Energy Distribution of Cosmic Rays

Anderson and Neddermeyer's[1] list of the energies of 78 of the individual rays in a "sample" of 104 vertical cosmic rays provides the energy distribution of any sample and has been used as such by Street, Woodward and Stevenson.[2]

An attempt to reproduce Anderson and Neddermeyer's distribution curve led to confusion as to how they had eliminated the rather large statistical variations in the number of rays for each energy increment. The sum of all rays greater than a given energy, however, ought to be largely independent of such variations. From their list it is possible to obtain a list of N's where $N=\sum_E^\infty \phi(E)dE$ and a corresponding list of E's for 3×10^8 ev $<E<6\times 10^9$ ev. Fig. 1 shows a plot of log N against E where it is seen that a linear relation might well connect these two quantities. This leads to an exponential energy distribution $dN=34e^{-0.34E}dE$ for a sample of 100 rays where E is measured in units of 10^9 ev. Similar independent treatments of the positive and negative rays lead to distributions with the same modulus where there are 52 positive rays in a sample of 100. Since both of these distributions are found to have the same modulus, the apparent predominance of positives in the higher energy ranges would have to be due to statistical fluctuations.

It is, however, possible to analyze the data in terms of possible Maxwellian distributions. This led to the equation

$$N=58\int_E^\infty 1.1E^{\frac{1}{2}}e^{-E}dE+47\int_E^\infty 0.13E^{\frac{1}{2}}e^{-0.25E}dE$$

which has been included as a smooth curve in the figure. Thus there are two energy groups, the first of 55 percent with a mean energy of 10^9 ev and the second of 45 percent with a mean energy of 4×10^9 ev. The energy distribution for a sample of 100 rays is $dN=62E^{\frac{1}{2}}e^{-E}dE+5.8E^{\frac{1}{2}}e^{-0.25E}dE$.

An analysis of the negative rays shows them to have only a low energy component which amounts to 67 percent of that group in the combined distribution. The positive rays, however, show the presence of both energy groups, and thus must include all of the higher energy group for the combined distribution as well as most of the 20 rays which

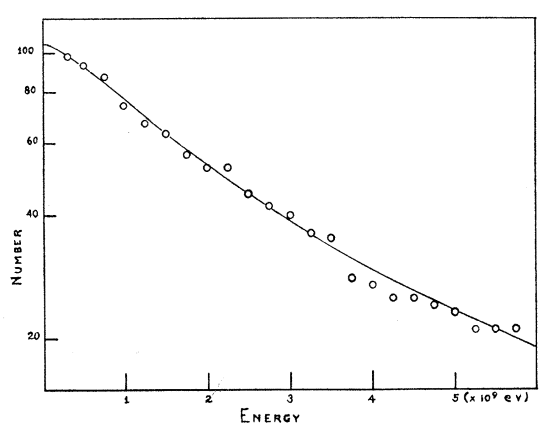

FIG. 1. Plot of log N against energy.

Anderson and Neddermeyer[1] mention as having energies too high to measure.

Thus a sample of 100 vertical cosmic rays will consist of 37 negative rays and 63 positive rays, the latter being divided into two groups of 18 in a low energy distribution and 45 in a higher energy distribution.

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[1] Anderson and Neddermeyer, Proc. London Conf. on Nuclear Physics (1934).
[2] Street, Woodward and Stephenson, Phys. Rev. **47**, 891 (1935).

On Relativity Corrections in the Theory of the Deuteron

Recently attempts have been made to compute the relativity correction in the theory of the deuteron.[1, 2] The calculations are based on the Gordon-Klein quadratic relativistic wave equation for a single particle with mass equal to the reduced mass of the deuteron. This equation should give correctly the order of magnitude of the relativity correction to the depth of the neutron-proton potential well; nothing more has been claimed for it. Actually a relativity correction can be computed in a straight-forward manner without recourse to an artificial single particle model.

From the classical relativistic kinetic energy

$$Mc^2\{(1+(P_1/Mc)^2)+(1+(P_2/Mc)^2)-2\}$$
$$\cong(P_1^2+P_2^2)/2M-(P_1^4+P_2^4)/8M^3c^2 \quad (1)$$

we obtain the modified Schroedinger equation

$$\{\Delta_1+\Delta_2+(2M/\hbar^2)(E+J(r_{12}))$$
$$+(\hbar/2Mc)^2(\Delta_1\Delta_1+\Delta_2\Delta_2)\}\psi=0, \quad (2)$$

in which the last term is the relativity correction to the kinetic energy correct to terms in $1/c^2$. Introducing the obvious assumption that the center of gravity is at rest, Eq. (2) becomes

$$\{\Delta+(M/\hbar^2)(E+J(r))+(\hbar/2Mc)^2\Delta\Delta\}\psi=0. \quad (3)$$

To estimate the effect of the correction term we make use of the Hermitian property of the operator Δ:

$$(\hbar^4/4M^3c^2)\iiint\psi\Delta\Delta\psi d\tau=(\hbar^4/4M^3c^2)\iiint(\Delta\psi)^2d\tau$$
$$\cong(1/4Mc^2)\iiint\psi(E-J)^2\psi d\tau. \quad (4)$$

Thus the energy correction has the same form, but is only one-fourth as large as in the quadratic relativistic wave equation for the artificial single particle model. If this factor of one-fourth is considered in connection with the actual numerical estimates[1, 2] of the relativity correction given by the single particle model, it is evident that the energy correction is entirely negligible for the effective range of the forces (about 2.25×10^{-13} cm) which appears to fit best the binding energies of H^3 and He^4. It is not difficult to compute the corresponding energy corrections in the 3 and 4 particle problems. The numerical results are $\Delta E(H^3)\sim -0.2mc^2$, $\Delta E(He^4)\sim -0.9mc^2$.

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Princeton University,
September 14, 1936.

[1] D. Blochinzew, Physik Zeits. Sowjetunion **8**, 270 (1935).
[2] H. Margenau, Phys. Rev. **50**, 342 (1936).