End Notes for Every Chapter

Chapter 7

[1] H.E. Suess and H.C. Urey, *Reviews of Modern Physics* **28,** 53 (1956). Hans Suess became my lifelong friend, and we met frequently in Heidelberg during 1977-84, years when we both resided during summers in Heidelberg. Suess's insights into the correlation between nuclear magic numbers and the natural abundances were prescient, and well noted by Fowler. Suess deserves regard in that sense as a pioneer of nucleosynthesis.

[2] Donald D. Clayton, *Physical Review* **128**, 2254 (1962). Tommy Lauritsen's drawings adorning the walls of the Kellogg hallway were submitted from time to time for publication in *Nuclear Physics* with his collaborator Fay Selove. In this way they were shared as published knowledge. These were an important aspect of the evolution of nuclear physics. What impressed me deeply was that drawings adorning the walls of a building would be the up-to-date knowledge in science, more up-to-date than the published literature. The difference from undergraduate education was glaring.

[3] Donald D. Clayton, "Hoyle's Equation", *Science* **318**, 1876 (2007). Fifty years after the publication of *B^2FH* I would attempt to redress the fame imbalance between Hoyle's 1954 paper and *B^2FH*. Not entirely coincidentally, my public foray into that arena began at Caltech in my presentation http://www.na2007.caltech.edu/program2.html during a conference called to celebrate the 50th anniversary of *B^2FH.* A third such foray was published one year later in *New Astronomy Reviews* **52**, 360 (2008). But during my graduate student years I was, like others, not aware of the sweep of Hoyle's 1954 paper. That awareness grew during the next two decades, as did my sense that *B^2FH* was overcited as a primary source for nucleosynthesis in stars.

[4] Clayton, Donald D., Fowler, W.A., Hull, T.E. and Zimmerman, B.A. "Neutron capture chains in heavy element synthesis", *Annals of* Physics **12**, 331 (1961). Tom Hull was an applied mathematician on sabbatical leave at Caltech who suggested the technique for matching the Laplace Transforms of an approximate solution to the exact Laplace Transforms. Barbara Zimmerman was a technical member of the Kellogg staff who did many practical things for Fowler, including the computations for the figures of this work. A second paper providing the first quantitative decompositions of heavy isotope abundances into their *s*-process and *r*-procss components followed almost immediately: Clayton, D.D. and Fowler, W.A. *Annals of Physics* **16**, 51 (1961). Our technique, based on the new *s*-process theory, has been repeated many times down the decades, and has had large consequences for understanding the chemical evolution of the early galaxy.

[5] The rates of change of the abundances of the species in the *s*-process capture chain are expressed by a sequence of coupled differential equations. Those species form successive integer steps from ^{56}Fe to ^{209}Bi. Their identity is determined by the nuclei that are generated when neutron capture increases the atomic weight by one unit and time is allowed for beta decays that happen within a week or so. If that nucleus at any point on the chain is represented by the subscript *k*, the equation for the rate of change of the abundance of nucleus *k* is $dN_k/d\tau = \sigma_{k+1} N_{k+1} - \sigma_k N_k$, where τ is the flux of free

neutrons in the stellar environment and σ_k is the neutron capture cross section for nucleus *k*. If one assumes, as B^2FH did for the sake of presentation, that the abundances are in steady state, unchanging with time, then $dN_k/d\tau = 0$, with the immediate consequence that the product $\sigma_k N_k$ has the same value for each nucleus on the chain. What my thesis did was to retain the time derivatives and seek solutions of the tine-dependent coupled equations. I sought those solutions that described the result of neutron irradiations of iron for various total neutron exposures, the integrals of the neutron flux τ over time.

[6] Macklin, R.L. and Gibbons, J.H. , *Reviews of Modern Physics* **37**, 166 (1965). A photograph of us working together fifteen years later is < 1980 Clayton, Beer, Kaeppeler and Macklin >.

[7] Seeger, P.A., Fowler, W.A. and Clayton, Donald D. *Astrophys. J Suppl.* **11**, 121 (1965). Phil Seeger was already hard at work on this problem as Fowler's student when I joined that effort.

[8] Donald D. Clayton, "Cosmoradiogenic Chronologies of Nucleosythesis", *Astrophysical Journal*, **139**, 637 (1964). Previous methods had been based on a different principle, originally suggested by Rutherford in 1929. Fowler and Hoyle had mined that idea in their attempt to determine the age of the elements by comparing the surviving abundances of uranium and thorium, both long-lived radioactive elements.