The Energetics of Positron Decay

TO THE EDITOR: In teaching residents and in conversations with nuclear medicine physicians and physicists, I have noticed over the last several years that there is a great deal of confusion regarding the energetics of positron decay. The problem lies in the explanation of the 1.022 MeV minimum energy requirement necessary for positron decay which is indicated as a vertical line originating from the parent nuclide in the MIRD decay schemes. Various textbooks state that this is the minimum energy which the nucleus must possess before positron decay can occur (*1–4*) or that the transition energy includes the energy of the two annihilation photons (*5–7*). The first explanation is incorrect, and the second is misleading. The problem arises because a nuclide, which by definition is an atom, is often confused with the nucleus of an atom.

In positron ($\beta+$) decay, as in beta ($\beta-$) decay, the nucleus ejects a particle with a rest mass energy of 511 keV (A neutrino and an antineutrino, respectively, are also ejected. They have either a zero or very small rest mass and can be ignored for the purposes of this discussion). Therefore, for either $\beta+$ or $\beta-$ decay, the parent nucleus must have a rest mass energy at least 511 keV greater than the daughter nucleus. Masses of nuclei, however, are not readily available. Masses of nuclides (which by definition are atomic masses) have been measured to a high degree of precision and are readily available, for example, in the Chart of the Nuclides or the Handbook of Chemistry and Physics. Therefore, when doing energy calculations for radioactive decay, it is simpler to use atomic (nuclide) masses. When using atomic masses in decay equations, the orbital electrons must be taken into account, and the ground states of the parent and daughter nuclides are used. $\beta+$ decay can then be written in the following way using the carbon-11 atom as an example:

$$\overset{11}{\underset{6}{\mathrm{C}}} \rightarrow \overset{11}{\underset{5}{\mathrm{B}}} + e^- + e^+$$

After nuclear decay, an electron is lost from the electron cloud because there is one less positive charge in the nucleus. Rewriting this equation as:

$$\overset{11}{\underset{6}{\mathrm{C}}} - \overset{11}{\underset{5}{\mathrm{B}}} \rightarrow e^- + e^+ = 1.022 \text{ MeV}$$

shows that the 1.022 MeV energy requirement comes from the fact that two particles whose total rest mass energy is 1.022 MeV are emitted from the parent atom.

It is unclear why positron decay has been described incorrectly in so many nuclear medicine textbooks (some textbooks do describe it correctly (*8,9*)) since the difference between atomic and nuclear decay is well described in standard physics texts (*10,11*). The problem may arise for two reasons: (a) a nuclide is an atom, not a nucleus, and atoms are represented in the MIRD decay schemes, (b) decay equations use the same notation for the nucleus as the MIRD decay schemes use for the parent and daughter atoms.

References

1. Mettler FA, Guiberteau MJ. Essentials of nuclear medicine imaging, 2nd ed. Orlando: Grune & Stratton, Inc., 1986:2.
2. Rollo FD. Radioactivity and properties of nuclear radiation. In: Rollo FD, ed. *Nuclear medicine physics, instrumentation, and agents.* St. Louis, C.V. Mosby Co., 1977:46–47.
3. da Rocha AFG. Atomic and nuclear structure. In: Harbert J, da Rocha AFG eds. *Textbook of nuclear medicine, Vol 1.* Basic Science. 2nd ed. Philadelphia: Lea & Febiger, 1984:13.
4. Hendee WR. Medical radiation physics: roentgenology, nuclear medicine, & ultrasound, 2nd ed. Chicago: Year Book Medical Publishers, Inc., 1979:24.
5. Sorenson JA, Phelps ME. Physics in nuclear medicine, 2nd ed. Orlando: Grune & Stratton, Inc., 1987:31.
6. Patton JA, Rollo FD. Basic physics of radionuclide imaging. In: Freeman LM ed. *Freeman and Johnson's Clinical Radionuclide Imaging,* 3rd ed. Orlando: Grune & Stratton, 1984:25.
7. Evans RD. Radioisotopes and their radiations. In: Blahd WH ed. Nuclear medicine, 2nd ed. New York: McGraw-Hill Book Co., 1965:16.
8. Chandra R. Introductory physics of nuclear medicine, 3rd ed. Philadelphia: Lea & Febiger, 1987:16.
9. Turner JE. Atoms, radiation, and radiation protection. New York: Pergamon Press, 1986:56.
10. Wehr MR, Richards JA Jr. Physics of the atom. London: Addison-Wesley Publishing Company, Inc., 1960:291–292.
11. Arya AT. Fundamentals of nuclear physics. Boston: Allyn and Bacon, Inc., 1966:225–226.

Jerry V. Glowniak
Veterans Administration Medical Center
Portland, Oregon