# STRANGE PARTICLE PRODUCTION IN 10 GeV/c $\pi^-$ INTERACTIONS IN HYDROGEN BUBBLE CHAMBERS

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*(presented by A. Wroblewski)*

To study the associated production of strange particles in $\pi^- - p$ interactions the 80 cm Saclay hydrogen bubble chamber was exposed to a 10 GeV/c $\pi^-$ beam from the CERN proton synchrotron. About 83,000 photographs with an average of 10.5 beam tracks per picture were obtained. The $\mu^-$ and $K^-$ admixtures were estimated to be 8% and <1% respectively.

About 95% of the photographs were scanned twice for $V^\pm$ and $V^0$ decays associated with interactions in a fiducial region of the chamber. Several thousands of $V$ decays were found, among them 313 events in which the decay of both strange particles produced was observed in the chamber. In the present work only those 313 events have been analysed to obtain information about the mechanism of $K\bar{K}$ and $YK$ production. The efficiency of scanning was estimated to be 99% for $V^0$, 91% for $V^-$ and 86% for $V^+$ decays.

The particles were identified according to the geometry measurements followed by calculations with the IBM 709 " GAP " programme and, if necessary, by ionisation measurements.

## 10 GeV/c $\pi^- - p$ CROSS SECTIONS

$$\sigma_{KK} = (2.0 \pm 0.3) \text{ mb}$$
$$\sigma_{\Lambda^0 K} = (0.8 \pm 0.1) \text{ mb}$$
$$\sigma_{YK} = (1.3 \pm 0.2) \text{ mb}$$
$$\sigma_{\bar{\Lambda}^0 Y} = (5.2 \pm 3.2) \ \mu\text{b}$$
$$\sigma_{\Xi^-} = (14.3 \pm 4.8) \ \mu\text{b}$$

Table I shows the results of identification of our events and the cross sections for strange particle production in 10 GeV/c $\pi^- - p$ interactions. The calculation of these cross sections was based on the value of the total cross section $\sigma_{\pi^- p} = (26.5 \pm 0.5)$ mb at this energy [1]. Transformations to the $\pi$-proton centre-of-mass system and kinematic analysis of particle were done using a Special Analysis Programme (SAP) for the IBM 709. The results presented below are based on about 70% of the events for which all the measurements and calculation have been finished.

TABLE I

Results of identification

| | | | |
|---|---|---|---|
| $V^0V^0$ | 172 | $K^0K^0$ | 70 |
| | | $K^0\Lambda^0$ | 100 |
| | | $\bar{\Lambda}^0\Lambda^0$ | 2 |
| $V^0V^-$ | 65 | $K^0\Sigma^-$ | 46 |
| | | $\Xi^-$ | 10 |
| | | $K^0K^-$ | 9 |
| $V^0V^+$ | 54 | $K^0\Sigma^+$ | 32 |
| | | $\Lambda^0K^+$ | 13 |
| | | $K^0K^+$ | 8 |
| | | $\bar{\Lambda}^0\Sigma^+$ | 1 |
| $V^+V^-$ | 15 | $K^+\Sigma^-$ | 13 |
| | | $K^+K^-$ | 2 |
| $V^+V^+$ | 7 | $K^+\Sigma^+$ | 7 |

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## THE $K^0\overline{K^0}$ PAIR PRODUCTION

The $P_T - P_L^*$ plot for $K^0\overline{K^0}$ events is shown in the upper part of Fig. 1. The points corresponding to two $K^0$'s produced in the same event are joined by a line. The histogram of $P_L^*$ for $K^0$ below shows that kaons are emitted mostly forward in $\pi^- - p$ CMS. The same predominance of forward emission can be seen in the $P_L^*$ distribution for $\pi^+$ and $\pi^-$ produced with $K^0\overline{K^0}$ pairs, while protons are emitted strongly backward (Fig. 1).

It seems to us, therefore, that the production of $K^0\overline{K^0}$ pairs can be explained in terms of a peripheral model with $\pi$ exchange. Most of the pions seem to be produced together with a $K^0\overline{K^0}$ pair in the mesonic vertex, while very few of them or none accompany the proton (or neutron) in the baryonic vertex.

To obtain information about possible production of unstable states in our $K^0\overline{K^0}$ events we calculated the $Q$-values for all possible pairs of secondaries. The results are:

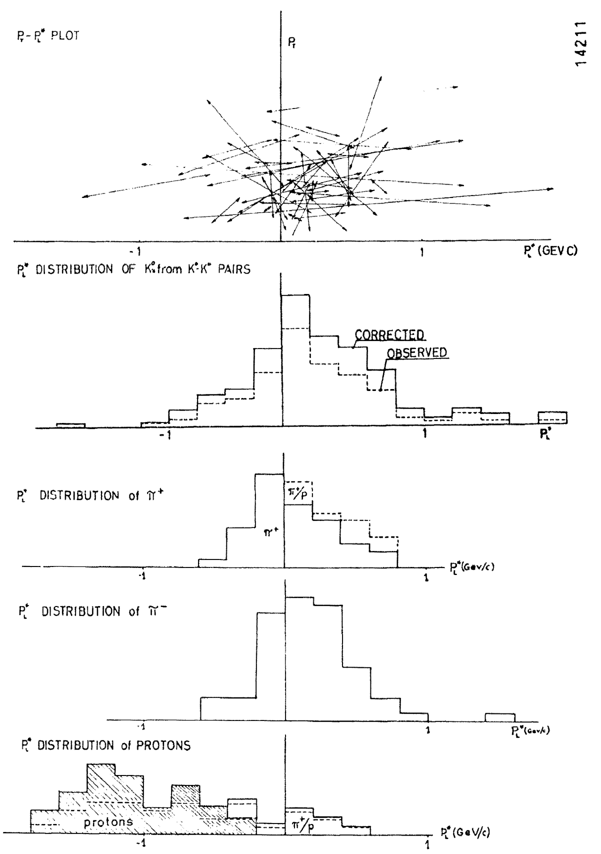


**Fig. 1** $P_T - P_L^*$ plot for $K^0 - K^0$ pairs. $K^0$'s from the same event are joined by a line. Below histograms of $P_L^*$ for $K^0$'s, $\pi^+$, $\pi^-$ and protons. For protons the dotted line indicates the observed distribution. The full line represents the distribution corrected for the detection probability of $K^0$'s.

(a) The $Q$-value distribution for $K^0\pi^+$ and $K^0\pi^-$ systems shows that there is very little or no $K^*$ production in the events with $K^0\overline{K^0}$ production.

(b) There is no evidence for $N^*$ production.

(c) The $Q$-value distribution for $\pi^+ - \pi^-$ shows no evidence of $\rho^0$ production, but the broad maximum between 0 and 400 MeV is what could be expected for the apparent $\pi^+\pi^-$ $Q$-value distribution from $\omega^0$ decay.

(d) In $Q$-value histogram for $K^0\overline{K^0}$ system (Fig. 2) we found a peak in the region 0-200 MeV. It is impossible in our case to calculate the phase-space background for this distribution as the relative probabilities of various final states is not precisely known. Moreover, as can be seen from Fig. 1, the production of secondaries in our events does not follow the predictions of statistical theory. Therefore it is important to know, if the $K\overline{K}$ correlation indicated by the peak at low $Q$-values corresponds to a real effect or if it is just a consequence of the forward emission of $K$'s displayed in Fig. 1. In order to decide this point, we calculated the " background " for 1000 random events, by the use of a Monte Carlo method, combining in pairs kaons from different events with energy conservation taken into account. The $Q$-value distribution

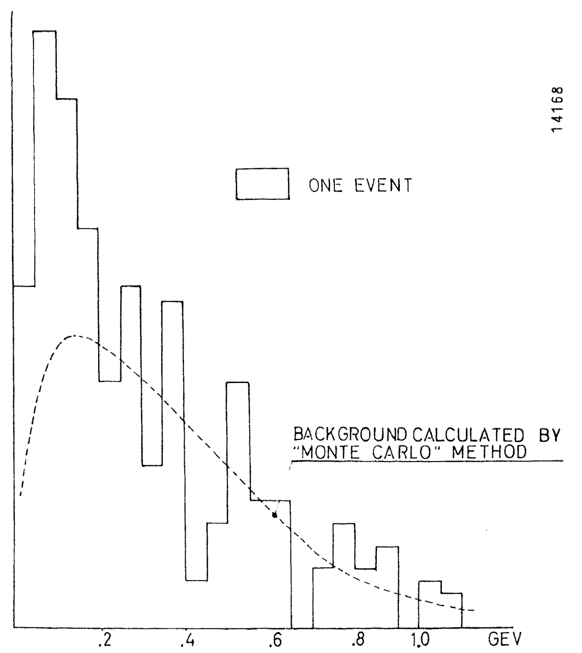


**Fig. 2** The $Q$-value distribution for $K^0 - K^0$ pairs. The dotted line was obtained by a Monte-Carlo method. The distribution was not corrected for the detection probability but this correction would make the difference between the true distribution and " background " larger.

for " random " events was then normalised to the part of experimental distribution with $Q_{KK} > 200$ MeV (Fig. 2). The experimental histogram rises above the background of " random " events by more than two standard deviations and might indicate the possible existence of a $K\overline{K}$ resonance with $Q$-value of the order of 50-100 MeV. An additional check of correlation between kaons produced in the same interaction was made by studying the angular correlation of two $K^0$'s. Fig. 3 shows that the opening angle of $K^0\overline{K^0}$ pairs with $Q < 200$ MeV is in general small (i.e. kaons go off together in most cases) and the correlation is

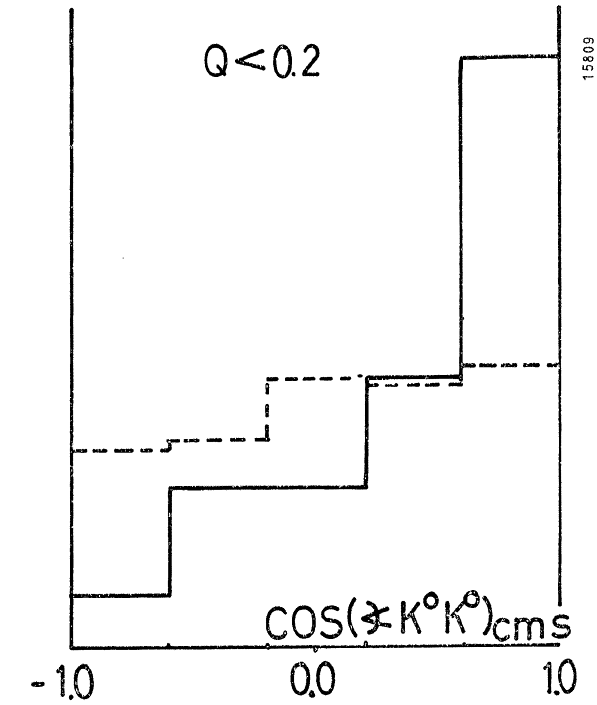


**Fig. 3** The distribution of the angle between the lines of flight of two $K^0$'s in $\pi-p$ cms for the pairs with $Q$-value less than 0.2 GeV. The full line is for real events, the dotted one for random ones.

much stronger than for the " random " events which contribute to the same $Q$-value region. This indicates that the comparison of the real $Q$-value distribution with the one for " random " events is too hard a test and that the true events in the peak have a physical significance different from the one in the maximum of the " random " distribution.

## THE *YK* PAIR PRODUCTION

Looking at the $P_T - P^*_L$ plot for $K^0\Lambda^0$ events it is clear that $\Lambda^0$ hyperons are emitted mainly in the

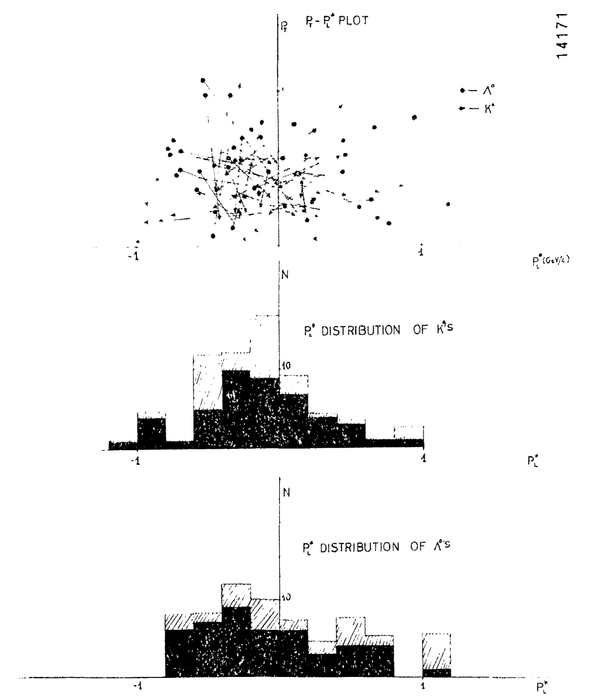


**Fig. 4a** $P_T - P_L$ plot and the histogram of $P^*_L$ for $\Lambda^0$-hyperons and $K^0$ mesons for non-peripheral $\Lambda^0 - K^0$ events.

backward hemisphere, as was already found in previous experiments [2)]. For further analysis we selected the events in which the momentum and direction of the $\Lambda^0$ does not differ very much from the proton before the collision (these events we call " peripheral "). The principle of this selection is of course arbitrary. Taking, however, as " peripheral " the events in which $\Lambda^0$'s have $P^*_L < -0.8$ GeV/c, we are left with a group of " non peripheral " events for which the average value of $P_T$ and average absolute value of $P^*_L$ are the same.

Fig. 4b shows the $P_T - P^*_L$ plot for $\Lambda^0$ and $K^0$ from " peripheral " events. One can see very pronounced correlation of $\Lambda^0$ and $K^0$ produced in the same interaction. Assuming the one meson exchange peripheral model $\pi^- - p$ interaction, this correlation indicates the $K$-meson exchange. In the " non peripheral " events no strong $\Lambda^0 - K^0$ correlation was found (Fig. 4a). The same pattern was observed in our $\Sigma$-$K$ events. The group of the " peripheral " events contains about 50% of all $Y$-$K^0$ events observed.

Fig. 5 shows the distribution of angles between $\Lambda^0$ and $K^0$ in $\pi^- - p$ CMS. The " peripheral " events contribute mainly to the peak observed near 180°.

The $P^*_L$ distributions of $\pi^+$ and $\pi^-$ are very similar to the $P^*_L$ distribution of $K^0$ in both " peripheral " and " non-peripheral " events (Fig. 6), which suggests that pions are mostly produced together with $K^0$ in the upper (mesonic) vertex.

For all possible pairs of secondaries produced in $K^0\Lambda^0$ events the $Q$-values were calculated. The results are:

(a) As it is seen in Fig. 7 the $(\Lambda^0K^0)$ $Q$-value distribution does not show any significant peak in comparison with the background. The background of " random " events was calculated by a Monte-Carlo

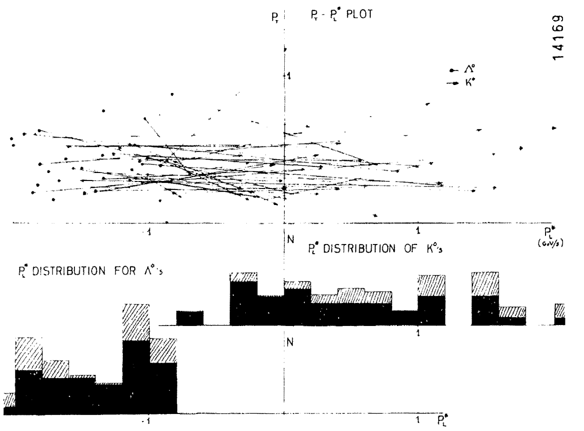


**Fig. 4b** $P_T$—$P_L$ plot and the histogram of $P_L^*$ for $\Lambda^0$-hyperons and $K^0$ mesons for peripheral. $\Lambda^0$-$K^0$ events.

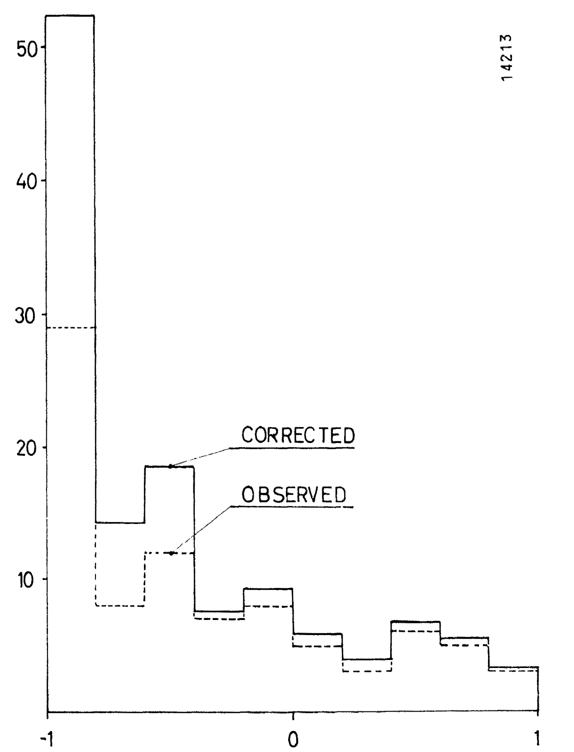


**Fig. 5** The distribution of angles between $\Lambda^0$ and $K^0$ lines of flight in $\pi$—$p$ cms.

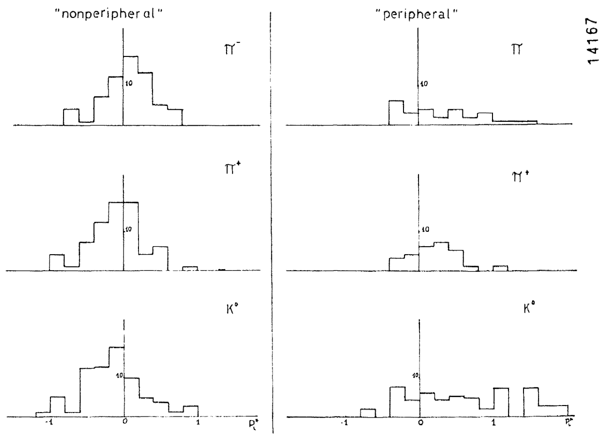


**Fig. 6** Histogram in $P_L^*$ for $\pi$ and $K$-mesons produced in "peripheral" and " non-peripheral" $K^0$—$\Lambda^0$ events.

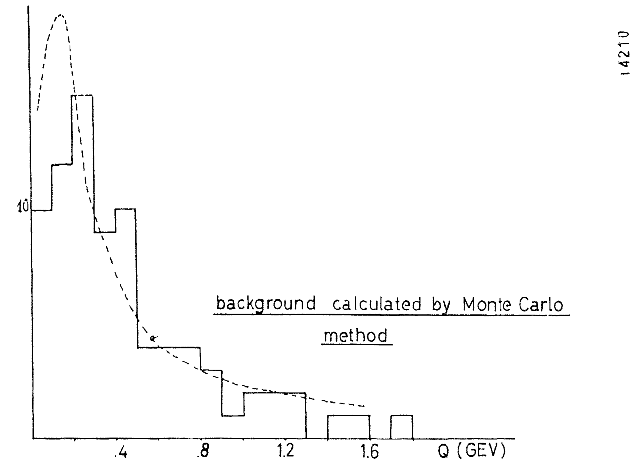


**Fig. 7** $Q$-value of $K^0$—$\Lambda^0$ pairs. The dotted line gives the background as calculated from 1000 " random "-pairs.

method separately for " peripheral " and " non-peripheral " events. The curve shown in Fig. 7 is the weighted sum of these two.

(b) $Q$-value distribution of $K^0$—$\pi^+$ system (Fig. 8) indicates that in 30-80% of events $K^*$ is produced. The lower limit was obtained by comparison of the $Q$-value distribution for $K^0\pi^+$ with the background of $K^0\pi^-$ distribution. The higher limit we got from the enhanced distribution (lower of Fig. 8) in which all other combinations of $K^0\pi^+$ were erased if in a given event one combination corresponding to $K^*$ was found.

(c) There is no evidence for abundant $Y^*$ production in the $(\Lambda^0$—$\pi)$ $Q$-value distribution.

(d) The distribution of $\pi^+\pi^-$ $Q$-value does not show any peak corresponding to the $\rho^0$, but could be explained if the $\omega^0$ is produced.

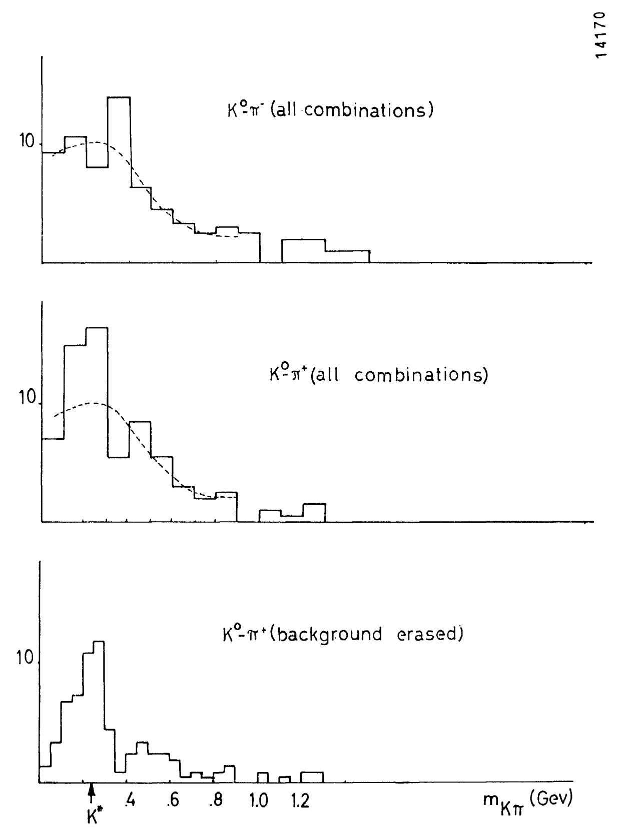


**Fig. 8** $Q$-value of $K^0\pi^-$ and $K^0\pi^+$ pairs from $K^0\Lambda^0$ events. The dotted line represents the upper histogram ($K^0-\pi^-$ pairs). but is smoothed.

## TRANSVERSE MOMENTUM OF PARTICLES PRODUCED IN 10 GeV/c $\pi^-$—$p$ INTERACTIONS

Fig. 9 shows the average value of $P_T$ for particles which were observed in our experiment. Contrary to the previous belief we find that $P_T$ of secondaries produced in $\pi^-$—$p$ interactions is not constant but seems to depend on the mass of the particle produced. At the moment we have no explanation of this experimental fact.

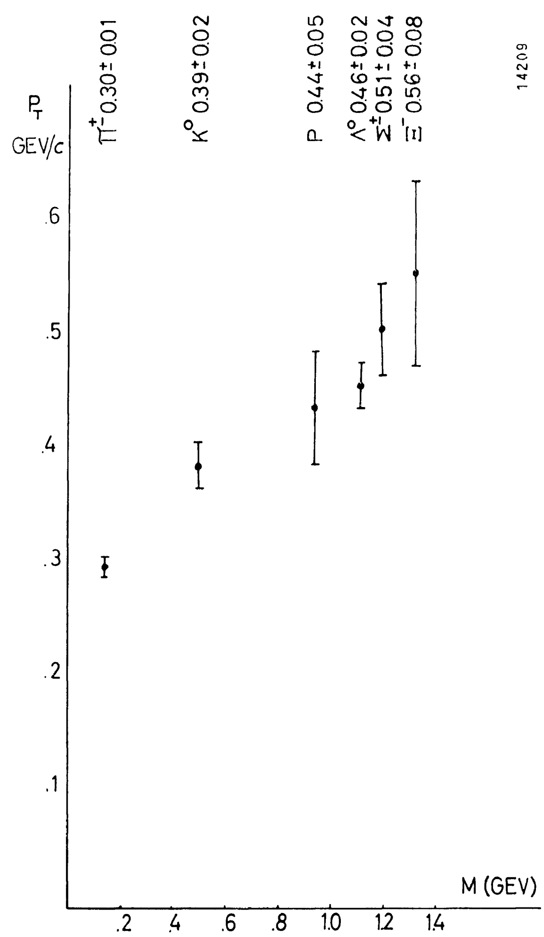


**Fig. 9** Dependence of the average transverse momentum for particles produced in 10 GeV/c $\pi^-$—$p$ interaction with two strange particles observed.

## LIST OF REFERENCES


1. G. von Dardel *et al.*, Phys. Rev. Letters *8*, 173 (1962).
2. J. Bartke *et al.*, Nuovo Cimento, *24*, 876 (1962).