$2v/c$ times the energy of the beam, and this limit can never be exceeded, however large H or h may be chosen.

An analysis of the considerations resulting from the assumption of a finite conductivity for the space external to the beam shows that the existence of such a conductivity does not change the conclusions.

* The full mathematical details pertaining to this paper, together with a discussion of their ramifications, will appear in the Journal of the Franklin Institute, for March, 1954.

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Coulomb Excitation of Heavy and Medium Heavy Nuclei by Alpha Particles. II

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We wish to report the results of the completion of our preliminary survey[1,2] of low-lying excited states of nuclei by 3-Mev alpha-particle Coulomb excitation, as well as some conclusions we can draw from the large amount of data now at hand.

Our experimental setup has been briefly described previously.[2] Of the 66 elements we have investigated, 45 show one or more excitation levels. Because of the inherent danger of being misled by impurities and surface contaminations of target materials, we felt it desirable to investigate as many elements as possible; as an example, we found a strong line in spectroscopically pure bismuth metal which later turned out to be due to a very small (0.01 percent) fluorine impurity. Certain generalizations concerning the nature of the levels reached will be given below.

In Table I we present a supplement to the list of elements previously given in I, Table I. Some very low-intensity lines we observe are not reported in this table pending further study by photographic means. It should be remembered that the rough relative intensities indicated in the fourth column (relative to 1.00 for the 137-kev line of Ta^{181}) are preliminary and even if accurate must still be subject to several transformations before they become meaningful for the determination of transition probabilities between energy levels. The principal obscuring factor is the strong dependence of the excitation cross section on the quantity $\xi=Z_1Z_2e^2/\hbar v$ (Z_1 and Z_2 are the charges of projectile and target, v is their relative velocity, ΔE is the excitation energy of the nucleus, and E is the center-of-mass energy of the projectile).[3] This factor is connected with the details of the excitation mechanism and is not related to the problem of interest, i.e., the determination of nuclear transition matrix elements between states. Furthermore, since we have used thick targets so far, a stopping-power correction must be made.

Table I. Continuation of survey of levels below 500 kev observed by Coulomb excitation with 3-Mev alphas. Approximate intensities relative to 137-kev line in Ta^{181} (*uncorrected* for relative abundance and internal conversion). For meaning of intensity, see text.

Element[a]	Abundance (%)	$E\gamma$ (observed) kev	Approx int.[b]	$E\gamma$ (known)[c] kev
$_{35}Br^{79}$	50.6	44, 213, 266	0.03, 0.23, 0.11	44, 263
$_{44}Ru^{?}$	?	91, 128, 360	0.31, 0.24, 0.05	?
$_{53}I^{127}$	100	57, 205	0.28, 0.90	57, 145, 200
$_{56}Ba^{?}$	?	60, 118	0.013, 0.013	?
$_{57}La^{139}$	99.9	56	0.005	166
$_{58}Ce^{140,142}$	88.5, 11	77, 129[d]	0.005, 0.005	?
$_{60}Nd^{?}$	?	70, 130	0.03, 0.36	135, 170, 329
$_{62}Sm^{?,152}$	?, 26.6	82,[e] 122	1.2	122
$_{64}Gd^{154,155}$	2.2, 14.7	82, 124	3.5, 0.21	85, 106, 124, 132
$_{71}Lu^{175}$	97.4	77, 113, 184?	0.15, 1.5, 0.036	89, 113, 138, 228
$_{72}Hf^{177,180}$ [f]	18.4, 35.4	112, 93	0.13, 1.14	89, 93, 112
$_{75}Re^{187}$	62.9	130	0.81	73, 133
$_{76}Os^{188,?}$	13.3, ?	157, 180, 188, 202	all $\sim$0.2[g]	152
$_{77}Ir^{191}$	38.5	129	>0.06	42, 65, 129
$_{78}Pt^{194}$ [h]	32.8	213, 328[i]	0.06, 0.02	290, 328
$_{78}Pt^{195}$ [h]	33.7	29, 98, 128	?, 0.03, 0.03	29, 97, 126
$_{79}Au^{197}$ [h]	100	77, 190, 277[i]	?, 0.0013, 0.001	77, 191, 279
$_{80}Hg^{199}$	16.9	163	0.03	50, 159, 209
$_{92}U^{238}$	99.3	44, 424(?)[i]	0.05, 0.06	?

[a] No lines were observed in Y, Sn, and Pb. For other elements, see I.
[b] Relative to the 137-kev line of Ta^{181} (=1.00).
[c] Only low-energy lines listed; see references 7 and 8.
[d] According to the regularity of first excited states of even-even nuclei [G. Scharff-Goldhaber, Phys. Rev. 90, 587 (1953)], these energies seem too low for cerium, which has only even-even isotopes and $N\cong 82$.
[e] This line was accidentally omitted in I.
[f] Previously seen as impurity (3 percent) in Zr target; see I.
[g] Incompletely resolved because of 4 isotopes of comparable abundance.
[h] Listed as showing no lines in I; see text.
[i] With protons and alphas.

It is interesting to note that an electric quadrupole transition lifetime of about 4×10^{-8} second (taking the specific example of Ta^{181}) corresponds to a Coulomb excitation cross section for alpha particles of about one millibarn for the inverse transition. Whereas it becomes easier to excite and detect states of *shorter* lifetime, measurement of the latter by delayed-coincidence techniques becomes more difficult, especially since our estimate *does not* include the speeding-up effect of internal conversion. Thus the two methods are seen to be complementary, with a comfortable overlap region. Our limit of detection is of the order of 10^{-30} cm^2, depending somewhat on the particular nucleus. In the case of mixed multipole transitions (e.g., $M1+E2$) we clearly measure only the *partial* lifetime for the quadrupole component.

A few special remarks are in order concerning some of the nuclei in Table I. Our careful reexamination of platinum revealed the three known gamma rays (29, 97, and 126 kev) belonging to the two first excited states of Pt^{195} at 97 kev and 126 kev, plus a line at 328 kev (probably the first excited state of Pt^{194}) and an unknown one at 213 kev.[4] A more thorough look at gold yielded lines at 190 and 277 kev coming from known levels; a comparison of x-ray line shapes as obtained with proton- and alpha-particle excitation, coupled with critical absorption tests, gave evidence for the presence of the 77-kev γ ray from the level of the same energy. A similar reexamination of lead did not reveal any γ rays. The new 44-kev level we find in uranium (presumably U^{238}) seems to fit very nicely into the regular pattern of first excited states (spin 2^+) of even-even nuclei in the heavy elements noted by Asaro and Perlman,[5] and Rosenblum and Valadares.[6]

The following points should be kept in mind in connection with our conclusions:

(1) Our knowledge of existing energy levels comes only from published summaries[7,8] and varies considerably as to reliability of spins, etc.

(2) If the γ-ray energies determined by us fall within about 3 kev of a known line, we consider them to be identical.

(3) Previously unreported lines are not considered in the summary.

The final assignment of new lines in polyisotopic elements must await investigation with separated isotopes, which we are undertaking in some important cases.

If, then, we accept the three points listed above, we may summarize our preliminary conclusions as follows:

(1) To date, we find no definite cases of transitions between levels which could not be connected by a spin change of 2 and no change in parity (electric quadrupole);[9] the present status of theoretical knowledge concerning the role of higher electric multipoles in the Coulomb excitation process is not clear,[10] although some ideas are contained in papers by Mullin and Guth[11] and Ter-Martirosyan.[12]

(2) In the case of even-even nuclei, we *always* find that the first (2^+) excited state, if it lies low enough, is reached with appreciable probability; this occurs mainly in the regions between $A=145$ and $A=200$ (rare earths), and $A>220$ (in practice, thorium and uranium). There are 12 such cases.

(3) In the case of even-odd and odd-even nuclei, we find about 9 cases where the excited state (according to present level assignments) has a spin *smaller* than the ground state. This seems to

rule out the possibility of a simple rotational interpretation.[13] In addition, we find 5 cases where the excited state spin *exceeds* that of the ground state (the latter being $\frac{3}{2}$ or greater), Ta^{181} being a well-known example, plus 8 cases having ground state spin $\frac{1}{2}$.

We are planning to study the excitation functions of some additional nuclei in this survey in the hope that higher multipole-order contributions might show up as deviations from the theoretical shape predicted for quadrupole excitation.[3]

We are greatly indebted to a long list of people from the National Bureau of Standards who so generously supplied us with samples of most of the rare substances appearing in the tables of this paper and reference 2.

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A New Spinor Theory of Elementary Particles

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The usual spinor theory of elementary particles[1] uses spinors of the kind

$$a^{\dot\mu_1\cdots\dot\mu_M}_{\nu_1\cdots\nu_N},\quad b^{\dot\mu_0\dot\mu_1\dot\mu_2\cdots\dot\mu_M}_{\nu_2\cdots\nu_N}$$

which possess dotted and undotted indices. The rank of these spinors is $r=M+N=2s$, where s is the spin of the particle. The spinors obey the generalized Dirac equations:

$$\partial^{\dot\mu_0\nu_1} a^{\dot\mu_1\dot\mu_2\cdots\dot\mu_M}_{\nu_1\nu_2\cdots\nu_N}=i\frac{mc}{\hbar}b^{\dot\mu_0\dot\mu_1\dot\mu_2\cdots\dot\mu_M}_{\nu_2\cdots\nu_N},$$

$$\partial_{\dot\mu_0\nu_1} b^{\dot\mu_0\dot\mu_1\dot\mu_2\cdots\dot\mu_M}_{\nu_2\cdots\nu_N}=i\frac{mc}{\hbar}a^{\dot\mu_1\dot\mu_2\cdots\dot\mu_M}_{\nu_1\nu_2\cdots\nu_N}.$$

These are 2×2^{2s} equations to which must be added the conditions of symmetry for all spinor indices as all spinors used have to be totally symmetric.[1] So the number of independent components is $(M+1)(N+1)$ for the a spinor and $N(M+2)$ for the b-spinor. One can see that the number of all spinor components used, namely $2MN+3N+M+1$, is greater than the number of states of the elementary particle. An elementary particle possesses two degrees of freedom: charge and spin. The charge contains two possibilities, $+e$ and $-e$, and the spin has $2s+1$ possibilities. Measurements made on an elementary particle distinguish, therefore, $2(2s+1)$ different states of a quantized spinor wave field of spin s. It must therefore be possible to describe an elementary particle sufficiently by only $2(2s+1)$ spinor components. As will be seen, this new method[2] has several advantages—for instance any problem can be solved regardless of the value of the spin. Furthermore, bosons and fermions differ only after quantization. So general electromagnetic (or other) interactions[3] or the scattering of particles with spin s by a Coulomb field have to be calculated only once for the spin s and not separately for $s=0$,[4] $s=\frac{1}{2}$,[5] and $s=1$.[6] Furthermore, it might be that the slightly different transformation properties of spinors (*vis à vis* tensors, used now for the description of bosons) give other results[7] for interacting particles.

By multiple application of formulas of the kind

$$\partial_{\dot\mu_M\nu_{N+1}} a^{\dot\mu_1\cdots\dot\mu_{M-1}\dot\mu_M}_{\nu_1\cdots\nu_{N-1}\nu_N}=i\frac{mc}{\hbar}a^{\dot\mu_1\cdots\dot\mu_{M-1}}_{\nu_1\cdots\nu_{N-1}\nu_N\nu_{N+1}},$$

one arrives finally at the spinors $a^{\dot\mu_1\cdots\dot\mu_{2s}}$ and $a_{\nu_1\cdots\nu_{2s}}$ which contain only indices of one kind and exactly $2(2s+1)$ components. These new spinors obey second-order differential equations:

$$(\Box-m^2c^2/\hbar^2)a^{\dot\mu_1\cdots\dot\mu_{2s}}=0,\quad (\Box-m^2c^2/\hbar^2)a_{\nu_1\cdots\nu_{2s}}=0,$$

which describe the propagation of the unquantized spinor wave field. There are no longer any first-order differential equations which, according to Pauli,[8] are not at all necessary.

It is possible to build up a relativistically- and gauge-invariant theory which is also invariant against inversions $x_k\to -x_k$ $(k=1, 2, 3)$, $x_4\to x_4$. After quantization,[9] the new theory reproduces for the free particle the well-known results of the usual theory[10] in a generalized manner, so that, for instance, the whole charge Q or the whole energy H is given by:

$$Q_{B,F}=e\sum_{r,k}^{\infty}(\mathfrak{N}^{(+)}{}_{r,k}{}^{B,F}-\mathfrak{N}^{(-)}{}_{r,k}{}^{B,F}),$$

$$H_B=\sum_{k,r}^{\infty}E_k(\mathfrak{N}^{(-)}{}_{k,r}{}^{B}+\mathfrak{N}^{(+)}{}_{k,r}{}^{B})+\sum_{k}^{\infty}E_k,$$

$$H_F=\sum_{k,r}^{\infty}|E_k|\mathfrak{N}^{(-)}{}_{k,r}{}^{F}+\sum_{k,r}^{\infty}|E_k|\mathfrak{N}^{(+)}{}_{k,r}{}^{F},$$

where B, F means boson *or* fermion, where $\hbar k$ is the momentum and r the spin number $r=0\cdots 2s+1$. The matrices $\mathfrak{N}^{(+)}{}_{r,k}{}^{B,F}$, $\mathfrak{N}^{(-)}{}_{k,r}{}^{B,F}$ are the well-known diagonalized matrices with infinite rows for bosons and with two rows for particles subject to the Pauli principle (fermions), depending on k and r and giving the number of particles present. Besides the possibility of giving other results for interacting particles, the new theory has the advantage of being a consistent general theory without superfluous components or accessory conditions, able to give the basis for a proposed unified nonlinear spinor theory of all elementary particles.[11]

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