MESON-NUCLEUS INELASTIC CROSS SECTIONS

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Abstract
The known π- and K-proton inelastic and elastic cross sections (up to about 200 GeV) have been used to calculate the inelastic π- and K-nucleus cross sections with a method similar to that used for calculating the inelastic proton-nucleus cross section i a previous paper (Ann Arbor 1992). The calculated results show good agreement with measured π- and K-nucleus inelastic cross sections from about 2 GeV lab energy up to 200 GeV, and cosmic ray results at 8000 GeV for π-nucleus inelastic collisions. Assuming that this method can be used also at higher energies, the π- and K-air nucleus inelastic cross sections can be calculated, for instance, at 10^7 GeV. This gives for the inelastic π-air nuleus cross section: 406 mb, which can be compared to the calculated proton-air nucleus inelastic cross section, which is 471 mb at this energy.

1 Introduction

A method used to calculate the inelastic proton nucleus cross section [1] will here be used in a slightly different form to calculate the inelastic charged π- and K- meson nucleus cross sections. For low energies, where cross sections measured at accelerators are available, these experimental results can be used to help determin the parameters. At high energies, the assumpton will be used that the differences of the square roots of different cross sections approach energy independense. This assumption was used for $\sigma^{inel}(pp)$ and $\sigma^{el}(pp)$ in ref .[1]: $(\sigma^{inel}(pp)/(\pi\cdot 10\text{ mb}))^{1/2} - (\sigma^{el}(pp)/(\pi\cdot 10\text{ mb}))^{1/2} \rightarrow 0.603$.

2 The proton nucleus inelastic cross section

For atomic mass $A > 9.5$ we find from accelerator measurements [2] that the inelastic proton nucleus cross section can be expressed by

$$\sigma^{inel}(pA) = \pi\,\{1.193A^{1/3} - 0.045 + \Delta_{step} + (A^{1/3} + 1)\Delta_{11}\}^2 \cdot 10\text{ mb} \qquad (1a)$$

and for A> 9.5 we have according to ref.[1] from accelerator exsperiments, after adding a term Δ_C

$$\sigma^{inel}(pA) = \pi\{1.313A^{1/3} - 0.299 + \Delta_{step} + (A^{1/3} + 1)\Delta_{11} + \Delta_C\}^2 10\text{ mb} \qquad (1b)$$

where $\Delta_C = -0.03$ for carbon ($A = 12.011$) and $\Delta_C = 0$ for other nuclei. We have $\Delta_{step} = 0.166$ generally for Serpukhov measurements, and $\Delta_{step} = 0$ for Fermilab measurements. Δ_{11} takes into account elastic scattering into the nucleuss with successive inelastic collision, along with the energy dependence. Therefore, $A = 1$, in eqs.(1) above does not give the inelastic pp cross section. Δ_{11} is obtained from $\sigma^{inel}(pp)$ and $\sigma^{el}(pp)$ as given in ref. [1]. The normalization is such that $\Delta_{11} = 0$ at about 200 GeV lab energy. That is: $\sigma^{inel}(11) = \sigma^{inel}(pp) + \{\sigma^{el}(pp) - \sigma_0^{el}\}\sigma^{inel}(pp)/\sigma^{tot}(pp)$ with $\sigma_0^{el} = 6.276$ mb, $\sigma^{tot} = \sigma^{inel} + \sigma^{el}$ and $\Delta_{11} = 1/2\{(\sigma^{inel}(11)/(\pi\cdot 10\text{ mb}))^{1/2} - 1.014\}$. Numerical values for $\sigma^{inel}(pp)$ and $\sigma^{el}(pp)$ are given in ref.[1]. Eqs.(1) do not apply to eneregies near threshould for particle production in pp collisions, partly because the effect of Fermi motion is not included. At laboratory momenta as low as $p = 1.8$ GeV/c and $p = 1.52$ GeV/c [3] the agreement with measured inelastic pC, pAl, pTi and pCd cross sections is satisfactory.

3 The antiproton nucleus inelastic cross section

In addition to particle production in the same way as in pp–collisions, $\bar{p}p$–collisions ($\bar{p}$ is antiproton) also gives $\bar{p}p$ anihilation. For the anihilation cross section in $\bar{p}p$ collisions we obtain, by comparison with the measured anihilation cross sections [2]:

$$\sigma^{anihilation}(\bar{p}p) = 36.47\{\ln(p + 0.5\ \mathrm{GeV/c})\}^{-1.148}\ \mathrm{mb} \qquad (2)$$

We use the measured antiproton-nucleus inelastic cros sections from p = 1.8 GeV/c up to 280 GeV/c [2, 3] to find an expressin for the antiproton inelastic cross section and extrapolate to higher energies:

$$\sigma^{inel}(\bar{p}A) = \{(\sigma^{inel}(\bar{p}p) - \sigma^{anihilation}(\bar{p}p))/\sigma^{inel}(pp)\}\sigma^{inel}(pA)$$

$$+ 0.904A^{2/3}\sigma^{anihilation}(\bar{p}p) \qquad (3)$$

p is the lab momentum in GeV/c and A the atomic mass.
This implies $(\sigma^{inel}(\bar{p}A) - \sigma^{inel}(pA)) \rightarrow 0$ for high energies. Some model, however, do not support $\sigma^{tot}(\bar{p}p) \geq \sigma^{tot}(pp)$ and $(\sigma^{tot}(\bar{p}p) - \sigma^{tot}(pp)) \rightarrow 0$ for high energies [4].

4 The p-meson nucleus inelastic cross section

We use the relation between $\sigma^{inel}(pA)$ and $\sigma^{inel}(\pi^{\pm}A)$ given in ref. [1] at 200 GeV and introduce $\sigma^{inel}(\pi,11) = \sigma^{inel}(\pi p) + \{\sigma^{el}(\pi p) - \sigma_0^{el,\pi}\}\sigma^{inel}(\pi p)/\sigma^{tot}(\pi p)$ with $\sigma_0^{el,\pi} = 1/2\sigma_0^{el}$ and $\sigma^{inel}(\pi p) = 1/2\{(\sigma^{inel}(\pi^+p) + \sigma^{inel}(\pi^-p)\}$ and $\sigma^{el}(\pi p) = 1/2\{\sigma^{el}(\pi^+p) + \sigma^{el}(\pi^-p)\}$ and $\Delta_{\pi,11} = 1/2\{(\sigma^{inel}(\pi,11)/(\pi\cdot 10\ \mathrm{mb}))^{1/2} - 0.814\}$ and introduce, taking $\sigma^{inel}(pA) = \pi(1.313A^{1/2} - 0.299)^2\ 10$ mb as at 200 GeV in ref.[1], for the inelastic πA cross section

$$\sigma^{inel}(\pi A) = \pi\{1.313A^{1/3} - 0.071(A-1)^{1/3} - 0.299 - 0.200 + \Delta_{\pi,step}$$

$$+ [0.6 + 1.4(A^{1/3} - (0.071/1.313)(A-1)^{1/3})]\Delta_{\pi,11}\}^2 10\ \mathrm{mb} \qquad (4)$$

with $\Delta_{\pi,step} = 1/2\Delta_{step}$. This expression for $\sigma^{inel}(\pi A)$ agrees well with the measured inelastic cross sections from lab momentum p = 2 GeV/c [5] up to 280 GeV/c [2] and can be compared with cosmic ray results at 800 GeV [6]: $\sigma^{inel}(\pi C) = 216 \pm 45$ mb, $\sigma^{inel}(\pi Fe) = 723 \pm 105$ mb and $\sigma^{inel}(\pi Pb) = 1728 \pm 140$ mb. Our result gives $\sigma^{inel}(\pi C) = 210$ mb, $\sigma^{inel}(\pi Fe) = 669$ mb and $\sigma^{inel}(\pi Pb) = 1717$ mb. Beyond the energies of accelerator experiments, we have introduced the asymptotic relation:
$(\sigma^{inel}(pp))^{1/2} - (\sigma^{inel}(\pi p))^{1/2} = 1{,}1301\ \mathrm{mb}^{1/2}$ and $(\sigma^{el}(pp))^{1/2} - (\sigma^{el}(\pi p))^{1/2} = 0.719\ \mathrm{mb}^{1/2}$ rather than that the ratios $\sigma^{inel}(\pi p)/\sigma^{inel}(pp)$ and $\sigma^{el}(\pi p)/\sigma^{el}(pp)$ should reach constant values at high energies.

5 The charged kaon nucleus inelastic cross sections

Here we use similar relations as for pions:
$\sigma^{inel}(K^{\pm},11) = \sigma^{inel}(K^{\pm}p) + (\sigma^{el}(K^{\pm}p) - 1/3\sigma_0^{el})\sigma^{inel}(K^{\pm}p)/\sigma^{tot}(K^{\pm}p)$, $\Delta_{K^{\pm},step} = 1/2\Delta_{step}$,
$\Delta(K^+,11) = 1/2((\sigma^{inel}(K^+,11)/(\pi\cdot 10\ \mathrm{mb}))^{1/2} - 0.744)$, $\Delta(K^-,11) = 1/2((\sigma^{inel}(K^-,11)/(\pi\cdot 10\ \mathrm{mb}))^{1/2} - 0.764)$

$$\sigma^{inel}(K^+A) = \pi\{1.313A^{1/3} - 0.101(A-1)^{1/3} - 0.299 - 0.270 + 1/2\Delta_{step}$$

$$+ [0.6 + 1.4(A^{1/3} - (0.101/1.313)(A-1)^{1/3})]\Delta(K^+,11)\}^2 10\ \mathrm{mb} \qquad (5)$$

$$\sigma^{inel}(K^-A) = \pi\{1{,}313A^{1/3} - 0.096(A-1)^{1/3} - 0.299 - 0.250 + 1/2\Delta_{step}$$

$$+ [0.6 + 1.4(A^{1/3} - (0.096/1.313)(A-1)^{1/3})]\Delta(K^-,11)\}^2 10\ \mathrm{mb} \qquad (6)$$

$\Delta(K^{\pm},11) = 0$ at about 200 GeV. From 1.8 GeV/c lab momentum and up to 280 GeV/c there is good agreement between our calculated inelastic $K^{\pm}$ nucleus cross sections and measuresd inelastic cross sections [2, 3].

6 Discussion

We can now calculate the inelastic p. $\bar{p}$, π and $K^{\pm}$ air nucleus cross sections. Up to about 10^5 GeV the calculated $\sigma^{inel}(pA_{air})$ is about the same as given by other models., see J. Knapp [7] for a comparison with other models. Above 10^5 GeV our result for $\sigma^{inel}(pA_{air})$ is higher than predicted by other models [7], but in agreement with cosmic ray experimental results. The proton proton inelastic cross section is also higer in this model, than what are predicted by most other models above 10^5 GeV. The results from this model are given in mb in the table below for air. The atomic mass for air is: A_{air} = 14.50

p/(GeV/c)	$\sigma^{inel}(pp)$	$\sigma^{inel}(pA_{air})$	$\sigma^{inel}(\bar{p}A_{air})$	$\sigma^{inel}(\pi A_{air})$	$\sigma^{inel}(K^{-}A_{air})$	$\sigma^{inel}(K^{+}A_{air})$
2	24.02	266	401	243	232	156
5	28.33	265	370	222	210	163
10	29.72	266	326	211	194	164
20	30.27	261	301	203	188	166
50	30.70	261	283	200	184	171
100	31.34	262	269	200	184	175
200	31.84	264	271	202	186	182
500	33.21	272	273	210		186
1000	34.37	279		216		192
10^5	46.90	355		290		261
10^7	66.07	471		406		368
10^9	90.46	612		533		504

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