radioactivity beta decay of the free neutron is representative of the Bohr-like nuclear model used to describe radioactivity decay processes for all radioactive atoms. A free neutron decays with a lifetime of 10.6 minutes. It emits a negatively charged electron with energy of .782 Mev, and an electron anti-neutrino.

The parent radioactive atom, in which a neutron particle decays, consequently has the atomic number increased by one unit to become a different element. A neutron has been changed to a proton.

The free neutron beta decay process is indicated in the following sketch:

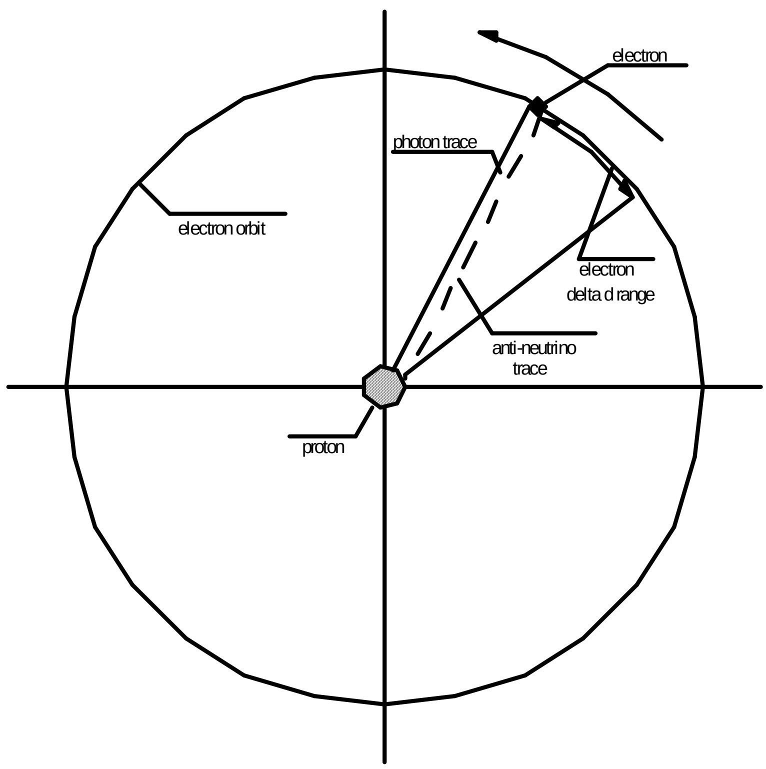


Figure 1

The Bohr-like Atom Model for Radioactivity Beta Decay

In this figure an orbital negatively charged electron circles a positively charged proton central nucleus.

Radioactivity Physics Fundamentals

Fundamentals for Radioactivity Decay Physics Calculations

Calculations can be made starting with a known neutrino mass to determine lifetime, or they can be made starting with lifetime to determine neutrino mass.

- A Bohr-like atom to represent a neutron particle is described.
- The orbiting electron is followed by photon and anti-neutrino traces.
- The anti-neutrino mass must be known (if any).
- An end-point, or distance, for the anti-neutrino trace is calculated to initiate decay.
- Photon energy is calculated, and this may determine anti-neutrino energy.
- A delay time for the anti-neutrino trace is calculated.
- Anti-neutrino delay time per orbit, times the number of orbits required for the anti-neutrino trace to reach the end point distance gives the lifetime for the radioactive atom or isotope.
- A reverse calculation starts with atom lifetime, and ends with the anti-neutrino mass.

Figure 1 above illustrates the Bohr-like atom that represents a neutron particle.

Radioactivity Decay Process

Basic physics of the radioactivity decay process includes two major nuclear processes:

1. Physics of the actual decay that includes ejection of a decay particle.
2. Physics of the clock within the neutron that determines when to initiate the decay process.

This radioactivity decay process is important to understand because it gives meaning to all radioactive particles.

Decay

Surprisingly, the physics for the actual radioactivity decay is simply an electrostatic repulsion process. Two particles with the same electric polarity have an electrostatic force between them. One particle is ejected from the other.

This electrostatic decay process occurs in the Bohr-like atom when the anti-neutrino trace reaches the end point distance mentioned above, and will be described in detail below. At that time, the anti-neutrino is no longer bound or associated with the orbiting electron.

By virtue of the weak charged current[(3)], the anti-neutrino goes to the proton and changes the electric charge from positive to negative. The orbiting electron, with the same negative electric charge, is ejected by electrostatic repulsion from the Bohr-like atom along with the anti-neutrino.

The proton electric charge then returns to positive. Radioactivity beta decay has happened!

The parent atom or isotope has the atomic number increased by one. A neutron has turned into a proton.

The nuclear equation for neutron beta decay is as follows:

$$ {}_0n^1 \rightarrow {}_1p^0 + \beta^- + \overline{\nu} + Q(.782Mev) $$

The anti-neutrino is an electron anti-neutrino.

Radioactivity Timing

Radioactivity decay time begins the moment when an atom or isotope is formed. The clock, or nuclear timing process, is within the Bohr-like atom that represents a neutron particle. It is a complicated process, but actually quite straight forward. See Figure 1.

Photons responsible for the attractive electrostatic force that holds the orbiting electron in orbit are indicated by the photon trace that extends from the proton to the electron.

The path of the anti-neutrino that tends to follow the orbiting electron is indicated by the anti-neutrino trace that extends from the central proton to the electron, or electron region.

The electron delta d range is the distance over which the electron can be considered to occupy. It is calculated using the Heisenberg uncertainty principal.

When the anti-neutrino trace moves to the end of the electron delta d distance, the actual decay process is initiated, as described above.

The number of orbital electron orbits required for the anti-neutrino trace to cover the delta d distance, times the electron orbital period yields the lifetime of the radioactive atom or isotope.

Calculations indicate that the number of orbital electron revolutions required for free neutron decay is 4.2×10^{18}. The decay time is 10.6 minutes or 636 seconds.

Stability of Bound Neutrons

Neutrons in an atomic nucleus are not free. They are bound to the atomic nucleus by the strong nuclear force. Pion particles mediate the strong nuclear force that continuously changes neutrons to protons and protons to neutrons. Electrically charged pions have an average lifetime of 2.6×10^{-8} seconds. Consequently, bound neutrons do not have time to decay, and they are stable.

Proton Particle Radioactivity Decay

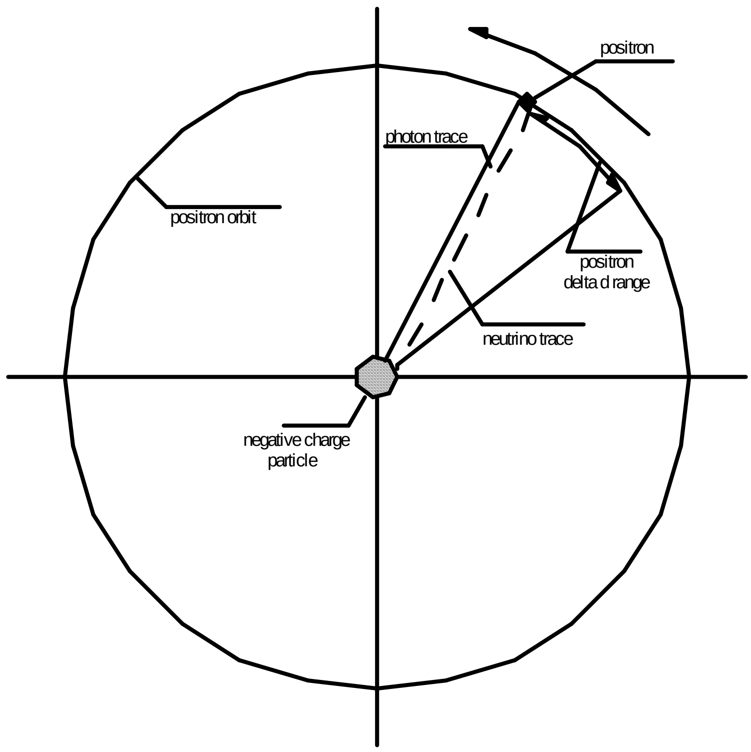


Figure 2

Bohr-Like Model of Proton

The proton radioactivity decay fundamental physics has a model similar to that for neutron beta decay. The orbiting particle is a positron rather than an electron and there is a neutrino rather than an anti-neutrino. The particle at the center of the atom necessarily has a negative electrical charge. It is like a negatively charged proton, or a neutron with a negative electrical charge. After proton decay, the central particle will be the neutron.

The nuclear equation for proton beta decay is as follows: Equation (1-1)

$$p \rightarrow n + e^{+} + \nu$$

The neutrino is an electron neutrino.

Because the neutron has more mass than the proton, it is clear that this reaction requires external energy to make it happen. In the sun this reaction is possible because of energy from the sun. In the Bohr-like model, proton decay would not be possible because the photon and neutrino traces would overlap due the the zero masses and high velocity of the electron neutrino.

Double Beta Decay

Double beta decay is a very interesting nuclear process. In an atom, two neutrons decay at the same time. The process is extremely rare and has a half life of about 10^{24} years[(4)]. The result of double beta decay is a parent atom with the atomic number increased by two. Two anti-neutrinos are produced by double beta decay. An example of double beta decay is given by the following equation: Equation (1-2)

$$ {}^{78}_{52}Te^{130} \rightarrow \beta^{-}\beta^{-} + {}^{76}_{54}Xe^{130} + Q(1.6Mev) $$

The very long half-life for double beta decay indicates that the masses for the anti-neutrinos must be very large. See Equation (1-3) page 9.

Neutrino and Anti-Neutrino Spins

Both neutrinos and anti-neutrinos have Fermi-Drac statistics. Their angular momentum is measured in units of $\frac{1}{2}\frac{h}{2\pi}$. The symbol h is Planck's constant. Neutrinos have a spin in a left hand direction, and anti-neutrinos spin in a right hand direction, relative to the velocity vector.

Electron Capture and Beta Decay

Electron capture by an atomic nucleus leads to a beta decay process. A proton in an atomic nucleus captures a nearby electron and becomes a neutron. A neutrino is emitted in the process. An Auger electron from an inner orbit is released to fill the captured electron vacancy.

Tritium Radioactivity Decay Fundamental Processes

Tritium is a hydrogen isotope with a nucleus consisting of a positively charged proton and two neutrons. There is an orbiting negatively charged electron that makes the electric charge neutral for the atom.

Tritium is a radioactive isotope with a lifetime of 12.33 years, or 3.88×10^8 seconds.

One of the tritium neutrons is considered stable and inactive, because of charged pion interaction with the proton to create the strong binding nuclear force. The other neutron in the tritium atom is then responsible for the tritium radioactive decay process. The clock for timing the decay process is within this neutron, and it executes the decay process just as described for the free neutron.

The subject neutron for tritium decay has a lifetime of 12.33 years while the lifetime for a free neutron is 10.6 minutes. Yet, the decay processes for these two neutrons are similar. This apparent anomaly is explained below.

Radioactive Atom Lifetimes and Neutrino Mass

Calculations indicate that the timing of the radioactive decay process in the Bohr-like atom representation of the neutron is governed by the mass of the anti-neutrino. This is true for tritium radioactive decay, and for the radioactive decay of all other atoms and isotopes.

The lifetime of all radioactive atoms and isotopes is governed by the mass of either the anti-neutrino or neutrino.

This has not yet been verified by experiment. However, calculations indicate that the anti-neutrino and neutrino masses are less for short lifetime radio-nuclides, and greater for those with longer lifetimes. This is an extremely important development that can lead to a better understanding of radioactivity and neutrino physics.

Calculations indicate that the lifetimes of radioactive atoms is proportional to the square root of the anti-neutrino or neutrino mass in the atoms, as indicated in the following equation:

Equation (1-3)

$$l = A\,(m_{\bar{\nu}})^{1/2}$$

Lifetime = l (seconds)

Anti-neutrino mass = m (electron volts)

A= constant

The destiny of the world and the destiny of all living things depend on neutrinos and anti-neutrinos. These are very small particles with no electrical charge and very little mass (if any). Yet, it is not known what they really are.

Designer Neutrinos and Neutrino Physics

Just as there are many nuclear reactions and nuclear procedures that can be performed with neutrons, it is reasonable that neutrinos and anti-neutrinos can provide many interesting interactions also. For example, with proper understanding and procedures, it is possible to perform neutron fusion experiments[(2)]. Two neutron particles can be fused together, and nuclear fusion reactors can be made.

Similarly, anti-neutrino and neutrino nuclear fusion reactions are possible. The nuclear fusion of anti-neutrinos and neutrinos should be a straight-forward process following neutron fusion techniques. Much depends on whether neutrinos have only two states according to the Majorana theory, left handed and right handed. Or, according to Dirac theory, four possible states: right or left handed for particle and anti-particle. A new world of a different species of atoms may be available for some interesting applications. There are people who would welcome stable tritium, for example.

Alpha Particle Radioactivity Decay

An alpha particle is an ionized helium nucleus. It consists of two neutrons and two protons bound together. The measured electric charge is 9.58×10^{-10} esu (electrostatic units) or about twice the basic electronic charge. The mass is that of the helium nucleus which is 4.003 amu (atomic mass units).

Examples of alpha particle radioactivity decay are given in Table 1-1. Alpha decays occur naturally in the uranium, actinium, and thorium radioactivity decay series. The decay process can be described by using the Bohr-like model that was used above to describe neutron and proton particle decay. Here the alpha decay process is assumed to be triggered by decay of one of the neutrons in the parent atom to produce a proton the can cause electrostatic ejection of the alpha particle from the atom.

Table 1-1

Alpha Particle Radioactivity Decay

Radionuclide	Energy (Mev)	Half-life	Binding Energy (Mev)
ThC$^{!}$ $_{84}{}^{128}Po^{212}$	8.783	3.0 x 10^{-7} sec	1.700 x 10^{3}
RaC$^{!}$ $_{84}{}^{130}Po^{214}$	7.683	1.637 x 10^{-4} sec	1.660 x 10^{3}
AcC $_{83}{}^{128}Bi^{211}$	6.621	2.16 min	1.770 x 10^{3}
RaA $_{84}{}^{134}Po^{218}$	5.995	3.05 min	1.730 x 10^{3}
RaF $_{84}{}^{126}Po^{210}$	5.297	138.38 day	8.050 x 10^{4}
$_{86}Rn^{222}$ $_{86}{}^{136}Em^{222}$	5.486	3.824 day	1.740 x 10^{3}
ThX $_{88}{}^{136}Ra^{224}$	5.681	3.64 day	8.058 x 10^{4}
$_{86}Tn^{220}$ $_{86}{}^{134}Ra^{220}$	6.282	55.6 sec	8.055 x 10^{4}
ThA $_{84}{}^{132}Po^{216}$	6.774	.16 sec	8.052 x 10^{4}

The timing clock, in the selected neutron, to initiate radioactivity decay is based on the neutron decay time of 636 seconds. Longer decay times are achieved by shutting down the neutron timer clock for certain increments of down time, or “off time”. The clock down time is the result of pion interchange particles that change neutrons to protons intermittingly while mediating the strong nuclear force.

For tritium, that has a lifetime of 12.33 years, the fraction of “on time” for the selected timer neutron is 1.64 x 10^{-6}. This means that the neutron timer is off most of the time.

Calculations show that there is more Bohr-like model “off time” for radioactive elements and isotopes that have greater binding energy.

Shorter radioactivity periods result from neutrino and anti-neutrino mass values that approach zero, like the photon mass for the photon trace in the Bohr-like model. See equation (1-3) page 9.

There are also energy level considerations that affect radioactivity decay, as mentioned above.

Pion and Muon Radioactivity Physics

Pion decay equations:

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu} \qquad (1\text{-}4)$$

$$\pi^{-} \rightarrow \mu^{-} + \overline{\nu}_{\mu} \qquad (1\text{-}5)$$

$$\pi^{0} \rightarrow \gamma + \gamma \qquad (1\text{-}6)$$

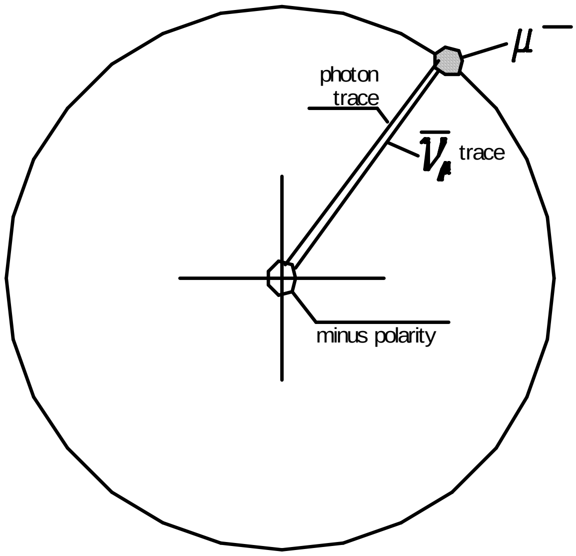
Muon decay equations:

$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \overline{\nu}_{\mu} \qquad (1\text{-}7)$$

$$\mu^{-} \rightarrow e^{-} + \overline{\nu}_{e} + \nu_{\mu} \qquad (1\text{-}8)$$

Bohr-like models of the negative pion and negative muon are given below.

The negative pion has a negative muon in orbit around a negatively charged central nucleus. The nucleus is said to be negative because that polarity is required for the daughter muon after 2.6 x 10^{-8} seconds. See figure 4. Prior to decay, the nucleus is a positively charged particle. There is a negative muon anti-neutrino trace between the central nucleus and the orbiting negative muon. There is also a photon trace between the central nucleus and the orbiting negative muon. Photons are necessary for the electrostatic attractive force between the central nucleus and the orbiting muon.



Bohr-like model of π^-

Figure 3

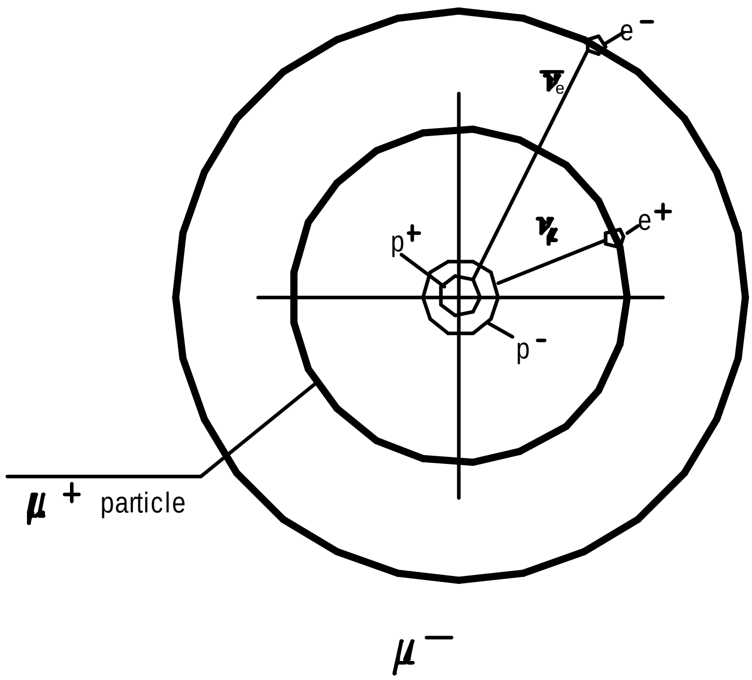


Figure 4

Bohr-like Model of Negative Muon

The Bohr-like models of the positive pion and the positive muon are similar to the respective negative models except for the appropriate polarity sign and neutrino changes.

Table 1-2

Table of Physical Properties

Particle	Mass (Mev)	Lifetime (seconds)
Π^{+}	139.6	2.6×10^{-8}
Π^{-}	139.6	2.6×10^{-8}
Π^{0}	139.6	$.9 \times 10^{-16}$
μ^{+}	105.6	2.2×10^{-6}
μ^{-}	105.6	2.2×10^{-6}

Pion particles enter the atmosphere from outer space. They quickly decay and produce muon particles that can reach sea level because of time dilation due to the relativity effect resulting from their high velocity. Pions and muons can both be formed in high energy accelerators.

The rate of decay, and lifetime, is influenced by the coupling constant and the difference between the parent mass and the masses of daughter products. The π^{0} decay is by the electromagnetic interaction, rather than the weak interaction, and that is the reason for its very short lifetime.

The neutrino mass can be calculated from the relation derived above for equation (1-3) page 9.

$$l = A\,(m_{\bar{\nu}})^{1/2}$$

This relation has not been verified by experiment. However, short lifetime atoms and isotopes can be expected to have neutrinos and anti-neutrinos with less mass that those atoms and isotopes that have longer lifetimes.

Muon Particle Decay

Muon particle decay is especially interesting because both anti-neutrino and neutrinos are emitted. This decay process can be understood from the Bohr-like model that shows the pion plus imbedded within the muon minus particle. See Figure 4, page 13. A similar model can be used for the muon plus particle in which a muon minus particle is imbedded.

Summary

Radioactivity is the atomic nucleus speaking. By their decay products you will know them. The importance of neutrinos and anti-neutrinos has been described above, both for radioactivity and for survival. The following table is presented to complete the picture:

Table 1-3

Charged Leptons and Their Neutrinos

Lepton	Mass (Mev)	Neutrinos
Electron	.511	$\nu_e \quad \overline{\nu}_e$
Muon	105	$\nu_\mu \quad \overline{\nu}_\mu$
Tau	1754	$\nu_\tau \quad \overline{\nu}_\tau$

References

1 Irving Kaplan, *Nuclear Physics*, p. 200, Addison-Wesley, 1958

2 Will Schmidt, *Make Chemical Elements*, p. 51, private printing, available Ebay, 2012

3 Yuval Ne'eman, Yoram Kirsh, *The Particle Hunters*, p. 254, Cambridge University Press, 1986

4 Robley D. Evans, *The Atomic Nucleus*, p. 288, McGraw-Hill, 1955