On the Showers of Mesons and Nucleons

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January 3, 1949

RECENT experimental results induce us to attempt a revised formulation of the fundamental assumptions proposed in previous papers in order to give a quantitative description of the production of mesons.[1]

1. We assume, of course, that the fundamental process occurring in a high energy collision of nucleons or nuclei is the production of showers of mesons (probably π-mesons and, eventually, other short-lived mesons) and nucleons. The direct production of photons and electrons is assumed to be a secondary phenomenon in most cases (except, perhaps, in the case of highly charged incident nuclei).

2. Indicating by ΔE the fraction of the energy E of the incident nucleon lost in the collision and measured in the terrestrial frame, we assume: $\Delta E/W\sim 1$, and we denote: $av(\Delta E/E)=k$. Considering the possible change of the spin and the charge, we can say that after the collision there will be usually one nucleon having an average energy $E-\Delta E=(1-k)E=qE\sim E$.

3. The energy amount ΔE lost by the incident nucleon will be shared between the created mesons and some nucleons taking part in the collision. We shall consider the center of mass system of this assemblage of mesons and nucleons and apply to it statistical laws. Then, following the deduction indicated in previous work,[1] we find: $\Delta E\cong An^2+Bn+C$ where A, B, and C are constants having values depending on the masses of the colliding nuclei and n is the number of mesons produced. For large values of n (e.g. $n>100$) we can put $\Delta E\sim An^2$ and thus, approximately, $n\sim(E)^{\frac{1}{2}}$ as pointed out.[1] For smaller showers $10\lesssim n\lesssim 100$ one has: $\Delta E\sim Bn$.

4. The cross section for meson production σ of a primary proton or a fast nucleon with a nucleon at rest is $\sim 3\times 10^{-26}$ cm^2. Thus the collision thickness l for production in cascade of showers of mesons and nucleons by fast nucleons is: $l\sim(M/\sigma)\sim 50$ g/cm^2.

Observations show that almost all energetic showers contain mesons and, therefore, are originated by nucleons. The average value of q can be found from the known value of the frequency of the primary protons and of the fast nucleons at sea level. Indeed, from the assumptions 2 and 4 it follows that the energy of a primary proton is reduced after n collisions by a factor $q^n=q^{x/l}$, where x is the atmospheric depth in g/cm^2. If we neglect the contribution of low energy nucleons, and assume the spectral distribution of the primary protons to be of the type: $dN_P=CE_P^{-\gamma}dE_P$ where $\gamma\cong 2.5$, the spectral distribution of fast nucleons after n collisions will be: $dN_N=Cq^{n(\gamma-1)}E_N^{-\gamma}dE_N$. Thus the spectral power law is conserved and the reduction factor is: $q^{n(\gamma-1)}=q^{0.03x}$. From the observations we have for the ratio of the primary and the sea-level intensity of fast nucleons a value $\sim 3\times 10^5$. Therefore we obtain $q\sim 0.7$. The resulting approximate description of showers of mesons and nucleons permits one to understand many observed phenomena. Here we want to discuss the remarkable formula giving the number dN' of showers having densities δ in the interval $(\delta, \delta+d\delta)$: $dN'=C'g(\delta)\delta^{-\gamma}d\delta$, where $g(\delta)\rightarrow 1$ for high δ, and $\lim_{\delta\rightarrow 0}g(\delta)\delta^{-\gamma'}=0$ and where $\gamma'\sim 2.5$. This spectral distribution is very similar to the distribution of primary protons ($\gamma'=\gamma$). Indeed for local showers the electronic density can be assumed proportional to the meson density. The latter is proportional to the multiplicity n, and thus to $Bn\sim\Delta E\sim E_N$. Comparing the formulas for dN' and dN_N we see: $\gamma'=\gamma$.

[1] G. Wataghin, Phys. Rev. **74**, 975 (1948).

The Isotopic Constitution of Dysprosium

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December 29, 1948

THE isotopic constitution of dysprosium was first investigated by Aston[1] who found isotopes of masses 161, 162, 163, and 164. He obtained the relative abundances of these isotopes by using a discharge tube with $DyBr_3$ as an ion source, and estimating line intensities on his photographic plates by photometry. Later, Dempster[2] discovered weak isotopes at masses 158 and 160 and estimated the abundance of these isotopes. He did not quote the percentage abundances of the other isotopes. Dempster's values for the percentages of Dy^{158} and Dy^{160} and Aston's values for the heavier isotopes, corrected for the presence of Dy^{158} and Dy^{160}, are given in Table I. Later Wahl[3] made a photometric determination of the abundances of all these isotopes in which he quoted more significant figures than did Aston. Recently[4] two of the authors reported the existence of a stable Dy^{156} isotope present to about one-twentieth of one percent. Because of the discrepancies between the values of Wahl (Table I) and the earlier investigators and because of the large errors inherent in the photometric method, it seemed desirable to measure electrometrically the relative abundances of the dysprosium isotopes. In the course of this work upper limits for the existence of other isotopes were set.

A sample of Dy^2O^3, especially purified with an ion exchange column by Dr. D. H. Harris of the Clinton Laboratories, was analyzed by a filament source mass spectrometer utilizing a recording vibrating reed electrometer to detect the ion beam. The instrument and techniques used in this mass analysis have been described elsewhere.[5] Dysprosium peaks of types Dy^+ and DyO^+ were both observed, but due to the weaker emission in the DyO^+ position, the precision of the measurements at this position was much less. Thus, the values given have been calculated only from the Dy^+ position. The DyO^+ values are, however, consistent with the Dy^+ results. The third row in Table I gives our values for the percentage abundances of the various dysprosium isotopes. The errors quoted are larger than the probable mean deviations in the percentages based on twenty separate determinations. Despite an apparent accuracy of about $\frac{1}{4}$ percent obtained for the probable error calculated on the basis of mean deviations, we do not wish to quote probable errors in any

TABLE I. Isotopic constitution of dysprosium (percent).

Investigator	156	158	160	161	162	163	164
Aston	—	—	—	22.0	24.0	24.0	28.0
Dempster	—	0.1	1.5	—	—	—	—
Wahl	—	0.1 trace	(0.1)	21.1	26.6	24.8	27.3
Inghram, Hayden, and Hess	0.0524 ±0.0005	0.0902 ±0.0009	2.294 ±0.011	18.88 ±0.09	25.53 ±0.13	24.97 ±0.12	28.18 ±0.14

mass to less than $\frac{1}{2}$ percent of the abundance of that mass. This is done because we have been unable to rule out systematic discriminations in mass due to selective emission from the surface ionization source and due to nonlinearities in the 10^{10}-ohm collector resistor to a greater precision than this.

The freedom of this dysprosium sample from rare earth impurities allowed upper limits for the natural occurrence of other isotopes of dysprosium to be set. For the possible isotopes we have $Dy^{154}<0.002$ percent, $Dy^{155}<0.002$ percent, $Dy^{157}<0.002$ percent, $Dy^{159}<0.008$ percent, $Dy^{165}<0.011$ percent and $Dy^{166}<0.002$ percent.

A calculation of the chemical atomic weight of dysprosium, based on these isotopic abundances and assuming a packing fraction of -1.0×10^{-4}, gives 162.51. The chemically determined value is 162.46.

[1] F. W. Aston, Proc. Roy. Soc. **A146**, 46 (1934).
[2] A. J. Dempster, Phys. Rev. **53**, 727 (1938).
[3] Wahl, Suomen Kemistiseuran Tiedonatoja **51**, 64 (1942).
[4] D. C. Hess, Jr., and M. G. Inghram, Phys. Rev. **74**, 1724 (1948).
[5] M. G. Inghram, R. J. Hayden, and D. C. Hess, Jr., Phys. Rev. **72**, 967 (1947).

The Vertical Intensity at 10,000 Feet of Ionizing Particles That Produce Penetrating Showers

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December 23, 1948

A LARGE cloud chamber was operated at Echo Lake, Colorado (10,600 ft.) for the purpose of measuring the intensity of ionizing particles that produce showers containing penetrating particles and to study the details of the showers. Since the films were destroyed by fire, it will not be possible to study the showers in detail but an estimate of the intensity can be based on a preliminary survey of the films, which were made in the field.

Collimating telescopes of small solid angle ($\frac{1}{8}$ sterad.) were placed above the chamber to insure that the events would occur in the useful region of the chamber. Since the events were expected to be rare, six two-counter telescopes were placed side by side, each directed into the useful region of the chamber. A shower tray of eight 1″×30″ G-M tubes, placed below the chamber and shielded on top and sides by two inches of lead, served to detect particles emerging from the chamber. A coincidence between any one of the telescopes and any three or more of the shower counters triggered the chamber and a stereoscopic picture was taken. A one-half inch lead plate was placed above the telescope array to facilitate identification of electrons entering the chamber.

In experiment *A* (Fig. 1), the chamber contained five one-inch lead plates. In a net observation time of 3750 minutes, 30 ± 5 pictures were obtained that showed penetrating showers originating in the lead plates. Assuming that ionizing particles which produce penetrating particle showers are absorbed in lead with a collision path of 180 g/cm², 40 percent of the incident particles will produce showers in 85 g/cm² of lead.[1] This leads to an estimate of 75 ± 15 incident particles in 3750 minutes. Using the same telescope array, but with $3\frac{1}{2}$ inches of lead between the telescope counters, it was found that 31 ± 1 penetrating particles per minute were detected by the telescope array. Hence there was about one shower-producing ionizing particle per 1500 penetrating particles from directions near the vertical. From the well-known intensity of the penetrating component and the above ratio, we obtain $1.1\pm0.3\times10^{-5}$ cm^{-2} sec.$^{-1}$ sterad.$^{-1}$ for the intensity of ionizing, penetrating, shower-producing radiation at Echo Lake. The estimated uncertainty is based on the estimated uncertainty in identification of nuclear disintegrations in the preliminary survey of the data.

If we assume that the majority of the primary cosmic rays can produce nuclear disintegrations of the type we have observed, it is possible to calculate an average absorption path length in air and to estimate an average collision path length. The total intensity of the primary radiation has been calculated by Rossi[2] to be 0.07 cm^{-2} sec.$^{-1}$ sterad.$^{-1}$ for energies greater than 4 Bev for protons. The average absorption path length, assuming exponential absorption, is therefore $L=700/\ln(0.07/1.1\times10^{-5})=80$ g/cm² between the top of the atmosphere and Echo Lake. Tinlot[3] has made direct measurements for the absorption in the atmosphere of locally produced showers of about the same energy as in our case with a result of 118 g/cm². The apparent differences are that Tinlot accepted both charged and uncharged incident particles, the entrance angle was large, and the measurements did not include the top 300 g/cm² of the atmosphere. It is not clear what conclusion might be made from a comparison of the two results.

A collision length in air can be estimated from our results since the primary spectrum presumably is known, and we can therefore take into account the effect of secondaries that can also produce disintegrations. The minimum effective energy for the secondaries is estimated to be one Bev from consideration of the detector and of the com-

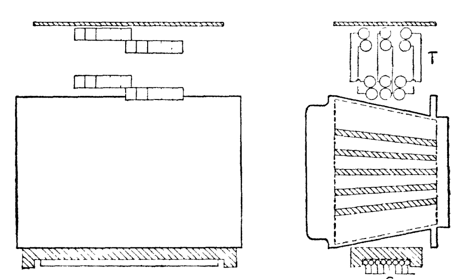

FIG. 1. Back and side elevations of cloud chamber, showing location of telescopes (*T*) and shower tray (*S*). The five lead plates shown are for experiment *A*. These were replaced by four aluminum and two lead plates for experiment *B*.