ATOMIC ENERGY AND ITS APPLICATIONS

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Preface

THE great advances of the past ten years in nuclear physics have produced new techniques with useful applications in almost every branch of science, medicine and industry. The achievements and potentialities of this branch of applied science are well known among the present generation of atomic physicists, but the relevant information is not often available in publications readily accessible to those trained and employed in other specialties.

This book has been written to provide a simple account of the physical foundations of nuclear science, a concise description of their applications and a guide to future progress in the exploitation of atomic energy.

After an introductory summary of current ideas on atomic structure, X-rays and radioactivity are discussed from an experimental standpoint. Chapter IV deals with nuclear stability and binding energy, providing a foundation for subsequent inquiry into the fission process. There follows a description of methods used for the detection of nuclear radiations by ionization chambers, Geiger-Müller counters and other devices. High-energy physics is next discussed, Chapter VI being devoted to particle accelerators and Chapter VII to consideration of the nuclear reactions initiated by energetic particles or radiations.

One particularly important class of nuclear reaction—the fission process—has a chapter to itself, thus completing the first section of the book. The various applications of atomic physics are then taken up and the three succeeding chapters deal with nuclear reactors, used for the release of energy and the production of radioactive materials. The atomic bomb is a nuclear reactor of a special kind and an account of its technical aspects occupies Chapter X.

Next comes an account of the production of artificial radioactive materials and a summary of the precautions necessary in their use, followed by chapters dealing with their practical applications in medicine, science and industry. Chapter XV contains some comments on the developments which may be expected during the next ten or twenty years and speculations on the more distant prospect.

The reader is assumed to be a person with modest scientific attainments, including a knowledge of physics to the standard of the ordinary degree or the intermediate B.Sc. Those concerned only to know something of the applications of nuclear physics to their own subjects should, however, be able to find useful information in the later chapters without having made a close study of the earlier part. Further study may conveniently begin with the references given at the end of each chapter. These have been carefully chosen and will all be found to convey fresh information of a practical kind in a readily intelligible form.

In writing this book, I have tried to give a straightforward factual survey of the topics suggested by its title, and have not concerned myself with the contentious political problems thrown up by the release of nuclear energy. On these topics, the scientist, as such, has no particular authority and any expository skill which he may possess is probably better employed in promoting a wider understanding of his own specialty.

I am grateful to Dr. E. G. Richardson for the suggestion that this book should be written and to Mr. T. H. O'Beirne for his help in reading the proofs.

J. M. A. LENIHAN

GLASGOW,
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Table XXI is taken from STOKLEY, J.: "Atomic artillery," *General Electric Review*, June, 1947, p. 9. (This table was originally prepared by Mr. G. A. Doxey of the General Electric Company, Schenectady, New York.)

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CHAPTER I

Atomic Structure

EVERY piece of matter in the Earth and, as far as we know, in other parts of the Universe too, is made up of one or more of the simple substances called elements. These elements may be found in the free state or, more commonly, in a variety of combinations. Eighty-nine elements occur in nature and in recent years nine more have been made artificially (Table II, pp. 2–4).

The smallest portion of an element which can exist is an atom and, according to present knowledge, every atom is built to a common plan, having a heavy central nucleus, positively charged, and a number of light negatively-charged electrons which may be considered to revolve around it. The nucleus itself is composed of neutrons and protons, and the essential properties of the elementary particles are set out in Table I.

TABLE I

PROPERTIES OF THE ELEMENTARY PARTICLES

	Relative Mass (proton = 1)	Relative Charge (proton = 1)
Electron .	1/1,840	− 1
Neutron .	1	0
Proton .	1	+ 1

Mass Number and Atomic Number

The total number of particles (neutrons and protons) in a nucleus is its mass number, A, which varies between 1 (hydrogen) and 238 (uranium) for the naturally-occurring elements. The number of protons in the nucleus is the atomic number, Z, of the element, which varies between 1 (hydrogen) and 92 (uranium). For an atom in its normal state the number of protons in the nucleus is equal to the number of electrons revolving around it, and the atom as a whole displays no electric charge. A few electrons may readily be removed from, or added to, an atom, leaving it with a surplus of positive or negative charge.

A few examples will make these matters clearer.

TABLE II

THE ELEMENTS

Atomic weights are given to four significant figures, where they are known to this accuracy. For certain radioactive elements, the atomic weight is not known with any accuracy; here the mass number of the most stable isotope is shown in brackets.

Atomic Number	Atomic Weight	Element	Symbol
1	1·008	Hydrogen	H
2	4·003	Helium	He
3	6·940	Lithium	Li
4	9·013	Beryllium	Be
5	10·82	Boron	B
6	12·01	Carbon	C
7	14·01	Nitrogen	N
8	16·00	Oxygen	O
9	19·00	Fluorine	F
10	20·18	Neon	Ne
11	23·00	Sodium	Na
12	24·32	Magnesium	Mg
13	26·97	Aluminium	Al
14	28·06	Silicon	Si
15	30·98	Phosphorus	P
16	32·07	Sulphur	S
17	35·46	Chlorine	Cl
18	39·94	Argon	A
19	39·10	Potassium	K
20	40·08	Calcium	Ca
21	45·10	Scandium	Sc
22	47·90	Titanium	Ti
23	50·95	Vanadium	V
24	52·01	Chromium	Cr
25	54·93	Manganese	Mn
26	55·85	Iron	Fe
27	58·94	Cobalt	Co
28	58·69	Nickel	Ni
29	63·57	Copper	Cu
30	65·38	Zinc	Zn
31	69·72	Gallium	Ga
32	72·60	Germanium	Ge
33	74·91	Arsenic	As
34	78·96	Selenium	Se
35	79·92	Bromine	Br

TABLE II—(*Contd.*)

Atomic Number	Atomic Weight	Element	Symbol
36	83·7	Krypton	Kr
37	85·48	Rubidium	Rb
38	87·63	Strontium	Sr
39	88·92	Yttrium	Y
40	91·22	Zirconium	Zr
41	92·91	Niobium	Nb
42	95·95	Molybdenum	Mo
43	(99)	Technetium	Tc
44	101·7	Ruthenium	Ru
45	102·9	Rhodium	Rh
46	106·7	Palladium	Pd
47	107·9	Silver	Ag
48	112·4	Cadmium	Cd
49	114·8	Indium	In
50	118·7	Tin	Sn
51	121·8	Antimony	Sb
52	127·6	Tellurium	Te
53	126·9	Iodine	I
54	131·3	Xenon	Xe
55	132·9	Cesium	Cs
56	137·4	Barium	Ba
57	138·9	Lanthanum	La
58	140·1	Cerium	Ce
59	140·9	Praseodymium	Pr
60	144·3	Neodymium	Nd
61	(147)	Promethium	Pm
62	150·4	Samarium	Sm
63	152·0	Europium	Eu
64	156·9	Gadolinium	Gd
65	159·2	Terbium	Tb
66	162·5	Dysprosium	Dy
67	164·9	Holmium	Ho
68	167·2	Erbium	Er
69	169·4	Thulium	Tm
70	173·0	Ytterbium	Yb
71	175·0	Lutetium	Lu
72	178·6	Hafnium	Hf
73	180·9	Tantalum	Ta
74	183·9	*Wolfram	W
75	186·3	Rhenium	Re
76	190·2	Osmium	Os
77	193·1	Iridium	Ir
78	195·2	Platinum	Pt
79	197·2	Gold	Au
80	200·6	Mercury	Hg

TABLE II—(*Contd.*)

Atomic Number	Atomic Weight	Element	Symbol
81	204·4	Thallium	Tl
82	207·2	Lead	Pb
83	209·0	Bismuth	Bi
84	210	Polonium	Po
85	(210)	Astatine	At
86	222	Radon	Rn
87	(223)	Francium	Fr
88	226·0	Radium	Ra
89	227	Actinium	Ac
90	232·1	Thorium	Th
91	231	Protoactinium	Pa
92	238·1	Uranium	U
93	(237)	Neptunium	Np
94	(239)	Plutonium	Pu
95	(241)	Americium	Am
96	(242)	Curium	Cm
97	†	Berkelium	Bk
98	†	Californium	Cf

* Formerly tungsten.
† The chemistry of these elements is not yet fully known.

Hydrogen, the simplest atom, has 1 proton for its nucleus and 1 electron. $A = 1$, $Z = 1$.

Helium has in its nucleus 2 protons and 2 neutrons, with 2 electrons revolving around it. $A = 4$, $Z = 2$.

Iodine has in its nucleus 53 protons and 74 neutrons, with 53 extra-nuclear electrons, making $A = 127$ and $Z = 53$.

The electrons are grouped round the nucleus in rings or shells, denoted K, L, M. . . . The 2 electrons of helium are in the innermost (K) shell and lithium ($Z = 3$) has its third electron in the L shell. At neon ($Z = 10$) the L shell is complete and the next element—sodium, $Z = 11$—has 1 electron in the M shell. The maximum numbers found in the different shells are $K = 2$, $L = 8$, $M = 18$, $N = 32$; shells further out are never completely occupied.

The shells are not always filled in the order K, L, M. . . . For example, argon ($Z = 20$) has 2 electrons in the K ring, 8 in L, 8 in M and 2 in N. The M shell, with a capacity of 18, is not filled until copper ($Z = 29$) which has $K = 2$, $L = 8$,

$M = 18$, $N = 1$. Uranium ($Z = 92$) has $K = 2$, $L = 8$, $M = 18$, $N = 32$, $O = 18$, $P = 12$ and $Q = 2$.

Most of the common chemical and physical properties of an element depend on the behaviour of its extra-nuclear electrons and are therefore dependent on the atomic number. Radioactivity, an important property of many elements, depends entirely on the structure of the nucleus, that is, on A and Z.

Isotopes

Each element exists in a number of varieties called isotopes, having the same atomic number but different mass numbers. For example, oxygen ($Z = 8$) is usually found in atoms of mass number 16, each containing 8 protons and 8 neutrons, but atoms with 8 protons and 9 neutrons are also known. These, having $Z = 8$, show all the chemical properties of oxygen and, except for a small difference in density due to the larger mass number, are indistinguishable from ^{16}O. Another isotope with $A = 18$ also occurs, and oxygen found in nature (whether in combination or in the free state) consists of a mixture of these isotopes in the proportion 99·76 : 0·04 : 0·2 approximately.

The 98 elements have, in all, more than 1,200 isotopes, of which about 300 are found in nature and 900 have been made artificially.

Atomic Weight

The atomic mass of an element (commonly called the atomic weight) is the average mass of its atoms, measured on some convenient scale. Usually the mass of the oxygen atom is taken as 16 units and others are referred to this standard. It should be noted that, when O = 16 was originally chosen to fix the scale, oxygen was thought to have no other isotopes, though we now know that the natural element is a mixture of ^{16}O, ^{17}O and ^{18}O. Two scales of atomic weight are in existence as a result of this confusion. On the chemical scale the average mass of oxygen atoms in the natural mixture of the three isotopes is taken as 16 mass units, and on the physical scale the mass of an atom of ^{16}O is the standard. The difference between atomic weights measured on the two scales is small—about 0·027 per cent—but is sometimes important. We shall use the physical scale in the rest of this book.