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Short-Lived Radio-Nuclides Produced by a Synchrocyclotron

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A method of studying short-lived radio-nuclides produced by the internal beam in a synchrocyclotron is described. Preliminary results on a number of proton-produced activities in the mass range below 70 are given.

SHORT-LIVED activities induced in a target by the circulating beam of a 200-Mev proton synchrocyclotron have been studied by use of detector close to the target and an electronic "time analyzer" for registering the detector pulses.

The target is irradiated during a short time interval, of the order of the half-life of the activity under investigation. After the beam has been shut off by pulsing the oscillator, the detector placed below the target starts detecting radiation. In order to determine the time distribution of the detector pulses, the latter are fed to a time analyzer with ten channels which are successively opened and closed. The pulses stored in a certain channel thus measure the radiation from the target at a certain time after the beam has been shut off. The time interval a channel is open is controlled by a pulse generator; it can be the same for all channels or it can be increased 2, 4, or 8 times for any desired channels. After this "count period," which is of the order of a few half-lives, a recovery period begins, which allows more long-lived activities produced during the irradiation to decay. A new period of bombardment then follows and the whole cycle is repeated automatically. By thus adding the pulses from many repetitions of the cycle one can gain information about nuclei of fairly small production cross sections. Typical experiments involve 10 to 1000 repetition cycles.

The range of half-lives which can be analyzed by the time analyzer extends from a few microseconds to seconds or minutes. At present there is no synchronization between the cyclotron "on" and "off" pulses and the modulation cycle. The lower limit is then about 1 millisecond.

The detector consists of a plastic scintillation phosphor placed in a heavy lead shield below the target and a Plexiglas light guide with a photomultiplier outside the magnetic field of the cyclotron. β rays are collimated into a vertical ray by the magnetic field. In some early experiments a pair of proportional counters in coincidence were used. The pulses were fed to 6*AK*5 cathode followers. There was some trouble in making these work satisfactorily in the strong magnetic field.

Most of the experiments were done with a single scintillation counter. It was found that nearly all of the activity came from the target. During the cyclotron pulse a burst of scattered particles hits the phosphor and gives rise to many pulses. There is no gating of the amplifier. The counting, however, is started 2 milliseconds after the cyclotron pulse and the amplifier employed is capable of heavy overloading with short recovery time. Some of the scattered particles give rise to nuclear reactions in the phosphor and the 13-millisecond $\mathrm{N}^{12}\ \beta^+$ activity $[\mathrm{C}^{12}(p,n)\mathrm{N}^{12}]$ is found as a weak background in some cases when using a plastic phosphor.

TABLE I. Elements irradiated and activities found. Bombardments were normally made at proton energies of 23, 50, 80 or 100, 130, and 180 Mev. The listed figure is the lowest energy at which the activity appears in appreciable amount. The purity of elements marked† was only about 99 percent.

Element irradiated	Activities sec	Proton energy Mev	Suggested origin	Reference
Li†	0.85	23	He^6	e
	$\approx$0.4	50	Be^6 or Li^4	a, b
Be†	0.85	23	Li^8	e
	0.4	50	Be^6 or Li^4	a, b
Mg	0.13	23	Al^{23} or Mg^{22}	
	2.3	23	Al^{24}	e
	7	23	Al^{26} or Al^{25}	e
	0.4	50		
	4.5	80		
Al	1.7	23	Si^{26}	
	$\approx$5	23	Si^{27}	e
	$\approx$0.2	80		
Si†	0.27	20	P^{28}	c
	$\approx$2.5	20		
	$\approx$4.8	20	Si^{27} or P^{29}	e
	$\approx$1	50		
S	0.28	23	Cl^{32}	c
	$\approx$1.7	23	Cl^{33}	e
Ca†	$\approx$0.35	23	Sc^{40}	
	$\approx$1.2	23	Ca^{39} or K^{37}	e
Ti	0.40	23	V^{46}	d
	0.58	80	Ti^{43}	e
	$\approx$0.2	80		
V	1.1	57	Cr^{46}	
	0.4	57	V^{46} or Cr^{47}	
Cr†	0.26	45	Mn^{50}	d
	0.43	100	Mn^{49} or Cr^{47}	
	1.1	165	Cr^{46}	
Mn	0.28	95	Mn^{50}	d
	0.77	95		
Fe	0.20	23	Co^{54}	d
	0.55	50		
Ni	3	23	Cu^{58}	e
	0.18	50	Co^{54} or Cu^{57}	
Cu	0.3	130		
	1.3	130		
Zn	0.15	100		
	0.8	100		

[a] See reference 1.
[b] See reference 2.
[c] See reference 3.
[d] See reference 4.
[e] See reference 5.

Some preliminary experiments on a number of elements have been made. Table I shows the element irradiated and the activities found. Some of the activities have been investigated or discussed earlier.[1-5] Experiments are under way to study short-lived isomeric states in some heavier elements, and also to detect short-lived α-decaying nuclides. In the latter case a thin layer of ZnS phosphor coated on Plexiglas has been used to discriminate α from β and γ pulses.

Experiments will be carried out with more channels in the analyzer to facilitate resolution of the decay curves and also perhaps with scintillation counters in coincidence.

Mass assignments will be made mainly by the study of excitation curves. Properties of the radiation will be studied by pulse-height analysis of the crystal pulses at different times after the cyclotron pulse.

The suggested assignments in Table I are from a simple consideration of preferred reaction types and estimates of thresholds, with some mass values obtained from the table of Metropolis and Reitwiesner.[6] It is probable that several corrections will have to be made as experiments proceed.

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[1] R. K. Sheline, Phys. Rev. **87**, 557 (1952).

[2] T. Lauritsen, Ann. Revs. Nuclear Sci. **1**, 85 (1952).

[3] Glass, Jensen, and Richardson, Phys. Rev. **90**, 320 (1953).

[4] W. M. Martin and S. W. Breckon, Can. J. Phys. **30**, 643 (1952).

[5] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

[6] N. Metropolis and G. Reitwiesner, Report NP-1980 (unpublished).

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Energy Level Displacements in Pi-Mesonic Atoms

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The energy level shifts and level widths of the s states of the π-mesonic atoms are discussed. The discussion is limited to fairly light nuclei. On the basis of Orear's determination of the scattering lengths for meson-nucleon scattering, semiquantitative predictions are made. It is pointed out that even a knowledge of the algebraic sign of the level shift would be of value.

I. INTRODUCTION

SEVERAL years ago[1] the low-energy properties of the π^--p, π^0-n system were discussed on the basis of a formalism closely related to that of Wigner and Eisenbud.[2] The system was treated as a two-channel nuclear reaction (taking into account only s state interaction, which we shall also do here) with the boundary conditions at the surface of a sphere of a radius, the meson Compton wavelength being specified in terms of three real energy-dependent parameters. The only unusual feature in the calculation is the treatment of the capture of a negative pion from a bound K orbit.[3] There appear quite naturally in the calculation the shift of the Bohr level associated with the pion-proton interaction and the width of the level due to the capture process. It is the purpose of the present note to deduce the level shift and level width in mesonic atoms in a more elementary and to a certain extent a less phenomenological manner than was done previously[1] and further to discuss briefly the possibilities of comparison with experiment.

II. DERIVATION OF THE LEVEL SHIFT AND LEVEL WIDTH

Before taking up the details of the calculation it is expedient to discuss the rather peculiar role played by the Coulomb field in the mesonic atom problem as well as in the ordinary low-energy scattering. The Coulomb force is of course essential for the very existence of mesonic atoms and its influence on the low-energy scattering is quite marked in so far as the interpretation of the data is concerned. On the other hand, provided that the nuclear charge is low (exactly how low will appear later) the Coulomb field may be treated very

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[1] E. Fermi and M. L. Goldberger (unpublished); a short account of the work appears in Phys. Rev. **83**, 239(A) (1951). An essentially equivalent derivation has recently been independently given by G. C. Wick (private communication). We are indebted to Prof. Wick for informing us of his results.

[2] E. P. Wigner and L. Eisenbud, Phys. Rev. **72**, 29 (1947).

[3] The usual formulation of reaction theory deals with scattering rather than bound states. The necessary formal extension of the theory was later given independently by J. B. Ehrmann, Phys. Rev. **81**, 412 (1951). Our problem is much simpler in that the small level shift and level width enables us to approximate the Coulomb functions in a simple way.