THE MASS SPECTRUM OF COSMIC RAY PRIMARIES

by

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INTRODUCTION

The History of Cosmic Rays

At the end of the last century the conductivity of air was the subject of extensive studies by many scientists. One finding of these investigations was that, despite careful shielding, there remained a residual conductivity in the air samples under study. As detected in an ionization chamber the effect was equivalent to the production of about ten ion pairs per second per cubic centimeter of standard air. It was shown that most of this effect was the result of radiation coming from outside.

V. F. Hess (1912) and W. Kolhorster (1914) showed definitely that the ionization decreases from ground level to about 2300 feet, and then increases steadily, reaching magnitudes of many times its ground level value at six to seven thousand feet. Just before the cessation of research activity due to the First World War, Hess observed that the ionization was substantially the same at night as in the day. He then put forth the hypothesis that an extremely penetrating radiation, whose immediate source was not the sun, falls on the earth from outer space. It was assumed that this penetrating radiation of cosmic origin consisted of gamma-rays of very high energy, since the gamma-radiation from naturally radioactive substances was far more penetrating than any corpuscular rays known at the time. In fact, this view persisted until 1929, when the character of cosmic ray research was revolutionized by the discovery that some rays are corpuscular.

At first scientists believed that there was not sufficient evidence for the existence of cosmic rays. But in 1926 it was universally agreed that cosmic rays existed. In 1928, W. Bothe and W. Kolhorster proved that charged particles existed among the cosmic rays in the earth's atmosphere. This was further reinforced by D. Dkobelyzen (1929) and B. Rossi (1932) working with Wilson cloud chambers. In 1932 a new particle, the positron, was discovered in cosmic rays by C. D. Anderson.

By 1933 investigations were being conducted on cosmic radiation near the "top" of the atmosphere, i. e., the upper 10% of the atmosphere by pressure, corresponding to altitudes above 50,000 feet. The first investigations at great heights are associated with the names of A. Piccard, M. Cosyns, G. Suckstorff, E. Regener, I. S. Bowen, and R. A. Millikan. Since this time cosmic ray research has progressed rapidly and steadily.

The Importance of Heavy Ions in Cosmic Rays

In this paper we are not interested in cosmic rays in general, but merely the heavy ions in the radiation. Although the total number of nuclei heavier than protons constitute only about 15% of the cosmic ray beam, their influence on the interpretation of the cosmic ray phenomena in the atmosphere is nevertheless considerable, since they represent 30 - 35% of the incoming nucleons, they carry perhaps 30% of the incident cosmic ray energy, and they provide about 50% of the ionization in the upper layers of the atmosphere. Also, apart from meteors, cosmic rays provide the only samples of extra terrestrial matter that is available for our direct inspection. And, since the majority of these particles are generally assumed to originate outside the solar system, they represent the only sample of galactic matter available to direct observation. Thus the study of the mass spectrum of cosmic ray primaries is of considerable importance to any understanding of the true nature of the universe. Unfortunately, a regretable feature of much of this type of work in the last ten to fifteen years is that it has produced many conflicting results, so that any conclusion on details may be rebutted by experimental data in apparent disagreement.

THE SPECTRUM OF HEAVY NUCLEI IN COSMIC RAYS

Heavy nuclei are generally divided into four classes: light (L), $3\leq Z\leq 5$; medium (M), $6\leq Z\leq 9$; heavy (H), $10\leq Z\leq 19$; and very heavy (VH), $Z\geq 20$. Plate I shows the percentage of each element present in cosmic radiation as found by various experimenters, and also the relative abundances of these elements in the universe as estimated by Suess and Urey and by Cameron. Notice here and in the following bar graphs, i. e., Plates II, III, and IV, that there seems to be a trend for there to be more nuclei with even Z than with odd Z. This is believed to be due to the fact that the H and VH nuclei are thought to be predominantly produced by helium capture processes and those of odd charge resulting from slow neutron capture. The table also illustrates a great enrichment of the cosmic radiation with heavy elements. As a consequence, it has been suggested that the source of cosmic radiation is composed solely of these nuclei, and that the observed spectrum is due entirely to fragmentation. However this suggestion has run into many difficulties, the most pronounced of which is that if this were so, the charge spectrum would not show any pronounced features. While, in general, no nuclei heavier than iron, cobalt, or nickel is usually identified among the tracks of heavy ions from cosmic rays, a few nuclei of higher charge have been reported by Freier et al (1948), Sörensen (1949), Fong (1950), Peters (1952), and a few others. Despite these reports, there seems to be not enough evidence for the presence of such nuclei in primary cosmic radiation to convence many experimenters. It is also doubtful whether a sufficient number of tracks of iron, cobalt, and nickel have been observed to make this apparent failure to detect heavier nuclei significant in any comparison with the cosmic abundances.

EXPLANATION OF PLATE I

The Relative Abundance of Heavy Primaries in Cosmic Rays

PLATE I

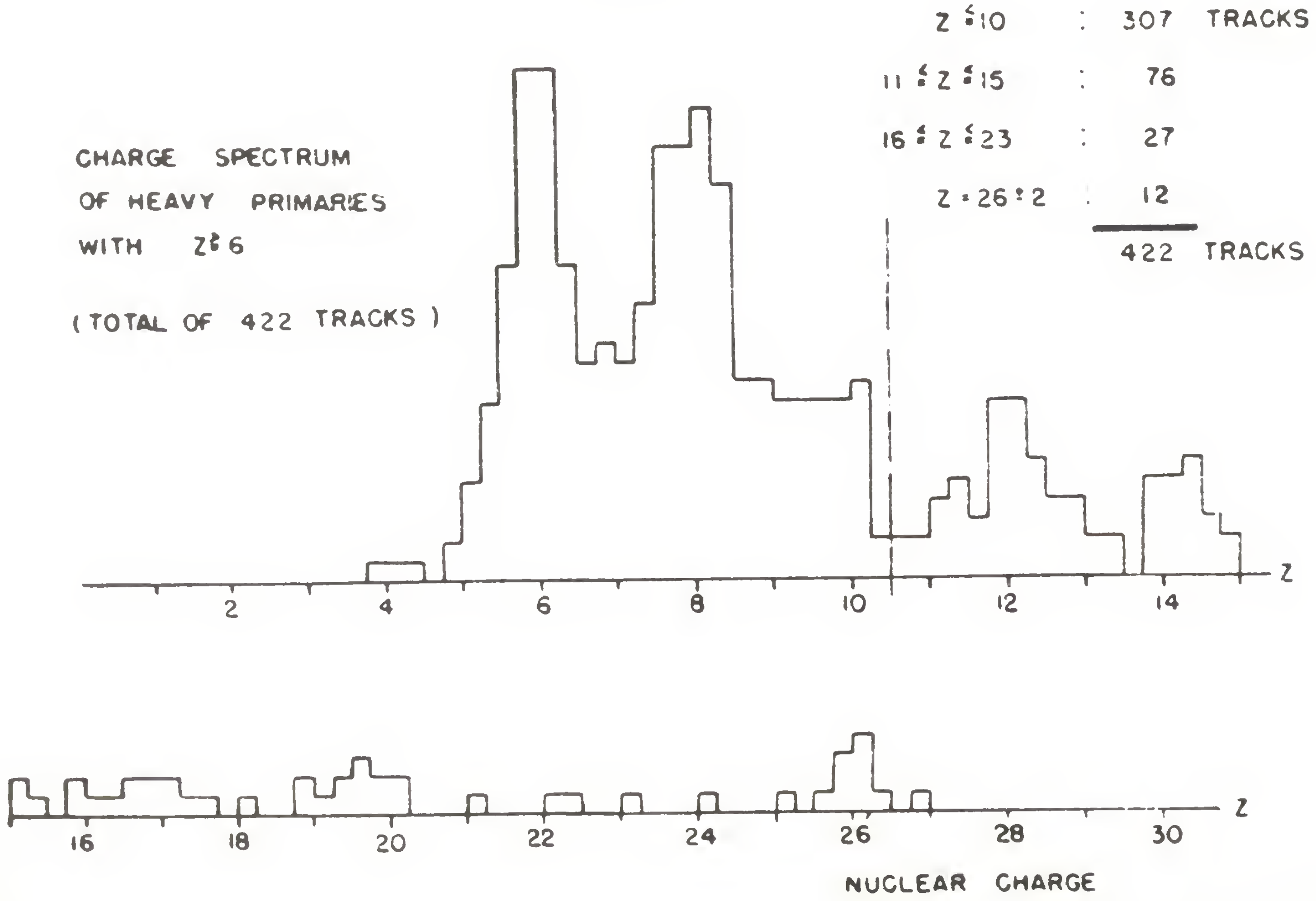
Author			Ginzberg & Syrovatskii		Kashiber		Aizu		O Dell	Waddington	Cosmic Abundance Suess & Urey	Cosmic Abundance Cameron
Date			1964		1959		1957		1958	1960		
Component	Z											
Li	3	L	4.3		5.7		5.2		5.2	3.9	1.76x10^{-4}	2.48x10^{-4}
Be	4		1.9		4.0		4.3		2.3	1.7	3.52x10^{-5}	4.96x10^{-5}
B	5		12.7		9.0		11.9		7.4	11.6	4.22x10^{-5}	5.95x10^{-5}
C	6	M	25.0		25.4		25.1		30.1	26.0	19.3	23.1
N	7		11.9		12.9		14.9		9.7	12.4	5.29	5.96
O	8		17.6		18.4		14.5		19.4	17.9	54.5	62.1
F	9		2.3		1.9		4.0		2.4	2.6	2.81x10^{-3}	3.97x10^{-3}
Ne	10	H	4.0	22.0	3.0	22.7	4.3	19.8	23.4	23.9	15.1	1.99
Na	11		2.5		3.6		2.7				.0770	.110
Mg	12		4.4		5.5		4.7				1.60	2.26
Al	13		.8		1.3		.9				.167	.235
Si	14		1.5		2.7		1.6				1.76	2.48
P	15		1.7		.9		.2				.0176	.0248
S	16		0.0		1.0		0.0				.660	.930
Cl	17		1.3		.4		.1				.0156	6.47x10^{-3}
A	18		.5		.4		.5				.264	.372
K	19		0.0		.1		0.0				5.56x10^{-3}	7.84x10^{-3}
Z≥20		VH	5.3		3.8		4.8				1.23	.335

EXPLANATION OF PLATE II

The Z-Spectrum of Primaries identified by δ-ray density

From Peters (1952)

PLATE II



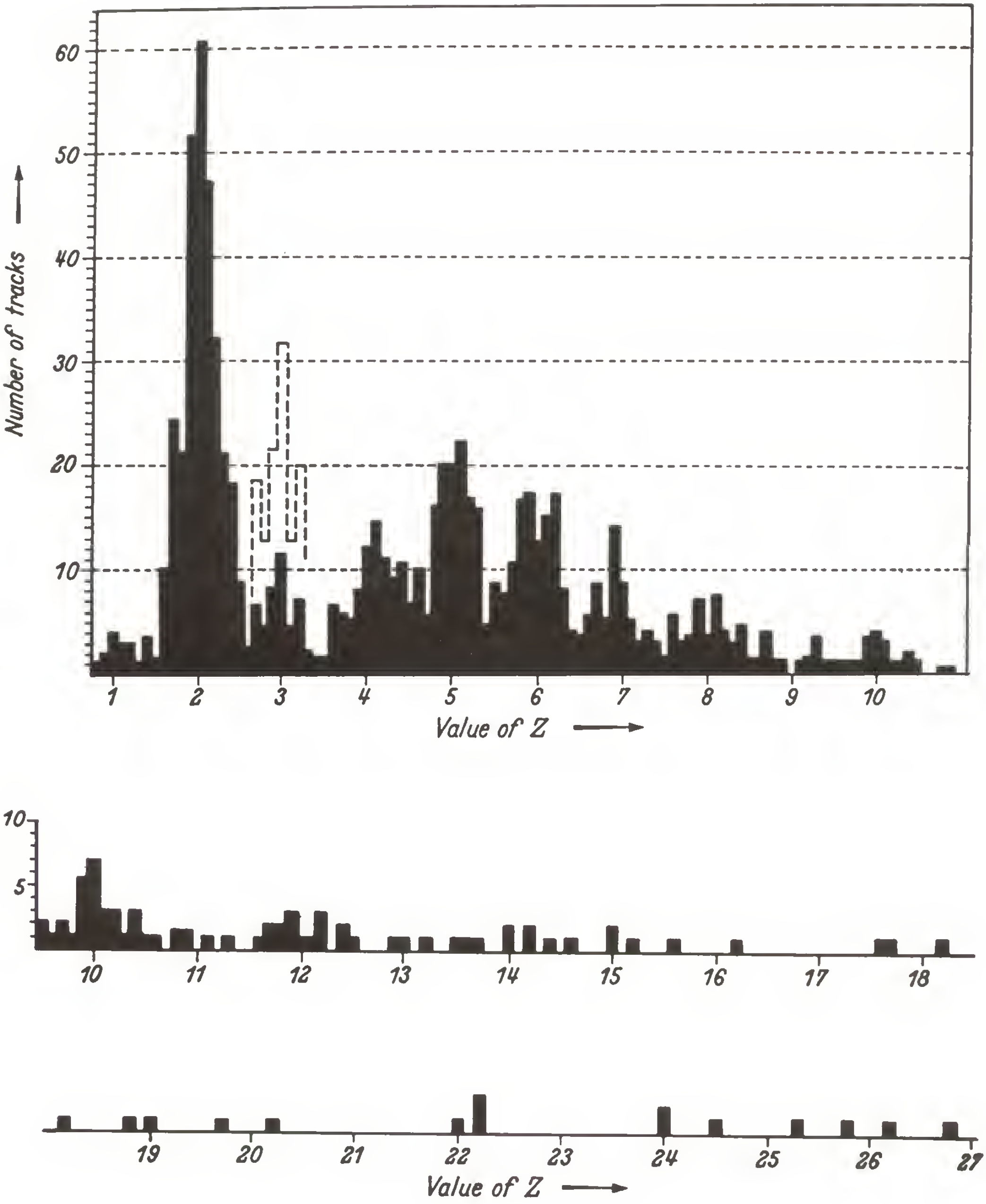
CHARGE SPECTRUM OF HEAVY PRIMARIES WITH $Z \geq 6$

(TOTAL OF 422 TRACKS)

EXPLANATION OF PLATE III

A Z-Spectrum from Powell, Fowler, and Perkins (1959) The estimated intensity of the Li nuclei, after correction for the inefficiency of observing these owing to their simularity to the tracks of α-particles and slow protons, is indicated by the dotted line.

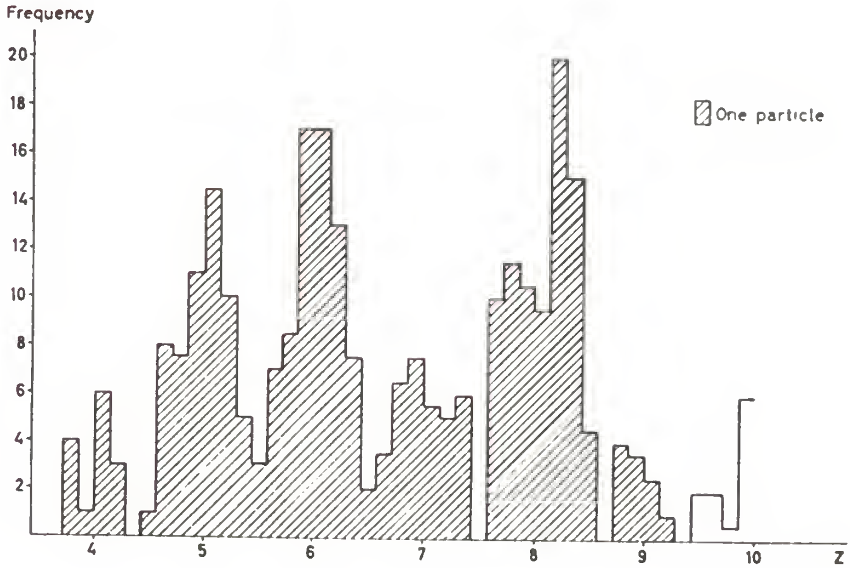
PLATE III

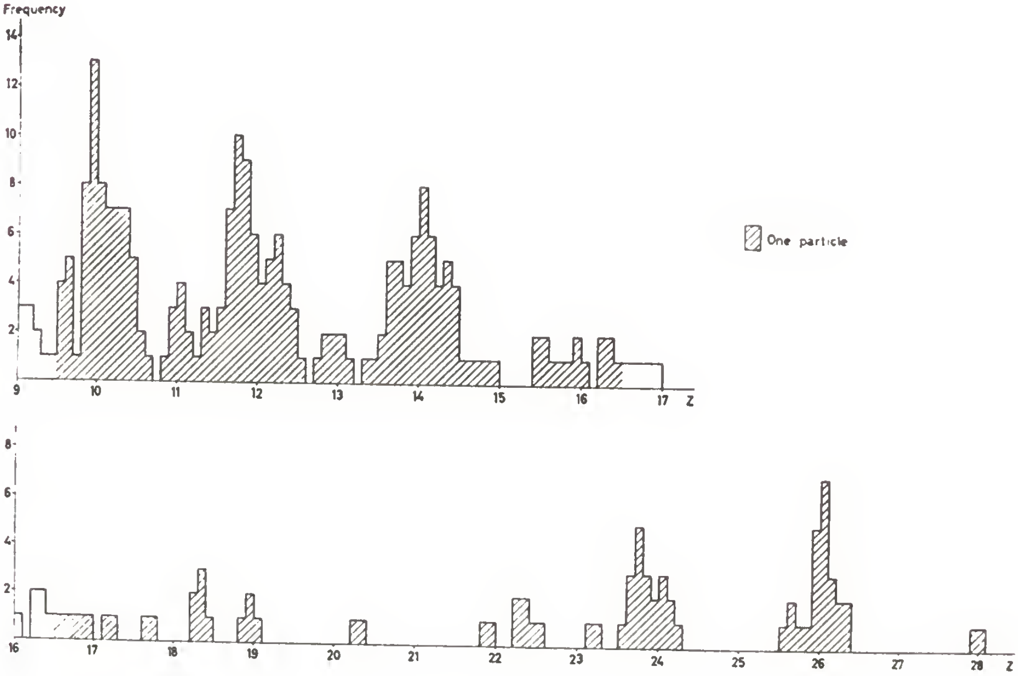

Number of tracks
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
Value of Z
10
5
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
Value of Z

EXPLANATION OF PLATE IV

The Z-Spectrum as Measured by
Kristiansson, Mathiesen, and Stenman
1962

PLATE IV


Frequency
20
18
16
14
12
10
8
6
4
2
One particle
4
5
6
7
8
9
10
Z


Frequency
14
12
10
8
6
4
2
One particle
9
10
11
12
13
14
15
16
17
Z
8
6
4
2
16
17
18
19
20
21
22
23
24
25
26
27
28
Z

PHOTOGRAPHIC EMULSIONS

The Emulsion

Before we discuss the spectrum found in our particular stack of emulsions, however, we must first investigate the nature of the instruments and the methodology of this experiment. The tracks that were measured were detected in nuclear research emulsions. This method was used for many reasons. Only a small volume is needed to analyze completely the radiation entering it. Also, emulsion has a memory, extreme sensitivity, and an enormous range of linear response. The trajectories of the particles are, moreover, preserved permanently.

Nuclear research emulsion consists of a matrix of gelatin in which there is suspended photo-sensitive silver bromide and silver iodide crystals. The gelatin is usually made from clippings of calf hides, ears, and certain other pieces. It can also be made from pigskin or bone. When hydrolized, it may be analyzed into a number of amino acids; the proportion of carbon, hydrogen, nitrogen, and oxygen being 50.8%, 6.9%, 17.5%, and 24.0% respectively. When dry, gelatin has great mechanical strength. When soaked in water, however, it swells greatly, becomes soft, and is easily torn. At 40 - 50°C it gradually melts to a liquid which can be diluted indefinitely. In concentrations exceeding 1% it sets to a jelly when cooled. The strength and rigidity of the jelly depends on the concentration of the gelatin.

The Photographic Process

Although the gelatin determines the physical properties of the emulsion, our chief interest lies in the photographic process, in which the gelatin acts mainly, but not exclusively as a holder for the photosensative silver. Little is known for sure about how the photographic process really works, and many of the theories are barely beyond the conjecture stage. The process is based on a special property of silver halide crystals, i. e., when a silver halide crystal absorbs energy from photons of moving charged particles incident upon it, the microcrystals may be conditioned by this experience so that, under the action of a chemical reducing agent, the conversion of the halide to metallic silver will proceed more rapidly than in an unirradiated crystal.

There are many theories as to how this happens, none entirely satisfactory. The most accepted theory at the present time was put forth by Mitchell in a series of papers in the mid and late fifties. It is as follows: All the outer electrons of an ion of the crystal lattice are bound, so that in the absence of light, and at low temperatures, the crystal is an insulator. It is generally assumed that the absorption of a quantum of energy causes the ionization of a bromine ion which is thus transformed into a bromine atom. The ejection of an electron leads to a region of positive charge which is referred to as a "positive hole", and, corresponding to it, there is an unoccupied level in the energy states associated with the bromine lattice. The electron, raised to a state of higher energy by the absorption of the quantum, is not free as in a metal. It can be regarded as being associated with the silver lattice. Since the conduction bands of metallic silver are about 1eV below those of the silver in silver bromide, a silver speck can act as a trap for the electrons. The trapped electron then can be considered as neutralizing one of the silver ions. The effect of the absorption of the quantum is, therefore, to transform two ions into atoms, one of silver and one of bromine.

It is believed that the next process in the formation of the latent image is that the positive holes, as they diffuse through the crystal, are trapped in the lattice imperfections on the surface of the crystal. Since the mean lifetime of an electron before being trapped is much longer than that of a hole, we can consider the trapping of the hole as the primary process. Therefore, it is believed that immediately following the passage of a charged particle or a photon through a grain, an excess of positive charge is established at the surface of the crystal in the form of silver ions, and a corresponding negative charge in the form of electrons in the conduction band. The silver is initially dispersed over the entire surface, but becomes concentrated into an aggregate which can act as a development center.

Mitchell (1954) has suggested that this concentration is due to the following: the radius of a silver ion is about 1.1A and of an atom, about 1.4A. If an ion were to capture an electron its nucleus would have to move out from the neighboring surface atoms about .3A. This process is rendered very improbable by the Frank-Condon Principle, and the immediate combination of electron and silver ion is prevented. A positive silver ion on the surface can, however, migrate, and on approaching a silver atom, a member of the sensitizing layer, it is attracted to it by Van der Waals forces. As a result, the positive charge of the original ion is shared between two or three atoms, and the distance from the neighboring atoms of those composing this small complex are such that an electron can be captured by it. It appears probable that the number of silver atoms in an aggregate is small, not more than three or four.

Development

The next step in the process of getting photographic images is to develop the emulsion. In general, film developer consists of five components, as follows:

The Developing Agent. This component reduces the exposed silver halide grains to metallic silver. Developer can be put into two general classes, physical and chemical. Physical developers contain silver, or perhaps some other metallic ions that deposit on the latent image centers. Chemical developers use the silver ions in the emulsion itself. Most developers in use, however, are combined physical and chemical developers. Sulfite and bromide are solvents of the silver halide, and complexes of silver halides form with these chemicals. The silver ions in the complex are reduced to metallic silver which precipitates in the gelatin and plates on the silver grains at the latent image sites. For nuclear research emulsions the most commonly used developing agent is a chemical known as Amidol. The chemical name for this is 2-4 diaminophenol ($2\text{-}4\ (NH_2)\cdot C_6H_3OH\cdot 2HCl$). This is especially favored for use with thick emulsions, because it penetrates the emulsion more rapidly than most other developing agents, and it is a strong reducing agent which functions at low pH. This last property is important because at low pH the swelling of the emulsion is modest and serious distortions are avoided. Amidol has one serious fault, however. It is easily oxidized and its oxidation products produce reddish stains on the gelatin. This tendency also makes it imperative to mix each batch of developer immediately before use.

The Preservative. The preservative, a sulfite, bisulfite, or metabisulfite, prevents destruction of the developing agent by oxidation and thus avoids gelatin stains. In addition, the preservative forms complexes which act as silver halide solvents. The most commonly used preservative is sodium sulfite, either dessicated (Na_2SO_3), or crystal ($Na_2SO_3\cdot 7H_2O$).

The Keeper. This is also a preservative that prevents aerial oxidation of the developing solution. The most common keepers are sodium bisulfite ($NaHSO_3$), and potassium metabisulfite ($K_2S_2O_3$).

The Activator or Accelerator. These are compounds that increase developing activity. Normally these are alkalies, or compounds which combine with sulfite to form complexes that hysrolize to liberate the necessary alkali. The accelerator also softens the emulsion, allowing the developing solution to penetrate more easily. The most common accelerator is sodium carbonate, either dessicated (Na_2CO_3), or monohydrate ($Na_2CO_3 \cdot H_2O$), followed closely behind by the borates--sodium metaborate and borax.

The Restrainer. Restrainers slow development. This tends to decrease the chance of staining by the oxidation products of the developer. They also increase contrast and decrease background fog, since the restraining action is greater on the fog than on the latent image. Alkaline bromides are usually used as restrainers.

After the emulsion is developed, it is fixed. The main job of the fixing agent is to convert the unexposed silver halides into complexes soluble in water. By far the most widespread fixing agent is sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$), commonly known as hypo. There is generally also an acid in the fixing solution to neutralize the alkali of the developer, stop development, and prevent staining due to the oxidation of the developing agent in the emulsion. The acids most generally used are acetic acid, sulfuric acid, boric acid, and sodium bisulfite (acidified sulfite). The acid also keeps the emulsion swelling within bounds which is very important in the fixing of thick emulsions.

Thick Emulsions

For emulsions of 200u or less the actual procedure of development is fairly straightforward. However, for thicker emulsions, a few more problems arise. As the emulsion becomes thicker, the time needed for the developer to diffuse through the emulsion becomes significant compared to the time for the emulsion to be completely developed. This leads to the condition that the images at the top of the emulsion become more developed than those deeper in the emulsion. One way to combat this is to develop the emulsion off the glass so that the solutions can seep into the emulsion from both sides. Emulsions up to 2000u have been developed using this method. However when the emulsion is developed unsupported by glass, the swelling and contracting of the emulsion introduce serious distortions into any measurement of the range, or angle. Since this experiment involved measurement of the range, this method was discarded. By far the most widely used method of relieving this difficulty has been to let the developer diffuse through the emulsion in a very inactive condition. This is accomplished by manipulation either of the pH or the temperature of the solution, or both. The temperature control method is by far the most widely used. When the emulsion has soaked up the developer, the conditions are made right for development. It is, however, necessary to keep the developer already in the emulsion from seeping out. A dry developing stage has been tried by coating the emulsion with beeswax and then raising the temperature of the emulsion. This proved to be too messy, however, and is not widely used as a consequence. The most convenient way of doing this is to conduct the warm development stage with the emulsion immersed in a developing solution of reduced concentration.

The next problem arises due to the physical properties of the gelatin. When dry, gelatin is very strong and rigid. It has been known to break the glass plate on which it was mounted during the drying process. This is due to the fact that the emulsion shrinks during drying. To reduce this danger the emulsion is dried slowly by soaking it in solutions of alcohol and water with increasing alcohol concentrations until a pure alcohol bath is reached and then air drying the emulsion in a RH 50 - 60%. Also, each of these baths contains glycerin which is used as a plasticizer. The glycerin is absorbed by the emulsion which keeps the emulsion from becoming too rigid.

THE EXPERIMENT

The Emulsion

In this experiment Ilford G-5 nuclear research emulsion was used as the detector for the cosmic rays. The data came from two balloon flights. In the first flight the pellicles of emulsion were 600u thick and in the second, were 400u thick. In both cases the pellicles were 2"x4". Ilford G-5 was used mainly because it is sensitive to all charged particles of all energy. In these emulsions the mean diameter of the photographic grain was .27u. Considering that the gelatin matrix of the emulsion is an organic material it is not surprising that the composition is liable to vary from batch to batch. It also varies with prevailing humidity. The following figures show the mean composition of 40 batches of Ilford G-5 emulsion in gm/cc, in equilibrium with air at 58% RH at normal room temperature.

Table 1. The composition of Ilford G-5 emulsion.

Ag	1.817	± .029
Br	1.338	± .020
I	.0120	± .0002
C	.277	± .006
H	.0534	± .0012
O	.249	± .005
N	.074	± .002
S	.0072	± .0002
Density	3.8278	± .0354

In both flights the stack consisted of 100 emulsions. The emulsions were first numbered from 00 to 99 and two holes were punched in the emulsion along a line equidistant from the two long edges and 1/2" from the edges. These holes were punched with a punch especially adapted by us from a design used at the Goddard Space Flight Center and pictured in Plate V. For rigidity and for protection of the face of the emulsion from exposure to light, aluminum plates of the same dimensions as the emulsion were placed at either end of the stack. To keep the aluminum from reacting with the emulsion material, plastic plates of the same size were placed at either end between the emulsion and the aluminum plate. These four plates had holes drilled in them in the same places as the emulsion. The stack was then bolted together with two stainless steel bolts running through the punched holes. Since the size of the pellicles varied by about 2%, two adjacent sides of the stack were milled flat in such a way that the corner between them was square. This corner was later used as a reference for mounting. The whole package was then wrapped in lighttight material and flown.

Both stacks were flown by Dr. Donald Guss of the Goddard Space Flight Center in balloons released near Fort Churchill, Manitoba, Canada. The first stack was flown July 28, 1962 at 8:00 P.M.. The balloon rose to a height of 135,000 feet in four hours and remained at this height for nine hours. The second stack was flown on June 12, 1965, at 4:00 A.M.. It reached a height of 132,000 feet in three and a half hours and remained at this height for ten and one quarter hours.

Development

The emulsions were developed at Washington University in St. Louis at the laboratories of Dr. Friedlander. First, however, they were mounted on glass plates. The plates were first wetted in a tray of water and Photo-Flo. Then they were placed, one at a time, in a tray containing the mounting solution.

EXPLANATION OF PLATE V

Emulsion Punch

PLATE V

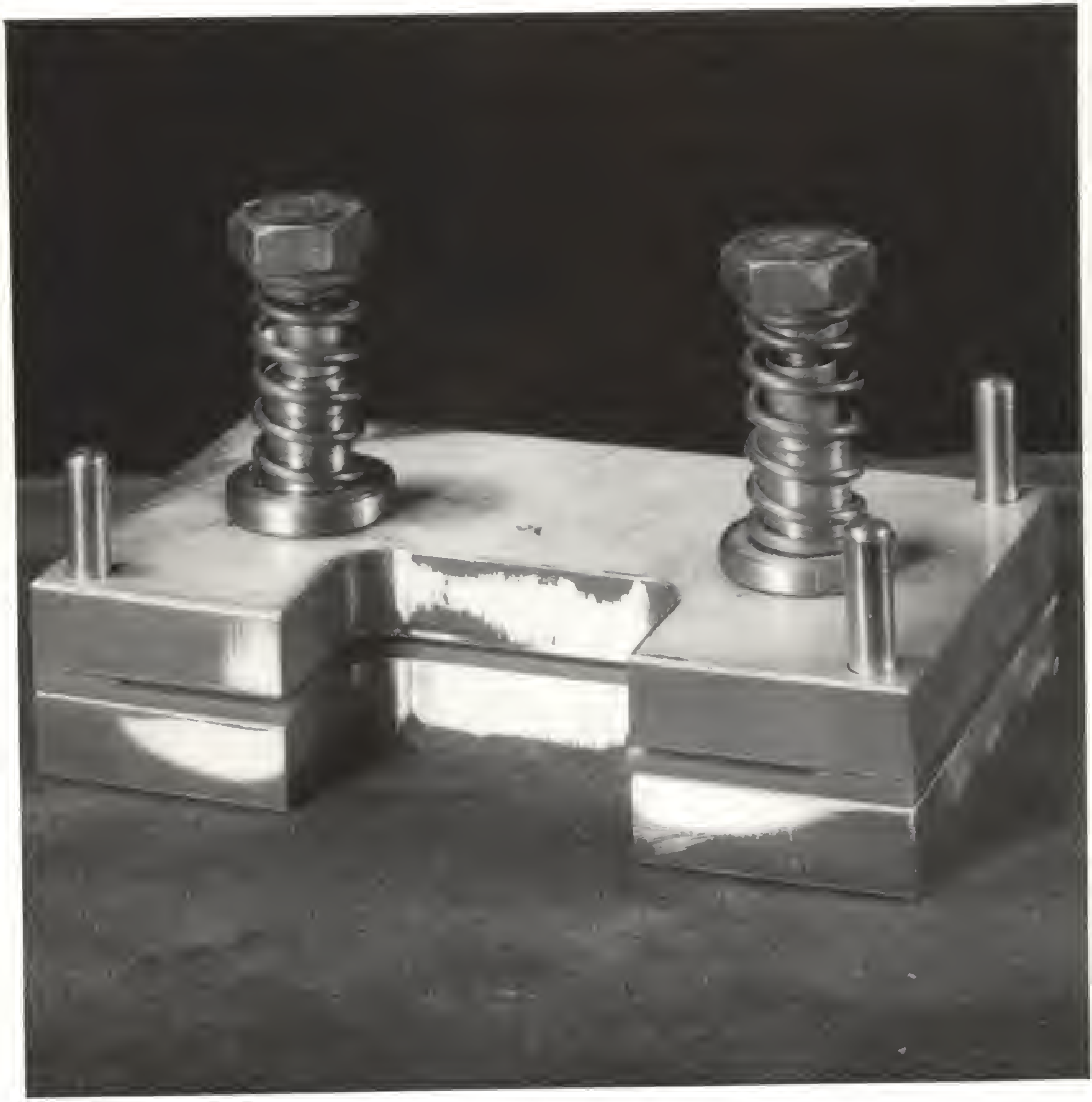


Table 2. Mounting solution.

Demineralized water	1000	cc
Gelatin	15	gm
Glycerin	5	cc
Photo-Flo	2.5	cc

This solution was made by letting the gelatin soak in the water overnight at room temperature. The solution was then heated to a temperature of 40 - 50°C until all the gelatin was in solution. Without the use of agitation, two hours was usually needed. The solution was then filtered and the other ingredients added to it.

With the glass plate completely immersed in this mounting solution a pellicle was mounted on it. The mounted plate was then passed through a wringer with moderate pressure, blotted with filter paper, and allowed to set for two days. From this step on the plates were handled in racks such as the one illustrated in Plate VI.

The plates were then soaked in demineralized water at 5°C for two hours for 400u emulsions and three hours for 600u emulsions. This time, however, is not critical. This bath has the effect of softening the emulsions so that the developer can diffuse through it faster. The plates are then immersed in the full strength developer for two hours at a temperature of 5°C.

EXPLANATION OF PLATE VI

Emulsion Holder for Developing
with One Emulsion
(The rubber bands keep the emulsion from falling out)

PLATE VI

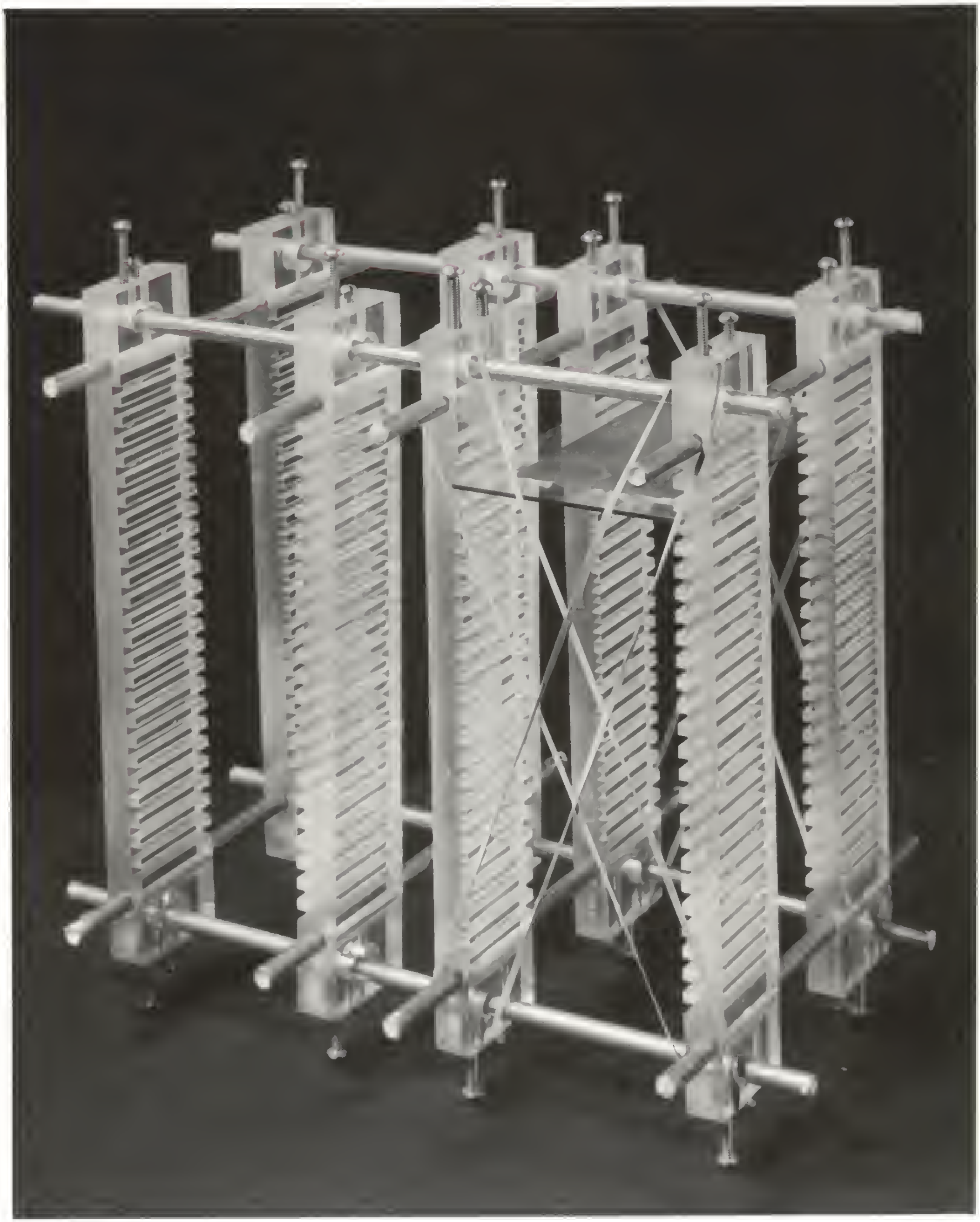


Table 3. Full strength developer.

Amidol	28.6	g
Sodium sulfate	227	g
Demineralized water	32	L

The plates were then transferred to a half strength solution of this developer which was at 20°C. The time that the plates remained in the half strength developer was determined by test plates and the requirements of the experiment.

In order to stop development, the plates were then immersed in a stop bath when the desired degree of development was achieved. This bath consisted of 160 ml of Acetic acid in 32 L of demineralized water, and lasted for two hours at a temperature of 5°C.

The plates were then fixed for one day longer than the time required for them to clear at a temperature of 5°C. The fixing solution consisted of 76 kg of Hypo (Sodium Thiosulfate) and 76 kg of Sodium Bisulfite dissolved in 50 gal of tap water. In order to decrease the time needed to fix the plates, new fixer was slowly, but constantly dripped into the tanks and the solution in the tanks was circulated.

The fixing solution was then removed from the emulsion by running water into the tanks and letting them overflow until there was no trace of fixer left in the solution. The plates were then put into a 1/3 alcohol solution (10 2/3L methyl alcohol, 22 1/3 L demineralized water, 1.92 L glycerin) for three hours, a 2/3 alcohol solution (22 1/3 L methyl alcohol, 10 2/3 L demineralized water, 1.92 L glycerin) for three hours and a pure alcohol bath (32.0 L methyl alcohol, 1.92 L glycerin) for three hours and then allowed to dry. The plates were then cleaned and trimmed of excess glass. Clear nail polish was then applied to the edges of the emulsion to prevent the emulsion from lifting off the glass plate.

Measurement

Photographs were first taken of the tracks using an Ernest Leitz Co. Aristophot camera in conjunction with an Ernest Leitz Co. Ortholux microscope. For these photographs an 8x para-plan eyepiece and a 100x plano, oil immersion objective were used. The tracks were then measured from 8"x10" prints made from these negatives.

The Z was then assigned to the track using the theory of Katz and Butts (1964). This theory identifies tracks by plotting the natural log of the range measured from the end of the track against the width of the track. As can be seen from Plate VII, the track of a heavy ion in emulsion is very rough and the width is rather indefinite. In order to smooth out this roughness a specific length of track was measured and marked off. The area within this length was then traced by four persons, independently. The traced areas were then measured by the use of a planimeter and the area was divided by the length to get an average width. Despite different tracing techniques, agreement as to the width was very good. Because of time considerations, the Z assignment was made by comparing the area between 100u and 200u and the maximum width with the theoretical values obtained by Katz and Butts (1964).

RESULTS

In the second stack, hereafter called the I stack, there were 94 useable tracks. There were roughly an equal number in the first, or K stack, but because of time considerations, only 24 of these were used making the total number of tracks identified 118. These are tabulated in Table 4. Each track is identified by a letter designating the stack, a two digit number to identify the particular track. The λ_0's refer to an additive constant that was used to normalize the measurements. This constant is the width of the track at its end and is the width of an undeveloped grain added to that of a developed grain. Each track is assigned two Z's, one using the area of the track between 100u and 200u, and the other by using the maximum width of the track. These rarely differ by more than two and are often identical.

EXPLANATION OF PLATE VII

Track of a heavy particle and scale showing how the track is traced.

(Each scale division is ten microns)

PLATE VII

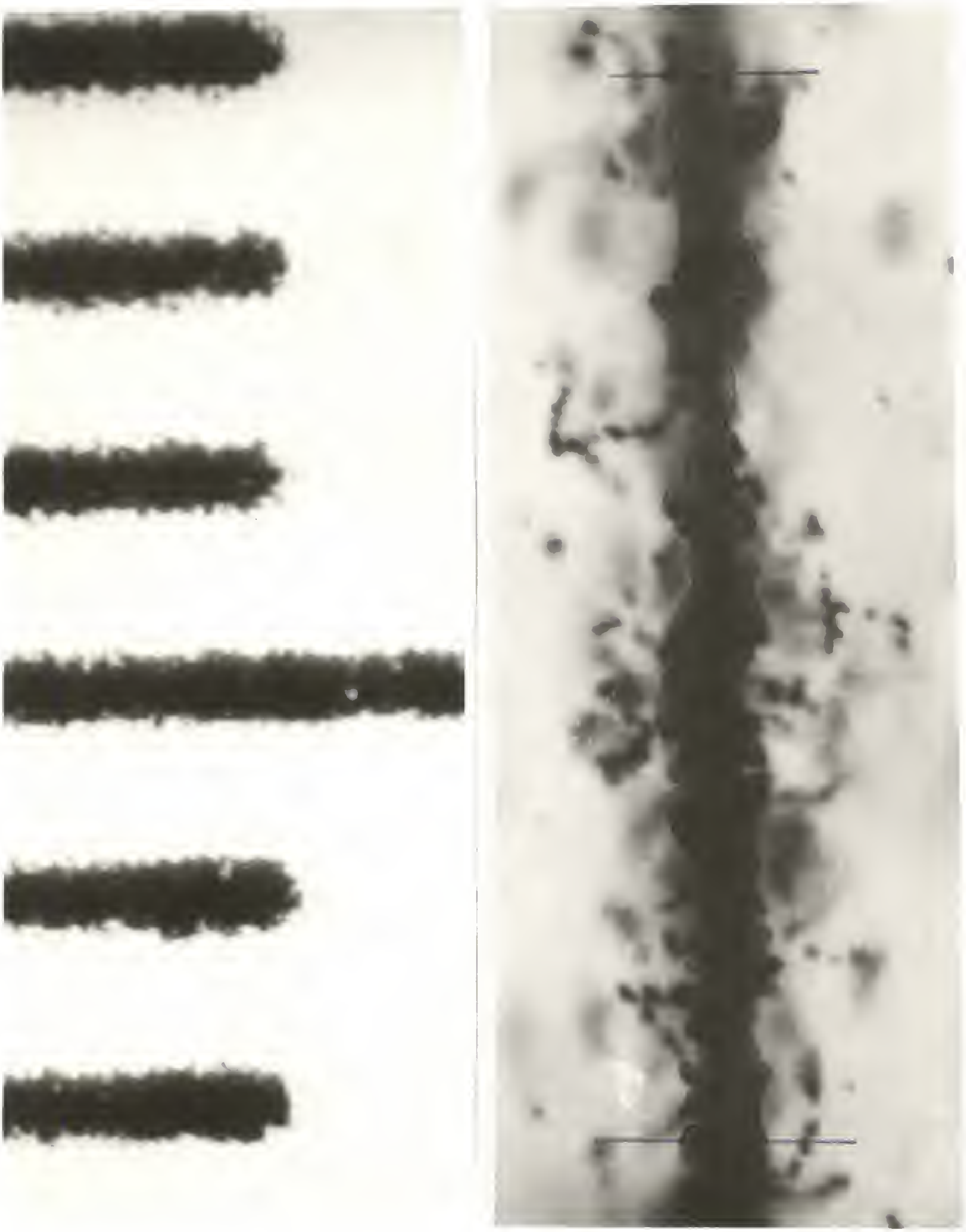


Table 4. The tracks measured.

Track		Area 100 - 200	Maximum width	Z A	W
I01-1	.92	292.56	3.740	19	16
I01-2	.80	207.04	2.392	12	9
I02-1	1.01	294.45	4.074	19	19
I02-2	.98	259.88	3.326	18	14
I10-1	.93	286.19	3.887	19	17
I10-2	.97	306.88	4.253	22	19
I10-3	.93	137.97	1.629	6	7
I11-1	.81	198.79	2.743	11	11
I12-1	1.09	130.29	1.521	6	5
I12-2	1.17	190.28	2.777	11	11
I13-1	1.04	270.90	3.465	17	15
I13-2	.98	204.68	2.641	12	11
I14-1	.82	129.72	1.446	6	5
I15-1	.81	177.01	2.384	10	9
I15-2	1.24	211.87	2.936	12	12
I17-1	.71	79.32	1.063	4	3
I17-2	.98	91.52	1.219	4	4
I22-1	.89	111.64	1.370	5	5
I23-1	.68	84.47	1.032	4	3
I24-1	.72	77.55	.909	3	3
I25-1	1.01	111.52	1.134	5	4
I26-1	.81	201.55	2.467	12	10
I26-2	.73	97.20	1.418	5	5
I26-3	.95	116.44	1.313	5	4
I27-2	1.01	112.44	1.474	5	5
I30-1	.95	272.08	3.590	7	6
I31-1	1.10	208.14	2.787	12	11
I35-1	.88	292.35	4.191	19	19
I36-1	1.15	165.71	2.143	8	9
I36-2	.89	268.88	3.623	18	16
I39-1	.82	92.86	1.087	4	4
I39-2	.78	143.50	1.561	7	5
I39-3	.97	95.81	1.122	4	4
I40-1	.85	151.76	1.890	8	7
I40-2	.83	127.76	1.515	6	6
I41-1	.63	75.66	.715	3	2
I41-2	1.04	213.40	2.465	13	9
I42-1	.98	154.49	1.824	8	6
I42-4	.88	132.27	1.617	6	6
I45-1	.78	144.73	1.776	7	6
I45-3	1.10	117.95	1.249	5	4
I46-1	.67	100.44	1.248	5	5
I49-1	.90	90.39	1.081	4	4
I57-1	.95	100.96	1.336	5	4
I58-1	.80	61.50	.837	3	3
I59-1	.81	78.83	.824	3	2

Table 4 (cont.)

Track		Area 100 - 200	Maximum width	Z	
				A	W
I61-1	.80	117.80	1.560	5	6
I61-2	1.01	281.72	3.627	19	16
I62-1	.77	88.43	1.239	4	4
I62-2	.88	240.57	3.328	15	14
I62-3	.80	72.47	.801	3	2
I62-4	.69	71.81	.767	3	2
I63-1	1.70	186.96	2.638	11	11
I65-1	1.10	256.51	4.107	7	8
I65-2	.73	81.56	.875	4	3
I68-1	.99	131.55	1.527	6	5
I69-1	1.04	134.37	1.795	7	6
I70-1	.97	125.42	1.460	6	5
I70-2	.83	55.92	.743	2	2
I70-3	.86	190.92	1.518	11	5
I73-1	.69	50.18	.611	2	2
I75-1	1.18	280.98	3.990	17	17
I76-1	1.05	70.79	.852	3	3
I77-1	.79	215.52	2.824	13	11
I77-2	1.13	256.34	3.820	16	16
I78-1	.80	125.70	1.507	6	5
I78-2	1.13	230.92	3.475	14	14
I78-3	1.08	257.85	3.416	6	4
I79-1	.88	94.23	1.009	4	4
I80-1	.79	94.02	1.093	4	4
I84-1	.89	73.59	.835	3	2
I85-1	1.10	44.56	.524	1	1
I86-1	.73	154.24	1.931	8	7
I88-1	.79	110.90	1.170	5	4
I89-1	.69	124.20	1.615	6	6
I90-1	.98	172.48	2.084	9	8
I90-2	.95	237.00	2.601	15	10
I90-3	.89	40.72	.692	1	1
I93-1	.76	145.93	2.037	7	7
I93-2	.85	140.49	2.287	7	7
I94-1	.92	276.92	3.901	7	7
I95-1	.83	138.72	1.894	7	7
I96-1	.96	136.85	1.916	7	7
K03-3	1.06	176.25	2.324	10	9
K04-1	.75	109.99	1.220	5	4
K04-2	.89	130.05	1.563	6	6
K06-1	1.00	125.72	1.408	6	5
K07-1	.72	115.75	1.335	6	4
K08-4	.74	87.06	.940	4	3
K09-1	.98	147.74	1.844	7	6
K14-1	.93	283.44	3.925	19	17
K15-1	1.15	313.89	5.375	22	26

Table 4 (concl.)

Track		Area 100 - 200	Maximum width	Z	
				A	W
K15-2	.87	86.33	.978	4	3
K17-1	1.05	254.87	3.627	16	16
K17-2	1.45	260.28	3.778	18	18
K18-1	1.06	291.30	4.944	21	23
K29-1	1.08	138.88	1.691	7	6
K31-1	.69	79.40	.885	4	3
K34-2	1.34	218.20	3.368	13	13
K36-2	1.05	256.09	3.687	16	16
K40-1	1.05	263.59	4.167	18	18
K40-3	.86	127.29	1.473	6	5
K42-3	.78	52.22	.724	2	2
K45-1	1.32	162.52	1.829	9	6
K45-2	1.49	306.59	4.118	22	19
K45-4	.82	151.77	1.774	8	6
K45-5	1.39	315.79	4.109	20	19

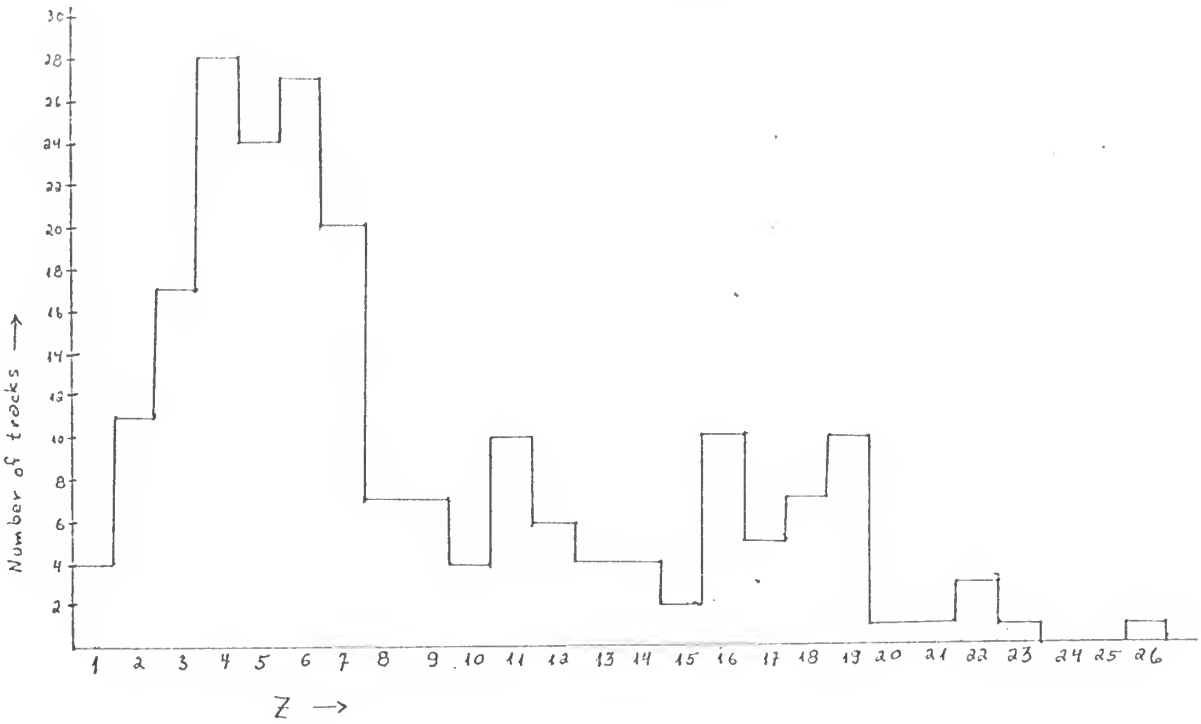
The spectrum obtained is illustrated by Table 5 and the bar graph in Plate VIII. It can be seen that the main peaks of the spectrum are at Z=4 and Z=6. Generally the peaks come at Z=6 and Z=8, although this is not always so as evidenced by Plate III. This would seem to indicate that the Z assignment is off by two in this region. A possible explanation for this result might be as follows: previous measurements of tracks by this group were obtained by projecting an image of the track through a microscope onto a piece of paper, and tracing around this image. This thesis contains the first data taken by the photographic method. There was no assurance that the images would be the same and it would seem that they were not. This explanation was put forth by Mr. Edward J. Kobetich before the present data was analyzed, and the data seems to confirm his idea. Mr. Kobetich predicted that the Z assignment would be off by two in the low end of the spectrum and about four in the high end. Unfortunately, new theoretical curves are not available at this time.

In order to test whether the assignment of Z on the basis of the area between 100u and 200u and the maximum width was valid, ten tracks that were assigned Z=18±1 were plotted completely and compared with the full theoretical curves. As can be seen from Plate X, the average widths for the curves fitted very well with the newest theoretical curves out to 1000u. There was also a good fit with the original curves of Katz and Butts out to 300u as is evidenced by Plate IX. Here the theory and the experiment depart. The fit of the experimental curves with the newest curves from theoretical considerations would seem to validate the practice of using the area - width method of assigning Z to a track.

EXPLANATION OF PLATE VIII

The Spectrum of Nuclei in this experiment

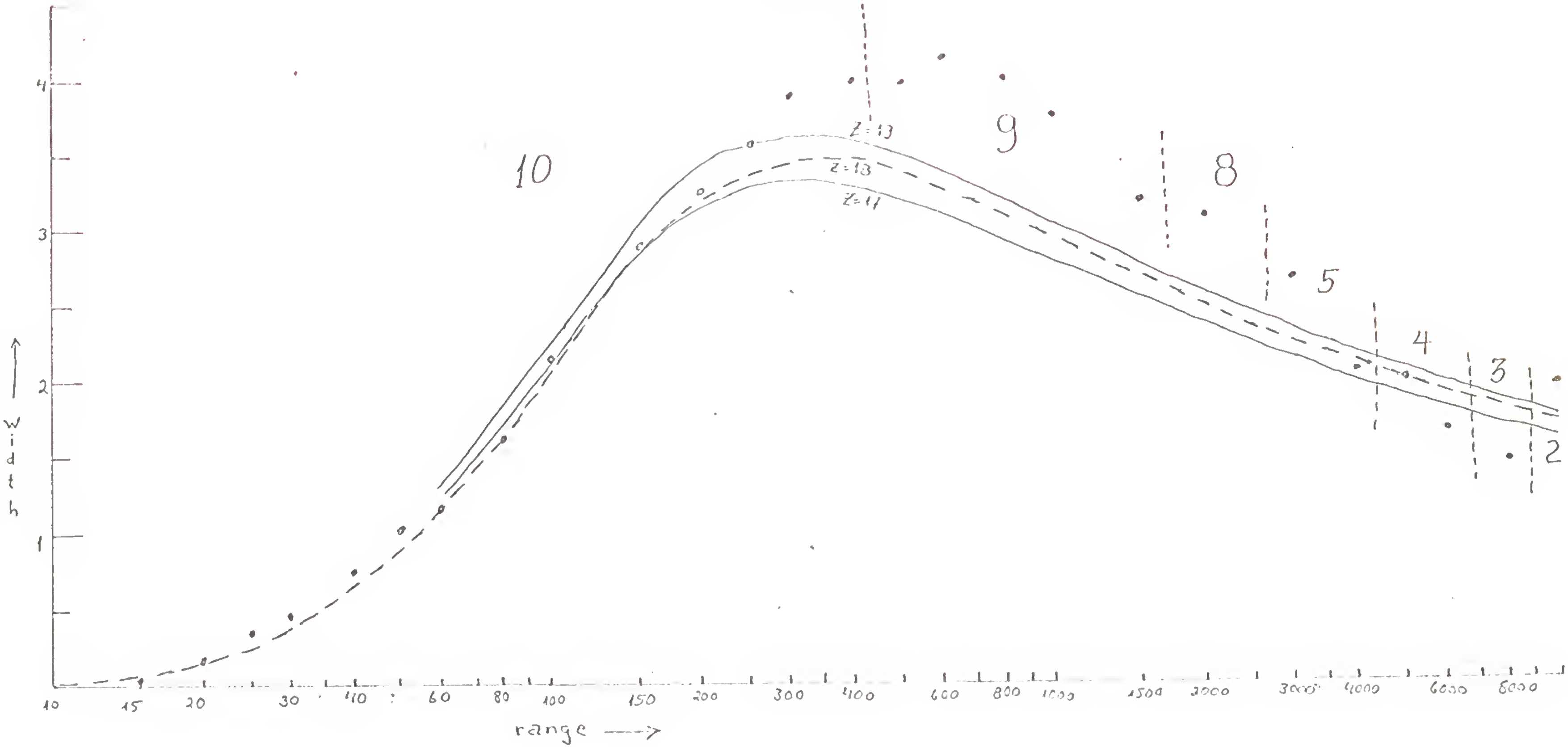
PLATE VIII


30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
Number of tracks →
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
Z →

EXPLANATION OF PLATE IX

Experimental Data for Ten Tracks $Z = 18 \pm 1$ Plotted Against
Theoretical Curves from Katz and Butts
The numbers refer to the number of tracks

PLATE IX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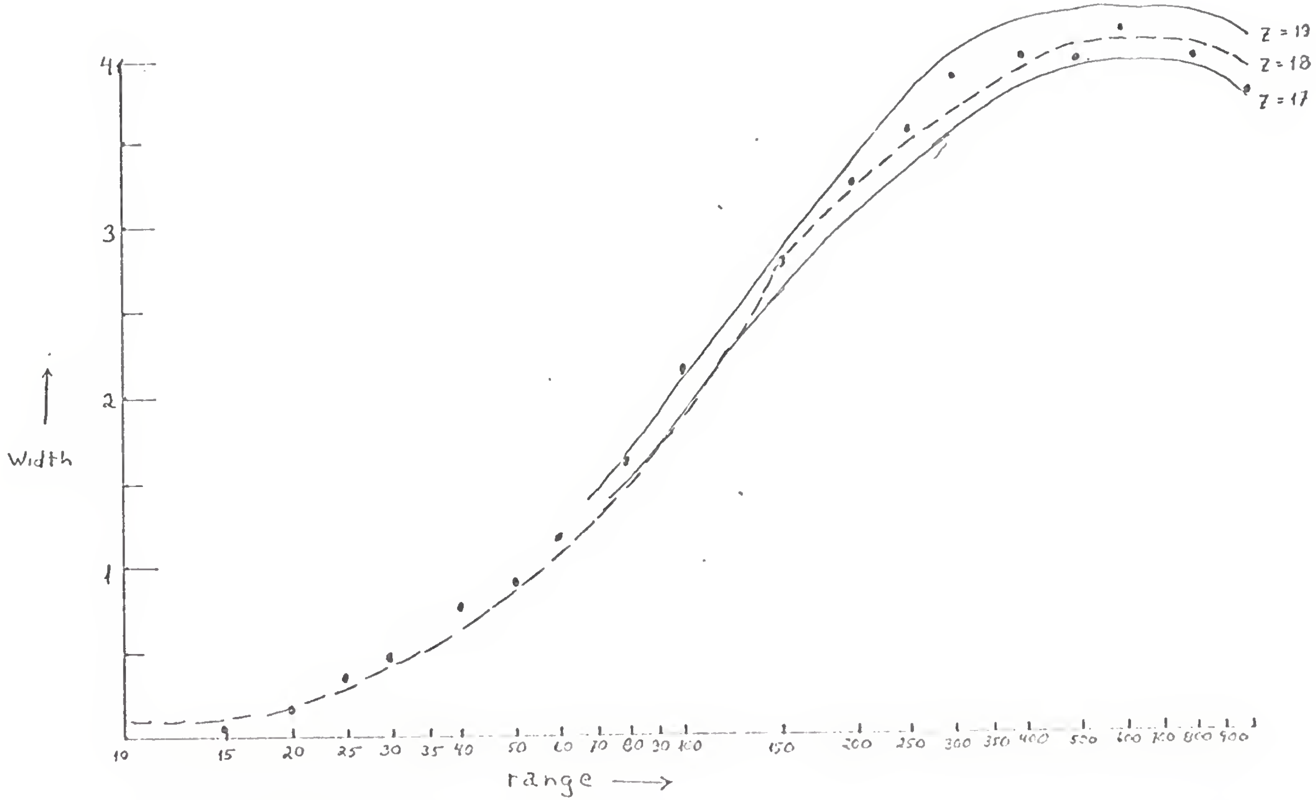
3
2
1
range
10
15
20
30
40
60
80
100
150
200
300
400
600
800
1000
1500
2000
3000
4000
6000
8000
Z=13
Z=13
Z=11
10
9
8
5
4
3
2

EXPLANATION OF PLATE X

Experimental Data for Ten Tracks $Z=18\pm1$ Plotted Against
Theoretical Curves from Kobetich

PLATE X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3
2
1
10
15
20
25
30
35
40
50
60
70
80
90
100
150
200
250
300
350
400
500
600
700
800
900
range
Z = 19
Z = 18
Z = 17

Table 5. The relative abundance of nuclei in cosmic rays.

Z	1	2	3	4	5	6	7	8	9	10	11
%	1.80	4.96	7.65	12.61	10.81	12.16	9.01	3.15	3.15	1.80	4.50
#	4	11	17	28	24	27	20	7	7	4	10
				L				M			
	12	13	14	15	16	17	18	19	20	21	22
	2.25	1.80	1.80	.90	4.50	2.25	3.15	4.50	.45	.45	1.35
	6	4	4	2	10	5	7	10	1	1	3
			H								
				23	24	25	26				
				.45	0.0	0.0	.45				
				1	0	0	1				
					VH						

The percentage of nuclei of Z=10 and above is 31.09% representing 69 tracks. The percentage of nuclei of Z=20 and above is 3.15% representing 7 tracks.

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BIBLIOGRAPHY

Aizu, Hideku, Kensai Ito, and Masatoshi Koshiba
Composition of Primary Cosmic Rays. Supplement of the Progress of Theoretical Physics #30 1964 p694

Barkas, Walter H.
Nuclear Research Emulsions. Academic Press 1963

Bradt, H. L., and B. Peters
1950 Phys. Rev. 77, 54

Cameron, A. G. W.
1959 Astrophys. J. 129, 676

De Carvalho, Hervasio
Particle Descrimination and Loading Techniques for Nuclear Emulsion. Progress in Nuclear Techniques and Instrumentation. vol 1 North-Holland 1965

Fong, H. T.
May 1951 Thesis Universite de Paris

Freier, P. E., J. Lofgren, E. P. Ney, F. Oppenheimer, H. L. Bradt, and B. Peters
1948 Phys. Rev. 74, 213

Freier, P. E., J. Lofgren, E. P. Ney, and F. Oppenheimer
1948 Phys. Rev. 74.1818

Ginzburg, V. L. and S. I. Syrovatskii
The Origin of Cosmic Rays. Macmillian 1964

Ginzburg, V. L.
The Origin of Cosmic Radiation. Progress in Elementary Particle and Cosmic Ray Physics. vol iv North-Holland 1958

Gurney, and M. F. Mott
1938 Proc Roy Soc 164, 151

Heisenberg, Werner
Cosmic Radiation Dover 1946

Janossy, Lewis
Cosmic Rays. Clarendon 1950

Katz, Robert and J. J. Butts
Width of Ion and Monopole Tracks in Emulsion 1965
Phys. Rev. 137, 198

Kieth, and J. W. Mitchell
Phil. Mag. 1953 44, 877

Kobetich, Edward J.
The Width of Ion and Pole Tracks in Emulsion. A Physics Colloquium given 1965

Kristianson, K., O. Mathiesen, and A. Stenman
The Relative Abundance of Nuclei Heavier than Lithium in Primary Cosmic Radiation Arkiv for Fysik 1962 44, 473

Leprince-Ringuet, Lewis
Cosmic Rays Prentice-Hall 1950

Mees, C. E. K.
Theory of the Photographic Process Macmillan 1954

Mitchell, J. W.
Rep. Prog. Phys. 1957 20, 433

Mitchell, J. W., and N. F. Mott
Phil. Mag. 1957 2, 1149

Mitchell, J. W.
Z. Physics 1954 138, 381

Mitchell, J. W.
Sci. et ind. phot. 1958 29, 1

Mitchell, J. W.
Brit. J. Phot Sci 1953 1, 110

Mott, N. F., and H. S. Massey
The Theory of Atomic Collisions. Oxford Univ. Press 1949

Peters, B.
The Nature of Primary Cosmic Radiation. Progress in Cosmic Ray Physics vol i North-Holland 1952

Powell, C. F., P. M. Fowler, and D. H. Perkins
The Study of Elementary Particles by the Photographical Method Pergamon 1959

Sorensen, S. O. C.
1949 Phil. Mag. 40, 947

Suess, H. E., and H. C. Urey
Handbuch der Physik 1958 51, 296

Waddington, C. J.
The Primary Cosmic Radiation. Proceedings of the Enrico Fermi School of Physics Course 19 Academic Press 1963

Waddington, C. J.
The Composition of the Primary Cosmic Radiation. Progress in Nuclear Physics vol 8 Pergamon Press 1960

Yagoda, Herman
An Improved Method for the Processing of Thick Nuclear Emulsion Pellicles. Presented at the first International Conference on Corpuscular Photography 1957

Yagoda, Herman
Isothermal Processing of Thick Nuclear Emulsions 1955
Rev. Sci. Inst. 26, 263

THE MASS SPECTRUM OF COSMIC RAY PRIMARIES

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AN ABSTRACT OF A MASTER'S THESIS

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In recent years, interest in cosmic radiation has grown considerably. At the same time, the use of nuclear research emulsion as an instrument of detection has multiplied. The two phenomena are not entirely independent, for nuclear research emulsions have proved themselves to be the most useful method of detection of radiation in balloons and space craft.

Stacks of nuclear research emulsions were sent aloft in balloons. When recovered, they were first developed and then scanned for tracks of cosmic rays. These tracks were then magnified and photographed, and the photographic images of the tracks measured.

Measurements were made on one hundred and eighteen tracks by tracing their outline as photographed. The area of each segment of track was then measured with a planimeter, and this area was divided by the length of the segment to find the average width. This data was compared with theoretical data computed from the theory of Katz and Butts on the width of ions in emulsion and with a revision of this theory by Kobetich. From these theories a Z was assigned to each track.

Preliminary results of the Z-spectrum obtained in this manner seem to agree with previous results.