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Helge Kragh

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## A Story of Dispute and Creation

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ISSN 2211-4564 ISSN 2211-4572 (electronic)
SpringerBriefs in History of Science and Technology
ISBN 978-3-319-75812-1 ISBN 978-3-319-75813-8 (eBook)
https://doi.org/10.1007/978-3-319-75813-8

Library of Congress Control Number: 2018932168



Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# Preface

This essay is about the endeavours of nuclear scientists to produce and investigate chemical elements beyond uranium and especially those "superheavy" elements that lie at the end of the periodic table. My interest in the subject was aroused when I studied Niels Bohr's semi-classical atomic theory and his application of it in the early 1920s to the electron configuration of heavy elements. Bohr even suggested an atomic model for the then dreamlike hypothetical element with atomic number 118—the same element which received official recognition in 2016 and is today the heaviest of all known elements. The amount of scientific literature on superheavy elements and related topics is frighteningly large, but by far most of it consists of technical papers whereas only little has been written from a historical or general perspective. In fact, historians and philosophers of science have shown almost no interest in the subject at all, something I hope the present work will help rectifying.

I would like to emphasise that the work is in no way intended to be a full history of how the science of superheavy elements has evolved. A history it is, but a fragmented one. Not only do I not deal with all the transuranic elements individually and in detail, there are also large parts of the development which I leave out or only mention cursorily. Thus, I ignore the technical apparatus—such as accelerators and detector systems—which have been of overwhelming importance in the synthesis of the very heavy elements since the 1940s. Detection methods based on nuclear chemistry are another and no less important part of the development that I have left out.

My focus is not so much on the scientific and technical aspects of this interdisciplinary branch of research as it is on conceptual and contextual aspects, including the criteria of element discovery and the inevitable priority controversies that these criteria are supposed to make an end to. In the last chapter, which relies on a recent paper in the journal *Substantia*, I argue that the history of heavy synthetic elements provides a valuable case study from the point of view of philosophy and sociology of science. For example, it problematises the notion of discovery and also the very concept of a chemical element. Moreover, the history is instructive with regard to the sometimes strained relationship between chemistry and physics. *From Transuranic to Superheavy Elements* is a story of how the periodic table was successfully expanded with new elements, but it is also a story of many mistakes and failed discovery claims. The latter category is no less interesting than the first, and I deal with it in some detail. For comments on and help with the manuscript, I want to thank Dieter Hoffmann and Sabine Lehr.

Copenhagen, Denmark Helge Kragh
November 2017

# Contents

# Chapter 1
# Beyond Uranium, Ca. 1890–1950

**Abstract** The transuranic elements at the end of the periodic table have since the 1960s been known as superheavy elements. Until 1939 no element heavier than uranium was known and yet there was in the earlier period considerable interest in the possible existence of such elements. The interest was in part of a speculative nature and in part based on calculations of the electron structure of heavy elements. After all, why should uranium be the heaviest element in nature? Although transuranic elements were "known" theoretically in the 1920s, it was only with the development of nuclear physics and technology in the following decade that the first of these elements—neptunium and plutonium—were actually produced. By 1951 six transuranic elements had been added to the periodic table, all of them by an innovative group of Californian nuclear scientists.

**Keywords** Transuranic elements · Periodic table · Niels Bohr
Enrico Fermi · Glenn Seaborg · Neptunium · Plutonium

Ideas of chemical elements even heavier than uranium go back to the late nineteenth century, where they emerged in connection with speculations concerning the end of the periodic system. Following the first quantum-based theories of atomic structure several physicists suggested electron configurations of hypothetical transuranic elements. But although there were theories of such elements by 1930, it was only with Fermi's pioneering neutron experiments a few years later that it seemed realistic to produce synthetic transuranic elements. The first man-made elements date from the late 1930s and by 1950 the periodic table had been extended with several elements beyond uranium. Although the term "superheavy elements" had not yet been coined, the development towards artificially produced and still heavier elements had begun.



H. Kragh, *From Transuranic to Superheavy Elements*, SpringerBriefs in History of Science and Technology, https://doi.org/10.1007/978-3-319-75813-8_1

## 1.1 Introduction

The discovery of the element uranium is often credited to the German chemist Martin Heinrich Klaproth who in 1789 recognised that the mineral pitchblende contained an unknown metal. Referring to William Herschel's sensational discovery of the planet Uranus a few years earlier, he proposed to the call the new metal uranium (Weeks and Leicester 1968, pp. 266–271). However, Klaproth's attempts to isolate the metal failed and it took until 1841 before Eugène-Melchior Peligot in France could produce a powder of pure uranium. In Mendeleev's original periodic table of 1869 the atomic weight of the metal was given as 116, but in a slightly later version he more than doubled the value (Scerri 2007, p. 129). He cited it as $M = 240$, thus making uranium the heaviest of all known elements. Over the next couple of decades it was generally accepted that no other element has an atomic weight as large as or larger than uranium's. The metal discovered by Klaproth (or perhaps by Peligot) marked the end of the periodic table. And this was not the only peculiarity exhibited by uranium, for in early 1896 Henri Becquerel demonstrated that uranium and its salts give off a new kind of rays. Radioactivity was discovered.

With atomic number $Z = 92$ and atomic weight $M = 238.0289$, uranium is the heaviest of the naturally occurring chemical elements listed in the periodic system. Strictly speaking, also the transuranic elements neptunium and plutonium occur naturally. However, the trace amounts found of these two elements are not of primordial origin but owe their existence to nuclear reactions in uranium or thorium such as neutron capture followed by beta decay. The two elements exist in nature in extremely low concentrations only, such as illustrated by the amount of plutonium in the uranium minerals pitchblende and monazite, which is about one part to $10^{11}$. For neptunium the ratio is even smaller, about one part to $10^{12}$. Some elements of lower atomic number, especially technetium (Tc, $Z = 43$) and promethium (Pm, $Z = 61$) but also astatine (At, $Z = 85$), francium (Fr, Z = 87) and protactinium (Pa, $Z = 91$), are also practically non-existent in terrestrial nature (Scerri 2013).

Beyond uranium the periodic table includes presently no less than 26 elements which have all been manufactured in the laboratory and the best known of which is plutonium of atomic number 94. The heaviest of the transuranic elements are often called "superheavy elements," a term with no precise meaning but which often refers to the transactinide elements with $Z$ ranging from 104 to 120. In some cases the term is used only for Z > 110 and in other cases it just refers to very heavy elements. What these elements have in common, as seen from a modern perspective, is that they owe their existence to effects due to the shell structure of the atomic nucleus. So far the last of the known superheavy elements is $Z = 118$, a substance which received official recognition as an element in 2016 and is named oganesson, chemical symbol Og.

The term superheavy element (SHE or SHEs in plural) largely owes its origin to the American physicist John Wheeler, who in the 1950s examined theoretically the limits of nuclear stability. However, the term can be found even earlier, first in an