Super Heavy Elements (SHE) and Natural Radioactive Decay

Current experimental results are consistent with the existence of an extended island of superheavy nuclei that are more resistant to radioactive decay and have much longer half-lives than somewhat lighter isotopes, as shown in figure 2. Indeed, some models predict half-lives up to a million years for new superheavy nuclei, and some even calculate them at around Earth's age.

Extensive chemistry studies have searched for traces of SHEs in geothermal waters, rare ores, and cosmic rays. However, to date all known elements beyond uranium ($Z = 92$) have been manmade first, in laboratories using large-scale devices like nuclear reactors and particle accelerators or in the violent conditions of nuclear explosions.

Since the discovery of nuclear fission in 1938 (see the article by Michael Pearson, PHYSICS TODAY, June 2015, page 40), researchers have artificially created 26 new elements and hundreds of isotopes, all by using nuclear reactions to modify the properties of existing nuclei. Attempts to change the nuclear properties of materials are not new. Historically, the hope of creating precious metals like gold out of more common ones like tin or lead drove such alchemical ambitions.

The dreams of medieval alchemists have nearly come true in the modern era of accelerators and nuclear reactions.[7] For example, one can fuse two metallic atoms, a germanium-74 ($^{74}_{32}$Ge) projectile with a tin-124 ($^{124}_{50}$Sn) target. When the $^{74}_{32}$Ge has a kinetic energy of 300 MeV, which corresponds to about 9% of the speed of light, a $^{198}_{82}$Pb* nucleus is created in the nuclear fusion.

That initial $^{198}_{82}$Pb* nucleus has a mass number equal to the sum of the Ge projectile's and the Sn target's mass numbers. The asterisk indicates that the nucleus—which is created "hot" with an excitation energy of about 50 MeV, corresponding to a temperature of more than 10^{10} K—is a compound nucleus, one that is not fully bound. It promptly evaporates several neutrons to cool down, and different Pb isotopes, called fusion-evaporation residues, are created in the process.

In the $^{198}_{82}$Pb* example, the evaporation of four neutrons to produce $^{194}_{82}$Pb accounts for about 60% of the evaporation residues. Within a few tens of minutes, beta decay transforms the $^{194}_{82}$Pb into thallium-194 ($^{194}_{81}$Tl). Then a second beta decay turns $^{194}_{81}$Tl into mercury-194 ($^{194}_{80}$Hg), a nucleus with a 520-year half-life. The nuclear alchemist seeking Au has to wait quite some time for the next beta decay into $^{194}_{79}$Au. Unfortunately, $^{194}_{79}$Au is an unstable isotope, with a half-life of only 38 hours.

The beta decay of $^{194}_{79}$Au does create stable and even more precious platinum-194 ($^{194}_{78}$Pt), but at typical beam intensities used in current SHE experiments, continuous irradiation of $^{124}_{50}$Sn with $^{74}_{32}$Ge would produce only 1 g of stable $^{194}_{78}$Pt in about 100 million years. So nuclear alchemy is possible in principle, but it is definitely not a wise capital venture. However, experiments creating superheavy nuclei are much more rewarding in terms of scientific gain.

Figure 5. Decay chains for isotopes ^{293}117 and ^{294}118, showing the half-life and alpha-decay energy of each nucleus in the chains. Black arrows indicate alpha decay and gray arrows indicate spontaneous fission. In both cases, hot-fusion reactions between calcium-48 projectiles and actinide target materials, either berkelium-249 or californium-249, produce compound nuclei, labeled with asterisks, that promptly evaporate off several neutrons. Toward the ends of the chains, roentgenium-281 (from ^{293}117) and flerovium-286 (from ^{294}118) can spontaneously fission or alpha decay into meitnerium-277 and copernicium-282, respectively. Both end-chain nuclei undergo spontaneous fission.

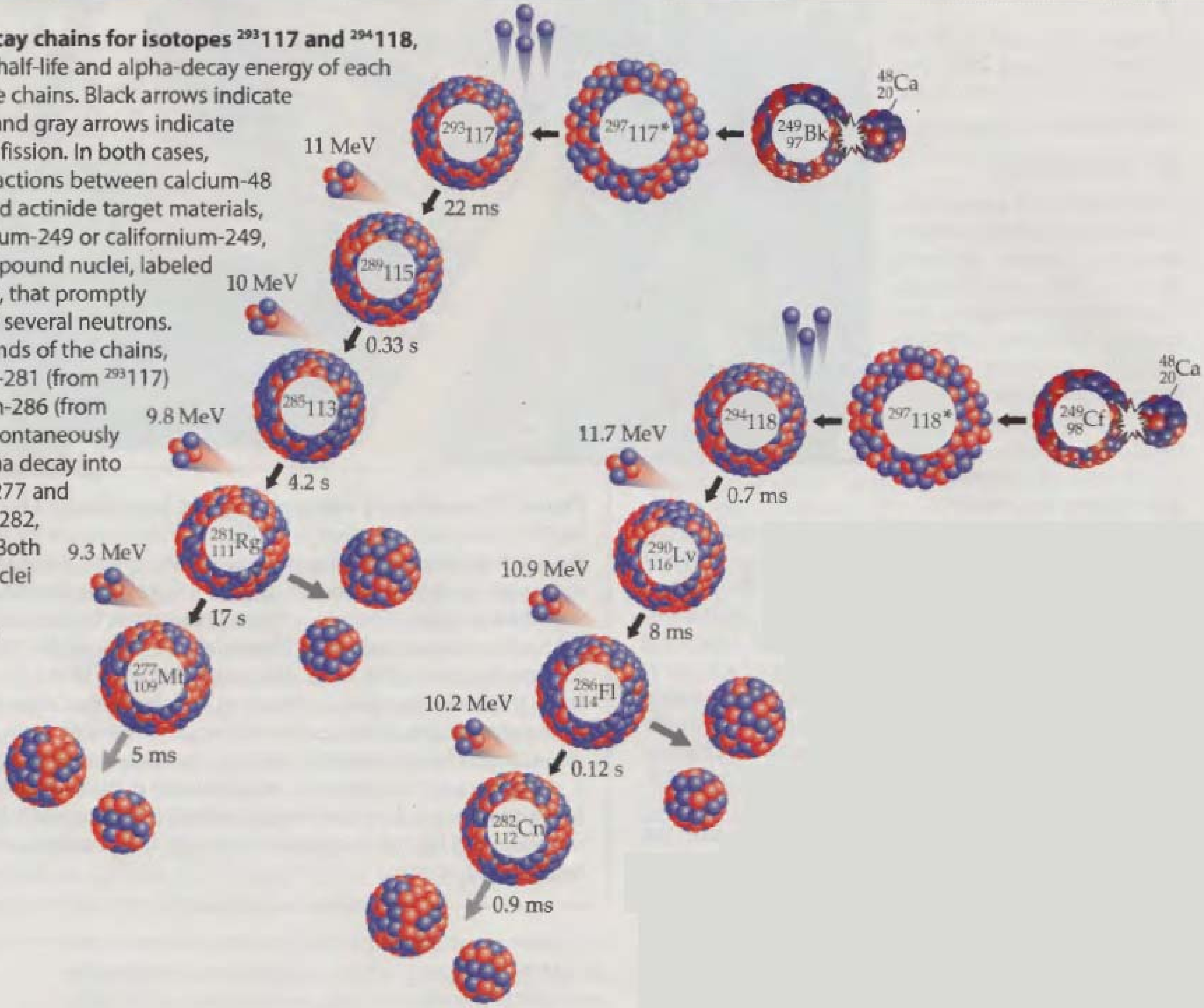

Figure 5 published in *Physics Today*, August 2015, page 36

Natural Radioactive Decay

Shown above are two series of natural radioactive decay for super heavy elements (SHE) created at particle accelerations using beam-target fusion.

(1) Create a decay diagram for each series, similar to the diagram you completed on the CP workbook page entitled **Natural Transformations**. You may place both series on the grid provided,

(2) For each element in these series, research its name, the year it was created, the country where the discovery took place, the chemical family to which it belongs, and an everyday element it is thought to resemble.

Atomic mass	Atomic Name	Year created	Country where it was first created	Chemical family	Everyday element in the same family
118					
117					
116					
115					
114					
113					
112					
111					
109					

(3) Define what is meant by the term isotope.

(4) Break down the number of protons and neutrons in the beam particles ${}^{48}_{20}Ca$

(5) Calculate the number of joules of energy carried off by a 10 MeV alpha particle.

(6) Calculate the velocity of the alpha particle in question 3 if the mass of an alpha particle is 4.0026 amu where 1 atomic mass unit equals 1.66×10^{-27} kg.

(7) Research and define the term half-life.

(8) Which transition in the first decay series has the longest half-life? Which transition in the second decay series?

(9) Research and report on the meaning of the term “island of stability?”