THE INNER GRANULOMETRIC DENSITY OF THE TRACKS IN NUCLEAR EMULSIONS AND ITS APPLICATION TO DETERMINE THE CHEMICAL SPECTRUM OF PRIMARY COSMIC RAY NUCLIDI.

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1.- Introduction. The classical formula of Lattes, Fowler and Cüer (1),

$$(1)\quad E = b\, Z^{2a} A^{1-a} R^{a}$$

which gives the energy E of a non-relativistic nuclide as function of the atomic number Z, the relative atomic mass A and the linear residual range R (b and a = constants) is valid for residual ranges of the order of 2,000 µm under the assumption that the nuclide itself does not capture electrons before its stopping point inside the nuclear emulsions. For a given interval $\Delta R = L$ (referred as a cell in this paper), with an effective ionizing atomic number Z_{eff} (due to a given number of captured electrons) formula (1) becomes,

$$(2)\,\Delta E = b\, Z_{eff}^{2a} A^{1-a} \{R_{eff}^{a} - (R_{eff} - L)^{a}\}$$

Actually, the linear residual ranges which are determined with the microscope (here denoted as R_r) neither are represented by R of (1) nor by R_{eff} of (2) because of the effect of the successive electron captures along the linear residual range. However, at a given value of R_r - or of Z_{eff} - the expression $R_r^a - (R_r - L)^a$ differs from the corresponding one of (2) as an infinitesimal of second order.

Therefore, if we measure R_r and determine ΔE in a cell $\Delta R = L$, we can obtain the particular value of the expression $(Z_{eff})^{2a} A^{1-a}$ at R_r .

2.- The Method. A direct counting of the number of developed grains inside a cell $\Delta R = L$ at a given residual range R_r was carried out on tracks of stopping monocharged nuclidi as those of protons and deuterons. By applying formula (2) with R_r instead of R_{eff} (taking $a = 0.568$ and $b = 0.281$ for our G-5 Ilford emulsions), ΔE was determined and consequently, also the value w of the energy transferred to each microcrystal of $Ag^{+}Br^{-}$ - involved in the formation of a single silver developed grain - was obtained.

For $Z \geq 2$, the inner granulometric density is defined by the ratio between the volume of the track segment of length $\Delta R = L$ and that one of the single proton developed grain.

The corresponding measurements of diameters of grains and thicknesses of tracks were carried out by strictly applying the Occhialini's Track Profile Method (2).

As it has already shown for protons and deuterons in Table I, the experimental measurements resulted coherent and compatible with the assumption that at a given value of the function $\mathcal{X}$ (Partition Function) given by,

$$(3) \quad \mathcal{X} = E/(Z^{2a} A^{1-a}) = b R^a$$

the energy loss of a nuclide involved in the formation of a single silver developed grain which, in turn, is located inside a small part of the track (e.g. L = 20 μm) is the same for any nuclide stopping inside a given plate, independently of the value of Z . This fact together with the value of the inner granulometric density permit us to determine ΔE corresponding to this track segment at the residual range R_r and consequently , to know the magnitude $Z^{2a} A^{1-a}$.

TABLE I

R_r (μm)	w_p (MeV/grain)	w_D (MeV/grain)
0-20	0.0423 ± 0.0040	0.0400 ± 0.0041
20-40	0.0204 ± 0.0019	0.0195 ± 0.0038
40-60	0.0163 ± 0.0015	0.0154 ± 0.0016
60-80	0.0140 ± 0.0013	0.0140 ± 0.0014
80-100	0.0117 ± 0.0012	0.0110 ± 0.0011
......	....	....
260-280	0.0078 ± 0.0008	0.0078 ± 0.0009
......	....	....
540-560	0.0055 ± 0.0005	0.0054 ± 0.0009

The extrapolated curve of w_p or w_D as function of R_r leads to the relativistic limit of w = 3.0 KeV/grain.

Besides, for the electron tracks with $R_r \leq$ 20.0 μm it was determined that w_e = (0.0433 ± 0.0042) MeV/grain. Actually this result was directly obtained with a radioactive standard source of $^{210}B_{183}$.

Table II shows the results of the measurements which were carried out on the last 20 μm of residual range. These short linear residual ranges were chosen to test the reliability of the method. The tracks were selected by a non systematic scanning. For any of these nuclidi, $\mathcal{X}$ = 1.540605 MeV.

The experimental value of ΔE was determined by the number of

TABLE II

Atomic Nuclide	$\dot{E}$(experimental) (MeV)	$\dot{E}$(theor.) (MeV)	$\bar{d}$ (um)	$\bar{Z}_{eff}$	Isotopic mass ratio.
$^{1}H_{1}$	(calibration nuclide)	1.540605	0.700 ± 0.023	1.0	$^{2}H_{1}/^{1}H_{1}$ =2.00082 ±0.50701
$^{2}H_{1}$	2.07880 ± 0.22757	2.078434	1.000 ± 0.080	1.0	
$^{4}He_{2}$	5.4400 ± 0.6100	5.467274	1.217 ± 0.023	1.8	$^{4}He_{2}/^{3}He_{2}$= 1.34253 ± 0.50812
$^{3}He_{2}$	4.7900 ± 0.5700	4.822833	1.142 ± 0.026	1.8	
$^{7}Li_{3}$	6.67546± 0.52357	6.962469	1.343 ± 0.021	1.8	$^{8}Li_{3}/^{7}Li_{3}$ = 1.12271 ± 0.14071
$^{8}Li_{3}$	7.01512± 0.52336	7.375913	1.377 ± 0.020	1.8	
$^{12}C_{6}$	9.6377 ± 1.9482	9.905302	1.614 ± 0.030	2.0	$^{13}C_{6}/^{12}C_{6}$ = 1.18083 ± 0.1100
$^{13}C_{6}$	10.3589 ± 2.2643	10.253803	1.6733± 0.048	2.0	

The following number of nuclidi are shown in this Table : 11, ^{1}H; 6, ^{2}H; 5, ^{4}He; 3, ^{3}He; 7, ^{7}Li; 5, ^{8}Li; 7, ^{12}C and 7, ^{13}C.

the inner silver developed grains times the value of w_p corresponding to R_r = 20.0 µm (Table I). The theoretical one, by formula (2). All the tracks were also identified by the classical method.Once knowing the experimental value of $\dot{E}$, Z_{eff} (average value in 20 µm) and the ratio between isotopic masses were deduced.

Table III indicates the results corresponding to a part of the 29 nuclidi which were inside of 37 central plates of a package of emulsions which flew at an average altitude of 4.5 g/cm^2 during 16 hours, in 19 to 20 of July of 1958 over Minneapolis, Minn.; the 200 plates of Ilford G-5 emulsions of 15x15 cm x 600 µm each,were kindly afforded to the author of the present paper by the late Professor of The University of Chicago, Dr. Marcel Schein.

The above mentioned 29 nuclear tracks, which had $Z \geq 3$ and stopped inside the emulsions, entered at 7 mm from the superior edge of each sheet and were distributed as it follows:

^{6}Li	^{7}Be	^{10}Be	^{10}B	^{11}B	^{11}C	^{12}C	^{13}C	^{13}N	^{14}N
1	3	1	1	1	3	6	1	2	5

$^{18}O - ^{21}Ne - ^{24}Mg - ^{27}Al - ^{35}Cl$
1 1 1 1 1

TABLE III

$Z^{1.136}A^{0.432}$ (exp.)	$Z^{1.136}A^{0.432}$ (theo.)	Assigned Nuclide	W (MeV/grain)	R_r
7.361951±0.730232	7.553897	$^{9}Li_3$	0.0081	205.28
11.640685±1.316993	11.194959	^{7}Be	0.0066	348.51
13.619709±1.540894	13.0599089	^{10}Be	0.0077	230.02
16.687503±1.887975	16.827900	^{10}B	0.0071	283.19
26.877412±2.994446	27.621999	^{13}N	0.0062	422.50
27.933732±3.160341	28.520602	^{14}N	0.0063	374.98
20.847880±2.358668	21.570562	^{11}C	0.0063	372.12
22.305500±1.596050	22.396808	^{12}C	0.0056	497.80
22.953260±2.596865	23.184799	^{13}C	0.0054	550.20
50.933117±5.762424	50.956400	^{21}Ne	0.0056	554.87
67.491854±7.635832	66.405056	^{24}Mg	0.0055	540.74
117.16624±13.25585	116.098704	^{35}Cl	0.0055	546.63

3.- Conclusions. Taking into account that the identification of the above measured nuclidi was done by determining the inner granulometric density in only two successive cells of 23.44 µm each and which were located at a residual range R_r (see Table III), to improve the precision of the determination of Z and A it is suggested that the measurements of each track have at least to observe the following steps:

(a) Start the determination of the inner granulometric density, in 2 or 3 consecutive cells, from the stopping point of the track. This zone has a very small number of standard δ-rays.

(b) Measurements of that granulometric density have to be carried out in several consecutive cells which should permit to determine the transition from Z_{eff} to Z .

(c) Measurements of several cells have to be done in the track segment in which the value of $Z^{1.136}A^{0.432}$ should remain as a constant one inside its experimental errors.

In (b) and (c) it is necessary to add the energy of the standard δ -rays (of 2 or more grains) which in our case resulted at a rate of 0.0423 MeV/grain.

To obtain the above given 29 nuclidi, the author of this paper has observed only point (c). Complementary measurements on this group of particles by taking into account points (a) and (b) shall improve the spectral distribution of A and Z . Besides, with this criterion measurements will be carried out on another group of 60 stopping nuclidi belonging to the same package of nuclear emulsions.

References:

(1) C.M.Lattes et al.: Proc.Phys.Soc., 59, 883(1947(
(2) G.P.S.Occhialini et al.:Suppl.Nuovo Cimento , 4, 244 (1956).