LETTER TO THE EDITOR

On the Σ -hypernuclear states in $(K^-, \pi^\pm)$ reactions on ^{12}C

R F Bishop and J Dąbrowski†

Theoretical Physics Group, Department of Mathematics, University of Manchester Institute of Science and Technology, PO Box 88, Manchester M60 1QD, UK

Received 12 November 1985

Abstract. The binding energies B_Σ of Σ hyperons in hypernuclei produced in $(K^-, \pi^\pm)$ reactions on ^{12}C are analysed, with the result that $B_{\Sigma^+} > B_{\Sigma^0} > B_{\Sigma^-}$. If confirmed by further measurements, the result suggests that charge independence of the ΣN interaction is broken.

The purpose of this Letter is to point out some difficulties in interpreting the results of Bertini *et al* (1984) for Σ -hypernuclear states produced in $(K^-, \pi^\pm)$ reactions on ^{12}C , especially with regard to attempts to estimate the Coulomb energies involved. In particular the results appear to indicate that charge independence of the ΣN interaction is badly broken.

By measuring the pion momentum in the strangeness-exchange reaction $(K^-, \pi^\pm)$, one determines the mass of the hypernucleus produced, M_{HY} , which is related to the binding energy B_Σ of the hyperon in the hypernucleus by

$$B_\Sigma = -(M_{\text{HY}} - M_T) + M_\Sigma - M_N + B_N \quad (1)$$

where M_T is the mass of the target nucleus, M_Σ the mass of the Σ hyperon, M_N the mass of the nucleon N converted into Σ , and B_N the binding energy of the nucleon N in the target nucleus.

In the case of the (K^-, π^+) reaction, the only possible elementary process, $K^-p \rightarrow \Sigma^+\pi^+$, leads to the formation of the hypernucleus ${}_\Sigma^{12}\text{Be}$, i.e., the ${}^{11}\text{B} + \Sigma^+$ system. Furthermore the peak in the π^+ distribution at $M_{\text{HY}} - M_T = 279$ MeV observed by Bertini *et al* (1984) may be assigned to the $(p_{3/2}, p_{3/2}^-)_{\Sigma^+p}$ configuration. By applying equation (1) with $\Sigma = \Sigma^+$, $N = p$, $B_p = 15.96$ MeV, we get for the binding energy of the $p_{3/2}$ Σ^+ hyperon in the ${}_\Sigma^{12}\text{Be}$ nucleus

$$B_{\Sigma^+} = -4.0 \text{ MeV}. \quad (2)$$

In the case of the (K^-, π^-) reaction, two elementary processes are possible: (I) $K^-p \rightarrow \Sigma^+\pi^-$ and (II) $K^-n \rightarrow \Sigma^0\pi^-$. However, at K^- momentum $P_{K^-} = 400$ MeV/c, the cross section for the process (I) is about five times larger than that for the process (II), $\sigma_I \simeq 5\sigma_{II}$. Consequently, we follow Bertini *et al* (1984) and assume that at $P_{K^-} = 400$ MeV/c the (K^-, π^-) reaction leads predominantly to the formation of the hypernucleus ${}_\Sigma^{12}\text{C}$, i.e., the ${}^{11}\text{B} + \Sigma^+$ system (although we are aware of the arguments of Dover *et al* (1984) in favour of the isospin basis). We also accept the interpretation of the peak in the π^- distribution at $M_{\text{HY}} - M_T = 270$ MeV observed by Bertini *et al* (1984) as

† On leave from the Institute for Nuclear Studies, Warsaw, Poland.

the $(p_{3/2}, p_{3/2}^{-1})_{\Sigma^+ p}$ configuration. By applying equation (1) with $\Sigma = \Sigma^+$, $N = p$, we get for the binding energy of the $p_{3/2} \Sigma^+$ hyperon in the ${}_{\Sigma}^{12}\text{C}$ hypernucleus

$$B_{\Sigma^+} = -3.0 \text{ MeV}. \quad (3)$$

Comparing equations (2) and (3), we come to the conclusion that $B_{\Sigma^+} > B_{\Sigma^-}$. Let us make the simplifying but highly reasonable assumption that

$$B_{\Sigma^-} = B_{\Sigma^-}^N + B_C \quad B_{\Sigma^+} = B_{\Sigma^+}^N - B_C \quad (4)$$

where $B_{\Sigma^-}^N$ and $B_{\Sigma^+}^N$ are the nuclear binding energies of the Σ^- and Σ^+ particles respectively, and B_C is the ${}^{11}\text{B}-\Sigma^+$ Coulomb energy (which is assumed to be equal in magnitude but opposite in sign to the ${}^{11}\text{B}-\Sigma^-$ Coulomb energy). If we further assume charge independence of the ΣN interaction, so that

$$B_{\Sigma^-}^N = B_{\Sigma^+}^N \equiv B_{\Sigma}^N, \quad (5)$$

and substitute equation (4) into equations (2) and (3), we find values $B_C = -0.5 \text{ MeV}$ and $B_{\Sigma}^N = -3.5 \text{ MeV}$. (We note parenthetically that the value of $B_C = +0.5 \text{ MeV}$ obtained by Bertini *et al* (1984), and referred to by Walcher (1985), is the result of an unfortunate sign error in solving their equations for their quantities denoted Δ_2 and Δ_3 .)

At $P_{K^-} = 450 \text{ MeV}/c$ the interpretation of the (K^-, π^-) reaction is more difficult, because here $\sigma_I \simeq \sigma_{II}$. Furthermore the splitting of the number of detected π^- mesons into two peaks at $M_{HY} - M_T = 270 \text{ MeV}$ and 275 MeV reported by Bertini *et al* (1984) is less visible. If, however, we accept the interpretation of the 275 MeV peak given by these authors, as corresponding to the formation of the ${}_{\Sigma}^{12}\text{C}$ hypernucleus, then equation (1) with $\Sigma = \Sigma^0$, $N = n$, $B_n = 18.72 \text{ MeV}$ gives $B_{\Sigma^0} = -3.4 \text{ MeV}$. As one would expect, $B_{\Sigma^0} \simeq B_{\Sigma}^N$.

The result that $B_{\Sigma^+} > B_{\Sigma^-}$ is very surprising, since if this result is true we clearly cannot make the simplifying assumption expressed in equation (5), as it leads to a negative value for the quantity B_C , which by its definition should clearly be positive. Suppose instead that we turn to more reasonable independent estimates of the Coulomb energy B_C . To be definite, we choose here to accept the value $B_C \simeq 2.5 \text{ MeV}$, which follows from the theoretical results of Dąbrowski and Rożynek (1985) for the energies of narrow decaying Σ -hypernuclear bound states embedded in the positive-energy continuum, which employ the absorptive Σ -nucleus potential described by Dąbrowski (1985). We also note that this value is completely consistent with the independent value $B_C = 2.85 \pm 0.15 \text{ MeV}$ quoted by Dover *et al* (1984), and which is based on calculations similar to those above but by Batty *et al* (1983). In this case, the experimental values of B_{Σ^-} and B_{Σ^+} quoted in equations (2) and (3), together with the assumed value of $B_C = 2.5 \text{ MeV}$, lead via equation (4) to the values $B_{\Sigma^-}^N = -6.5 \text{ MeV}$ and $B_{\Sigma^+}^N = -0.5 \text{ MeV}$.

It seems very unlikely that the large difference $\Delta B \equiv B_{\Sigma^+}^N - B_{\Sigma^-}^N \simeq 6.0 \text{ MeV}$ can be wholly due to the presence of a Lane (or symmetry) term in the Σ -nucleus interaction potential $V_{\Sigma A}$. For example, Dąbrowski and Rożynek (1985) parametrise the $\Sigma^\pm$ interaction in the commonly assumed form

$$V_{\Sigma A}(r) = [-V_0 \pm V_1(Z - N)/2A] \rho(r)/\rho(0) \quad (6)$$

for a nucleus of mass number A , proton number Z and neutron number N and a nuclear density profile $\rho(r)$ of usual Woods-Saxon form. Using a value $V_0 = 30 \text{ MeV}$ for the binding of a Σ hyperon in infinite symmetric nuclear matter, and a Lane (or symmetry) potential of strength $V_1 = 55 \text{ MeV}$ as suggested by Dover *et al* (1984), Dąbrowski and Rożynek (1985) find that ΔB is reduced only by about 1 MeV . By far the most obvious

explanation for the large remaining difference ΔB must then be that the charge independence of the ΣN interaction is severely broken.

We are bound to caution, however, that before drawing any definite final conclusions, it is important to confirm the experimental results of Bertini *et al* (1984). In this context we recall only that Yamazaki (1985) has reported the result $B_{\Sigma^-} = -2.1 \pm 0.3$ MeV from experiments with stopped K^- mesons, which differs by about 2 MeV from the result of Bertini *et al* (1984) given in our equation (2).

We conclude, however, that a definitive resolution of the points raised in this Letter will be of considerable interest and importance to the field of hypernuclear physics, whatever the eventual outcome.

One of us (JD) would like to express his gratitude to members of the Department of Mathematics at UMIST for their kind hospitality during his visit to Manchester. The visit was made possible by a Visiting Fellowship awarded by the Science and Engineering Research Council of Great Britain, whose support is gratefully acknowledged, as is the partial support of the Polish–US Maria Skłodowska-Curie Fund under Grant No P-17P037P.

References

- Batty C J, Gal A and Toker G 1983 *Nucl. Phys. A* **402** 349
Bertini R *et al* 1984 *Phys. Lett.* **136B** 29
Dąbrowski J 1985 *Nucl. Phys. A* **434** 373C
Dąbrowski J and Rożynek J 1985 *J. Phys. G: Nucl. Phys.* **11** L197
Dover C B, Gal A and Millener D J 1984 *Phys. Lett.* **138B** 337
Walcher T 1985 *Nucl. Phys. A* **434** 343C
Yamazaki T 1985 *Nucl. Phys. A* **434** 363C