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K_S^0 REGENERATION ON NUCLEI AND THE COHERENT PRODUCTION MODEL*

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We use the coherent production model to calculate the energy dependence of the forward K_S^0 regeneration amplitude on nuclear targets. The agreement with experiment is satisfactory.

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In this note we wish to apply the coherent production model[1] to the analysis of K_S^0 regeneration reaction on nuclei

$$K_L^0 A \to K_S^0 A . \qquad (1)$$

A is the mass number. The data for this reaction[2,3] for hydrogen, copper, and lead targets show two distinctive features:

(a) The forward differential cross sections, $d\sigma/dt$ are proprotional to $P_L^{-n_A}$ for $2.5 \le P_L \le 7.5$ (GeV/c) where P_L is the laboratory momentum of incoming K_L and n_A is a constant for a fixed A. There is no apparent pomeron exchange, as expected, since charge conjugation, c = - 1 must be exchanged in the t-channel.

(b) For each nuclear target, the regeneration phases, ϕ_A, are near -45 degrees $|\phi_A + 45°| \le 15°$. Strong exchange degeneracy[4] assumption predicts -45 degrees for the regeneration phase of the nucleon target.

Since the regeneration from nucleons is a much weaker process than elastic scattering $[(d\sigma_{K_LP\to K_SP}/dt)/(d\sigma_{K_LP\to K_LP}/dt)|_{t=0} < 0.05$ for hydrogen target in the momentum region of our interest], it may be reasonably assumed that $K_L^0 \to K_S^0$ occurs at most once as the K_L^0 (and K_S^0) repeatedly scatters elastically on traversing the nucleus.

Then the coherent nuclear regeneration amplitude from nucleus A is given by[1,5]

$$f_{K_L^0 A \to K_S^0 A}(q) = \frac{ik}{2\pi}\sum_{j=1}^{A}\int d^2b\, d^3r_1 \cdots d^3r_A \,|\psi(\vec r_1 \vec r_2 \cdots \vec r_A)|^2 e^{i\vec q\cdot\vec b}$$

$$\times \prod_{Z_i < Z_j}\left[1 - \Gamma_{K_L}(\vec b - \vec S_i)\right]\Gamma_{Reg}(\vec b - \vec S_j)\prod_{Z_k > Z_j}\left[1 - \Gamma_{K_S}(\vec b - \vec S_K)\right], \qquad (2)$$

where ψ is the target wave function, $\vec b$ is the impact parameter of the incident particle, and $\vec S_i$ is impact parameter of the ith nucleon (the transverse part of $\vec r_i$). It has been assumed that the nucleus is left in the initial state; by explicit calculation we have verified that the cross section for nuclear excitation is small in the forward direction. The Γ's are profile functions which are defined in terms of the regeneration and elastic scattering amplitudes of nucleon by

$$\Gamma_{Reg}(\vec b) = \frac{1}{2\pi ik}\int f_{K_LN\to K_SN}(\vec q)\, e^{-i\vec q\cdot\vec b}\, d^2q ,$$

$$\Gamma_{K_{\substack{L\\S}}}(\vec b) = \frac{1}{2\pi ik}\int f_{K_{\substack{L\\S}}N \to K_{\substack{L\\S}}N}(\vec q)\, e^{-i\vec q\cdot\vec b}\, d^2q .$$

Since the $K^0N \to \bar K^0 N$ transition is much weaker than the elastic $K^0(\bar K^0)N \to K^0(\bar K^0)N$ reaction, we can safely approximate

$$f_{K_LN} \equiv f_{K_LN\to K_LN} = f_{K_SN\to K_SN} = \frac{f_{K_0N\to K_0N} + f_{\bar K_0 N\to \bar K_0 N}}{2}$$

Therefore,

$$\Gamma_{K_L}(\vec b) = \Gamma_{K_S}(\vec b) .$$

We approximate the nucleus wave function by neglecting correlations and using a product of single nucleon density function

$$\left|\psi(\vec{r}_1, \vec{r}_2 \cdots\cdots \vec{r}_A)\right|^2 \to \prod_{i=1}^{A} \rho(\vec{r}_i) . \qquad (3)$$

This assumption simplifies Eq. (2) to the form

$$f_{K_L A \to K_S A}(\vec{q}) = \left[\left(\frac{N_P}{A}\right) f_{K_L P \to K_S P}(0) + \left(1 - \frac{N_P}{A}\right) f_{K_L n \to K_S n}(0)\right]$$

$$\times \int e^{i\,\vec{q}\cdot\vec{b}}\; T(\vec{b})\; e^{-\frac{1}{2}(1-i\alpha)\,\sigma\; T(\vec{b})}\, d^2 b, \qquad (4)$$

assuming the nuclear density $\rho(\vec{S}, z)$ varies slower comparing to $\Gamma(\vec{b}-\vec{S})$ as a function of S. N_P is the number of protons in the nucleus, where

$$\sigma = \left(\frac{N_P}{A}\right) \sigma^T_{K_L P} + \left(1 - \frac{N_P}{A}\right) \sigma^T_{K_L n} ,$$

$$\alpha = \frac{\left(\frac{N_P}{A}\right) \mathrm{Re}\; f_{K_L P}(0) + \left(1 - \frac{N_P}{A}\right) \mathrm{Re}\; f_{K_L n}(0)}{\frac{N_P}{A}\; \mathrm{Im}\; f_{K_L P}(0) + \left(1 - \frac{N_P}{A}\right) \mathrm{Im}\; f_{K_L n}(0)} ,$$

and

$$T(\vec{b}) = A \int \rho(\vec{r})\, dz .$$

The coherent regeneration cross section is then

$$\frac{d\sigma_A}{dt} = \left(\frac{d\sigma_N}{dt}\right)_0 \left| \int Jo(qb)\; T(b)\; e^{-\frac{1}{2}(1-i\alpha)\sigma\; T(b)}\; bdb \right|^2 , \qquad (5)$$

where we have defined an average nucleon regeneration forward cross section by

$$\left(\frac{d\sigma_N}{dt}\right)_0 = \left|\left(\frac{N_P}{A}\right) f_{K_L P \to K_S P}(0) + \left(1 - \frac{N_P}{A}\right) f_{K_L n \to K_S n}(0)\right|^2 . \qquad (6)$$

In the numerical calculation we use a Woods-Saxon nuclear density for both proton and neutron:

$$\rho(b, z) = \rho_0 \left[1 + \exp\left(\frac{r-c}{a}\right)\right]^{-1} .$$

We use $c = 1.20\ A^{1/3}$ fm and $a = 0.6$ fm.

These nuclear parameters are larger[6] than those from electron scattering experiments due to the finite range, strong interaction of K mesons.

The calculation requires the real parts of the nucleon regeneration amplitudes, which have not been well investigated experimentally in the energy range of interest to us. An alternative would be to use dispersion relations, but this would require fairly accurate high-energy total cross sections, which are also not available. We use instead the strong exchange degeneracy hypothesis[4] which gives, using the optical theorem,

$$\alpha = \frac{\frac{1}{2}\left[-\left(\frac{N_P}{A}\right) C_P\, P_L^{-\beta_P} - \left(1 - \frac{N_P}{A}\right) C_n\, P_L^{-\beta_n}\right]}{\left(\frac{N_P}{A}\right)\sigma^T_{K_L P} + \left(1 - \frac{N_P}{A}\right) \sigma^T_{K_L n}} ,$$

where we have parameterized KN total cross sections as constant, the $\overline{K}N$ as

$$\sigma^T_{\overline{K}^0 N} = \sigma^0_{\overline{K}^0 N} + C_N\, P_L^{-\beta_N} ,$$

and where P_L is in units of GeV/c.

The numerical values used are

$$\sigma^T_{K^0 P} = 17.6 \text{ mb},$$

$$\sigma^T_{K^0 n} = 17.7 \text{ mb},$$

$$\sigma^T_{\overline{K}^0 P} = (18.2 + 7.2\ P_L^{-0.52}) \text{ mb},$$

and

$$\sigma^T_{\overline{K}^0 n} = (20.2 + 19.5\ P_L^{-0.92}) \text{ mb},$$

extracted from $K^{\pm}$ scattering experiments using charge symmetry. The fits involved in the latter two cross sections are shown in Fig. 1.

We first assumed the neutron and proton to have the same regeneration amplitude, then

$$\left(\frac{d\sigma_N}{dt}\right)_0 = \left(\frac{d\sigma_H}{dt}\right)_0 = 3.17\, P_L^{-1.28} ,$$

which is shown in Fig. 2. Finally, we obtained the results shown (as dotted lines) in Fig. 3a, which may be compared with the best fits to experiment of the form $P_L^{-n}A$ (solid line). The agreement is on the whole satisfactory although there is a tendency for the results of the calculation to fall too fast with P_L. This potential discrepancy may be an indication of a different energy dependence of the proton and neutron regeneration cross section. The regeneration phases of nuclei ϕ_A are plotted in Fig. 3b. Again the agreement is satisfactory, the difference between the nuclear regeneration phases and that of hydrogen is larger for heavier nuclei and goes to zero with increasing momentum. Note that the fact that the nuclear regeneration phases are nearly that of hydrogen strongly justifies the assumption that proton and neutron regeneration phases are approximately equal. In addition, there is one experimental point in this momentum region for a carbon target[9] (which has no neutron excess) in which this calculation would disagree with the forward differential cross-section measurement by a factor of about 2, but would agree with the regeneration phase measurement. Further experimental studies would be valuable in clarifying this situation.

The regeneration effect in Cu has also been successfully fitted using an optical model.[10] The difference between the optical model and this one-step coherent production model can be summarized in two integrands below:

$$I^{coh} = i\,[\overline{P}(b) - P(b)]\, e^{\frac{i}{2}[P(b) + \overline{P}(b)]} , \tag{7}$$

$$I^{op} = e^{i\overline{P}(b)} - e^{iP(b)} , \tag{8}$$

where

$$P(b) = \frac{4\pi}{k}\left[\left(\frac{N_P}{A}\right) f_{K_0P}(0) + \left(1 - \frac{N_P}{A}\right) f_{K_0n}(0)\right] T(b),$$

and I's are normalized as

$$f_{K_LP \to K_SP}(q) = \frac{ik}{4\pi}\int I(b)\, J_0(qb)\, b db . \tag{9}$$

Equations (7) and (8) are easily verified to be equivalent if the difference $\Delta P(b) = \overline{P}(b) - P(b)$ is smaller than both 1 and $P(b)$ [and $\overline{P}(b)$]. This is not always true for heavy nuclei at $b \simeq 0$ due to large $T(b)$. However, the extra b in the integrand lessens the difference. The detailed quantitative discussion of the difference is given in Ref. 6. The advantage of the present treatment is the clean separation of hadronic effects and nuclear effects shown in Eq. 5. The first factor (nucle<u>on</u> effects) gives most of the energy dependence, while the second (nucle<u>ar</u> effects), controls the angular distribution. In the optical model this factorization does not occur.

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FOOTNOTES AND REFERENCES

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1. R. J. Glauber, Boulder lectures in Theoretical Physics 1968 (Interscience Publ. Inc., New York, 1969) Vol. 1 ; K. S. Kolbig and B. Margolis, Nucl. Phys. B6, 85 (1968).

2. A. Bohm, P. Darriulat, C. Grosso, V. Kaftavov, K. Kleinknecht, H. L. Lynch, C. Rubbia, H. Ticho, and K. Kittle PL 27B, 594 (1968); H. Foeth, M. Holder, E. Radermacher, A. Staude, P. Darriulat, J. Deutsch, K. Kleinknecht, C. Rubbia, K. Tittel, M. I. Ferrero, and C. Grosso, Phys. Lett. 31B, 544 (1970); M. Ya. Balats, V. M. Berezin, M. E. Vishnevskii, N. D. Galanina, V. N. Markizov, V. V. Memelov, V. A. Murysov, F. A. Paviovskii, Yu. A. Semenov, and V. I. Chistilin, ITEF-856 (1971).

3. See Lawrence Berkeley Laboratory Report No. LBL-55, "K_L^0N Interaction" (1972) p. 32, for compiled data for hydrogen target and their references.

4. P. G. O. Freund, Phys. Rev. Lett. 20, 235 (1968); H. Harari, Phys. Rev. Lett. 20, 1395 (1968); H. S. Goldberg and V. L. Telegdi, Phys. Lett. 35B 327 (1971).

5. B. Margolis, Acta Phys. Pol., B2, 57 (1971).

6. The nuclear radius for strong interaction will be discussed in more detail by W. L. Wang and Fumiyo Uchiyama in Lawrence Berkeley Laboratory Report No. LBL-2313, (to be submitted to Nucl. Phys.)

7. For references see Compilation of Cross Sections II, CERN/HERA Report No. 72-2, 1972 (unpublished).

8. Particle Data Group, Rev. Mod. Phys., 45, S1 (1973).

9. M. Bott-Bodenhausen, X. De Bonard, D. G. Cassel, D. Dekkers, R. Felst, R. Mermod, and I. Salvin, Phys. Lett., 23, 277 (1966).

10. H. Faissner, H. Foeth, A. Staude, K. Tottel, P. Darriulat, K. Kleinknecht, C. Rubbia, J. Sandweiss, M. I. Ferrero, and C. Grosso, Phys. Lett., 30B,204 (1969).

FIGURE CAPTIONS

Fig. 1. K^-p and K^-n total cross sections (data points from Ref. 6), together with the best fit of the forms $\sigma_{\overline{K}N} = \sigma_N^0 + C_N P_L^{-\beta_N}$. All data points between 2.5 (GeV/c) to 20.0 (GeV/c) are used to obtain the parameters but only representative data points are shown here.

Fig. 2. Hydrogen regeneration cross section extracted from Ref. 3.

Fig. 3a. Nuclear regeneration cross sections. The experimental points are from Ref. 2; the solid line is the best fit to experiment of the form $P_L^{-n}A$, and the broken line is the result of the calculation.

Fig. 3b. Calculation of the nuclear regeneration phases. The points are from Ref. 2; the values of $\phi_A - \phi_H$ were obtained using $\phi_\pm = 42.0° \pm 3°$ (Ref. 8).

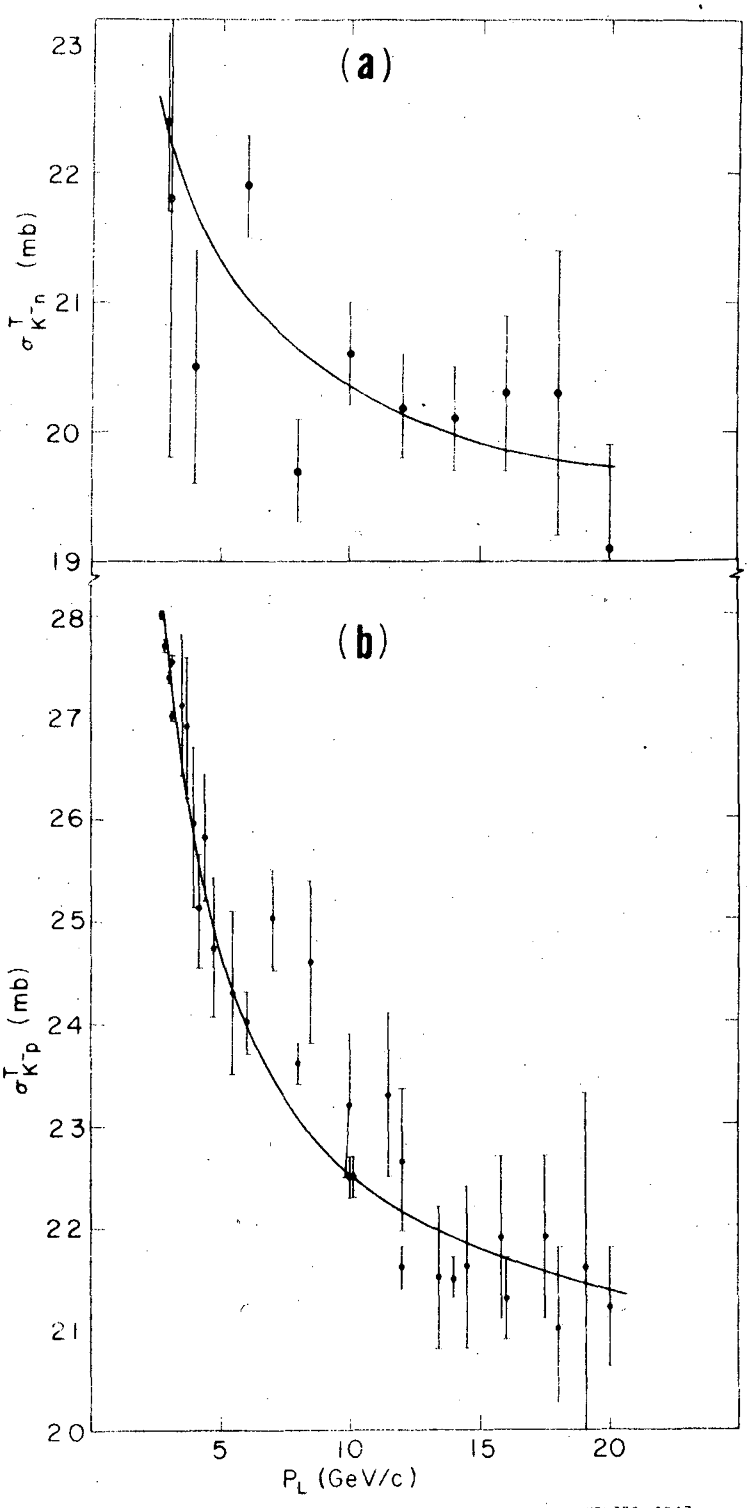
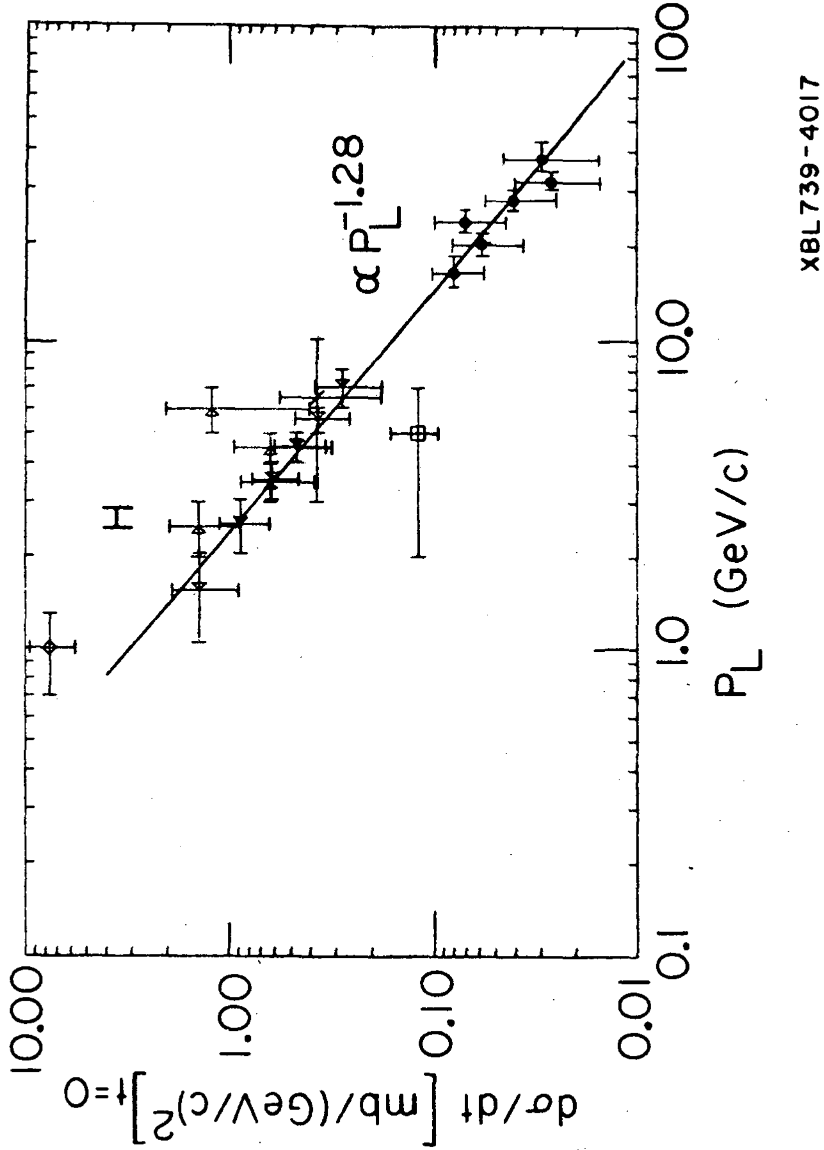

(a)
(b)
$\sigma^T_{K^-n}$ (mb)
$\sigma^T_{K^-p}$ (mb)
23
22
21
20
19
28
27
26
25
24
23
22
21
20
5
10
15
20
P_L (GeV/c)
XBL738-3947

Fig. 1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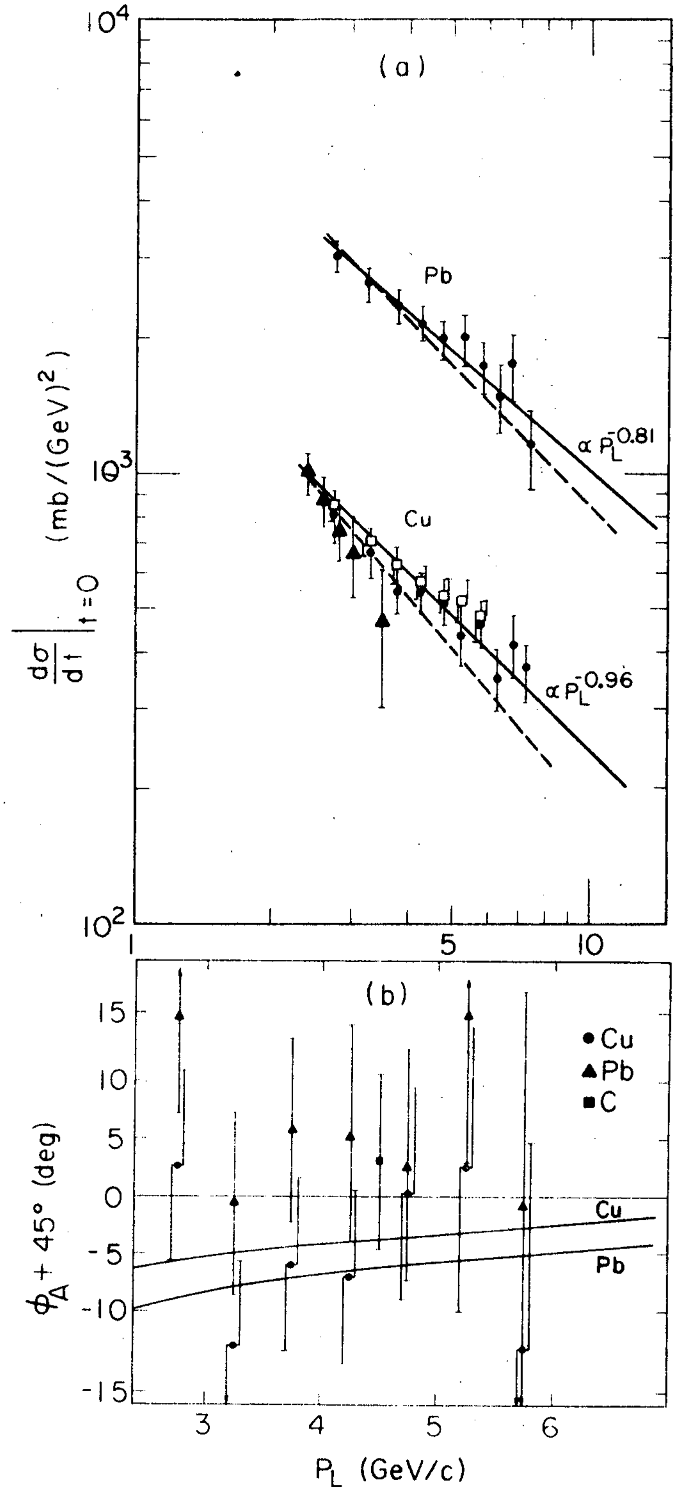
10.00
1.00
0.10
0.01
0.1
1.0
10.0
100
P_L (GeV/c)
α P_L^-1.28
XBL 739-4017

Fig. 2



XBL738-3944

Fig. 3

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