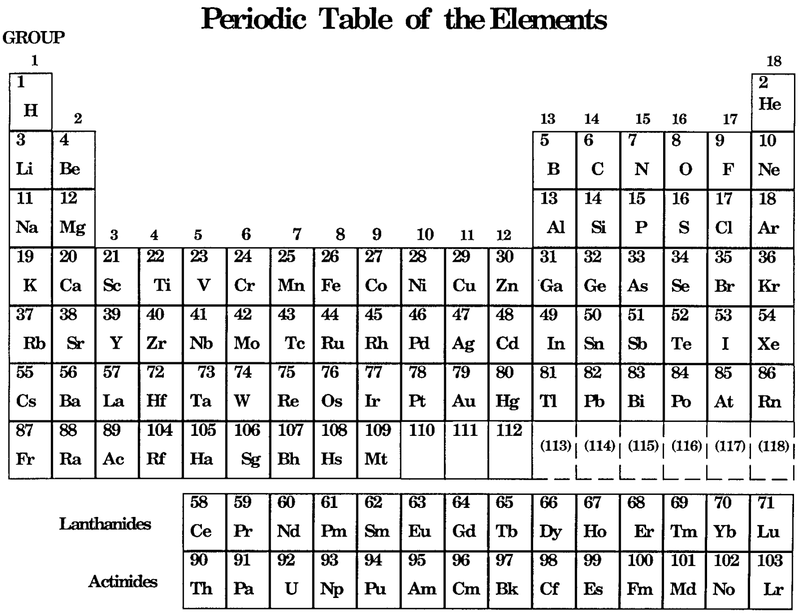
The AEC authorized the construction of the twin accelerators at Berkeley and Yale and they were promptly built. The HILAC consisted of a 750 kV Cockcroft–Walton injector that produced ions with a low charge state for injection into a 30-foot-long, grid-focussed prestripper linac to accelerate the heavy ions up to 1.0 MeV/A. These ions were then passed through a cloud of mercury vapor to strip more electrons from each ion to raise it to a higher charge state and thus minimize the necessary length of the second tank. The second tank was a 90-foot-long linac with magnetically strong focussed drift tubes that took the ions up to 10 MeV/A. The final energy was fixed and the pulse rate was only 2 Hz. The tanks were 10 feet in diameter, so there was a lot of internal surface area to be outgassed. It turned out that the low duty cycle (a pulse rate of 2 Hz with a pulse width of only 2 ms) meant that it was difficult to inject enough power to break through the various “ion locks” very quickly, and as a consequence it was many months before the vacuum was good enough to allow high RF voltage gradients to be established so that acceleration experiments could begin.

1.4. Current Status

The first real transuranium element (neptunium, 93) was identified in 1940. Since then, we have seen the synthesis and identification, i.e., the discoveries, of 20 elements with atomic numbers greater than that of uranium (element 92) — the transuranium elements. These discoveries have added more than 20% to our list of chemical elements and the study of these elements has added much to our understanding of nuclear and atomic structure, the periodic table, nuclear fission and the limits to nuclear stability, and nuclear reaction mechanisms.

The current periodic table, as of April 1998, is shown in Fig. 1.6. The elements through 112 are now known. The names and symbols we shall use throughout this book are those approved by The International Union of Pure and Applied Chemistry (IUPAC) in August 1997 or earlier, except for element 105, for which we shall continue to use hahnium (Ha), in honor of the great German scientist and codiscoverer of fission, Otto Hahn. Table 13.5 lists the names and symbols approved by IUPAC in August 1997, and Chapter 13 gives a detailed discussion of the many controversies concerning priority of discovery and the naming of the transfermium elements. A time-line for the discovery of the transuranium elements is shown in Fig. 1.7. Strangely enough, the production of Elements 99 (einsteinium) and 100 (fermium) was not planned; they were produced as "by-products" of the first thermonuclear device, tested by the USA in the South Pacific in November 1952. This remarkable story is recounted in Chapter 6. The elements heavier than fermium (100) cannot be produced at reactors via neutron capture and must be produced via light or heavy ion bombardments at suitable accelerators.



Periodic Table of the Elements

GROUP

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Ha	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112	(113)	(114)	(115)	(116)	(117)	(118)
Lanthanides				58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides				90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Fig. 1.6. Periodic table as of April 1998.

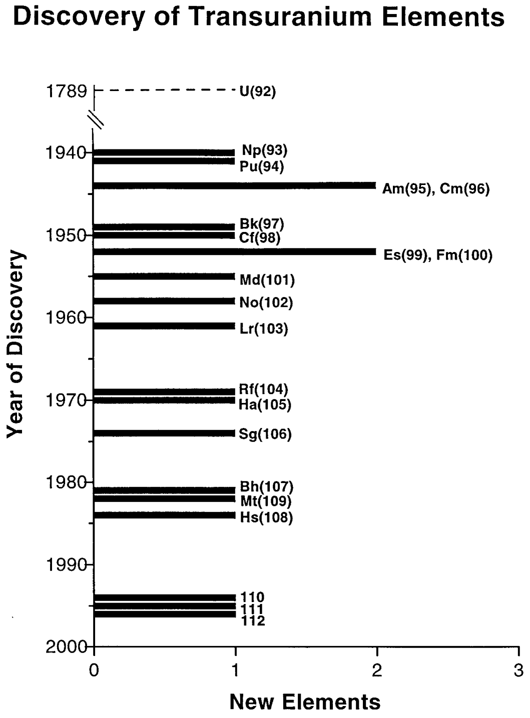


Fig. 1.7. Time-line for discovery of the transuranium elements.

All of the transuranium elements through 101 (mendelevium) were first discovered using chemical separation techniques. However, mendelevium was the first element to be produced and chemically identified on an "atom at a time" basis at an accelerator; its discovery is described in Chapter 7. One-atom-at-a-time chemistry has now been conducted on the elements through seaborgium (106) and plans are underway to extend these studies still further.

Beyond mendelevium the elements were first identified via detection of their nuclear decay and new techniques had to be devised for their positive identification. This is one reason for the ensuing controversies concerning the discoveries of element 102 and heavier. The controversies over priority of discovery and naming are discussed in detail in the chapters on those elements (Chapters 8 through 12), as well as in Chapter 13. The elements from 102 through 106 (seaborgium) were first produced using “hot fusion” reactions in which the initially produced compound nucleus is highly excited and a competition ensues between neutron emission and prompt fission before the desired product can be reached. The ever-increasing probability for prompt fission leads to lower and lower cross sections, and beginning with element 107 the “cold fusion” reaction using targets near the doubly magic ^{208}Pb region with heavy projectiles to produce a less excited compound nucleus has been utilized. A discussion of these reactions and the advances in instrumentation required to extend the known elements to 112 is given in Chapters 11 and 12.

Some reported discoveries of superheavy elements (SHE), how scientists can sometimes be led astray, and current plans to produce them are reviewed in Chapter 14. Finally, in Chapter 15, we reflect on the past and try to use our “cloudy crystal ball” to predict the future.

Many of the transuranium elements can be produced and isolated in large quantities through the use of neutrons furnished by nuclear fission reactors. Plutonium can be produced by the ton; neptunium, americium, and curium by the kilogram; berkelium by the 100 milligrams; californium by the gram; einsteinium by the milligram, and fermium in only sub-picogram quantities. Transuranium isotopes have found many practical applications — as nuclear fuel for the large scale generation of electricity; as compact, long-lived power and heat sources for use in space exploration; as means of diagnosis and treatment in nuclear medicine; in pacemakers and smoke detectors; as tools in numerous industrial processes; in agriculture; and in research in the arts and humanities.

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