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ENERGY LOSSES OF STRONGLY INTERACTING PARTICLES PASSING THROUGH HYDROGEN

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Energy losses due to strong interactions are calculated on the basis of experimental data for nucleons and pions passing through hydrogen.

WHEN strongly interacting particles pass through matter, apart from the energy loss due to electromagnetic interactions, there is also an energy loss due to the strong interactions (s.i.e.). In contrast to the electromagnetic energy loss, the s.i.e. loss cannot be calculated theoretically in view of the absence of a theory of strong interactions. However, on the basis of the experimental data, we can obtain information on these losses and compare them with the electromagnetic loss. This problem is considered below for the case of hydrogen.

1. When nucleons of energy up to 400 MeV pass through hydrogen, the total s.i.e. loss is equal to the loss in the elastic channel, which can be found by numerical integration if the c.m.s. differential cross section is known. Since the differential cross section for proton-proton scattering in the c.m.s. energy interval from 150 to 400 MeV is independent of the scattering angle and the energy, the s.i.e. loss in this interval can be calculated directly, without numerical integration. On the basis of the experimental data[1] (wherever possible we will refer to survey articles in which there are references to the original papers), we calculated the elastic s.i.e. loss for protons of energy 460, 560, and 660 MeV passing through hydrogen; these losses turned out to be 3.4, 4.25, and 5 MeV-cm^2/g. We also calculated the elastic s.i.e. loss for neutron-proton collisions at 260 MeV from the data of [2] and for 380 and 580 MeV from the data of [3]. For these energies, we obtained the losses 2.17, 4.1, and 4.15 MeV-cm^2/g, respectively.

Starting with an energy of 400 MeV, the energy losses in the inelastic channels become appreciable. In this case the total s.i.e. loss is equal to the sum of the losses in both channels. If it is assumed that most of the energy of an incident particle is lost in a collision, then for the sum of all inelastic s.i.e. losses we obtain

$$(d\varepsilon / dx)_r = (N / A)\, T_0 \sigma_r, \tag{1}$$

where N is Avogadro's number, A is the atomic weight, T_0 is the kinetic energy of the incident particle, and σ_r is the total cross section for all inelastic processes.

Under this assumption, the s.i.e. loss calculated from formula (1) will exceed the actual energy loss. However, if the energy spectra of the produced particles are known, formula (1) can be made more accurate. We shall illustrate this for the specific case in which the energy of an incident proton is 657 MeV. In this case, the s.i.e. loss in the inelastic channel is due to the production of one π^0 or π^+ meson, for which the total cross sections, according to [3], are $\sigma_{\pi^0} = 3.4$ mb and $\sigma_{\pi^+} = 13.3$ mb. Then from formula (1) we obtain 1.34 and 5.26 MeV-cm^2/g for $(d\epsilon/dx)_{\pi^0}$ and $(d\epsilon/dx)_{\pi^+}$, respectively. On the other hand,

$$\left(\frac{d\varepsilon}{dx}\right)_{\pi+} = N \int (T + \mu + t)\, \sigma(T, t)\, dT dt, \tag{2}$$

where T and t are the kinetic energies of the recoil nucleon and the produced meson, and μ is the mass of the π^+ meson. Then, obviously,

$$(d\varepsilon / dx)_{\pi+} > N \int (\mu + t)\, \sigma(\vartheta, t)\, dt\, d\Omega. \tag{3}$$

In [5,6], experimental curves for $\sigma(\vartheta, t)$ are given for the following angles ϑ: 29, 46, 60, 75, 90, 105, and 120°. For each of these angles, we carried out a numerical calculation of the integral $\int t\sigma(\vartheta, t)\, dt$. The results were then integrated numerically over ϑ. For the right-hand part of (3) we obtained 2.45 MeV-cm^2/g. Taking for $(d\epsilon/dx)_{\pi^+}$ the average between 2.45 and 5.26 MeV-cm^2/g and combining this value with $(d\epsilon/dx)_{\pi 0}$ and with the loss in the elastic channel, we obtain 10.19 MeV-cm^2/g for the total s.i.e. loss.

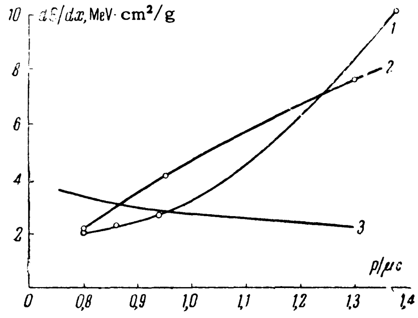

FIG. 1. Energy loss for the passage of protons and neutrons through hydrogen. Curve 1 refers to protons, curve 2 refers to neutrons, and curve 3 indicates the electromagnetic loss in carbon.

In Fig. 1, the curves represent the total s.i.e. loss as a function of p/μc for the passage of protons and neutrons through hydrogen. For neutrons, the inelastic s.i.e. loss was calculated from formula (1), where we took the total cross section for the inelastic processes[4] as $\sigma_r = 10$ mb. It is seen from Fig. 1 that the energies 300—400 MeV the nuclear losses overtake the electromagnetic loss and then become dominating.

2. By a similar method, we calculated the s.i.e. loss for the passage of $\pi^{\pm}$ mesons through hydrogen on the basis of the experimental data.[7-11] The results are shown in Fig. 2, from which it is seen that the s.i.e. loss for pions has a maximum at an energy of ~ 200 MeV, which reflects the resonance character of the interaction at this energy. Starting with an energy ~ 300—350 MeV, the curve again begins to rise owing to meson production.

In conclusion, I express my gratitude to K. A. Ter-Martirosyan for suggesting the problem and for his interest in the work, and to G. S. Saakyan for discussions.

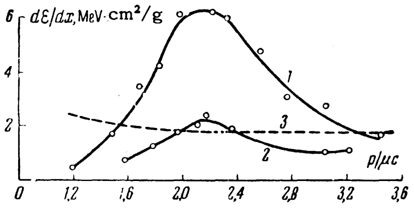

FIG. 2. Energy loss for the passage of $\pi^{\pm}$ mesons through hydrogen. Curve 1 refers to π^{+} mesons, curve 2 refers to π^{-} mesons, and curve 3 represents the electromagnetic loss in carbon.

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