Elastic $p$-$p$ scattering is investigated from our point of view that dynamical aspects of hadron reactions correspond to the pattern of urbaryon rearrangement diagram (URD).\textsuperscript{1,2} $\frac{d\sigma}{dt}(pp)$ exhibits two breaks over a wide region of $s$ and $t$, indicating that the amplitude is decomposed into three of different characters. In the URD picture we have also three $N$-$N$ amplitudes, $f^D$, $f^X$ and $f^{Xa}$, corresponding to three types of URD in Fig. 1. In the present letter, we give the qualitative arguments that (i) the break of $\frac{d\sigma}{dt}|_{90^\circ}$ manifests a shift of dominant contribution from $f^X$ to $f^{Xa}$ and (ii) the shoulder-like structure of $\frac{d\sigma}{dt}$ is a consequence of antisymmetrization for $f^X$ and $f^{Xa}$.

$f^D$ is the diffractive, non-rearrangement amplitude. Let us parametrize $f^X$ tentatively as

$$f^X(s, t, u) = s^{-\delta_1(t)} \exp(\sigma t) + r s^{-\delta_1(u)} \exp(\sigma u).$$

From $t$-$u$ crossing expected from Fig. 1, $f^{Xa}(s, t, u) = f^X(s, u, t)$ is obtained. The assumed form\textsuperscript{3} $G_0(t) = r_0 \cdot n + G_0 \cdot \sqrt{-t}$ represents the characteristic power law of energy dependence $s^{-\gamma_0}$ at $t=0$ of the URD approach where $n$ is the number of the rearranged urbaryon ($\gamma_0 = 0.25 \sim 0.5$). Other features of (1) are similar to the $X$-type URD amplitude applied successfully to meson-baryon reactions\textsuperscript{3,4} except for some practical simplifications. The helicity change is neglected. The factors $\exp(\sigma t)$ and $\exp(\sigma u)$ are the simplest expressions representing smooth forms of the $X$-type amplitude. As we discussed in a previous letter,\textsuperscript{4} the URD may be connected to properties of hadronic forces with the $X_a$ force range shorter than the $X$ one ($B > B_d$).

Finally $f^X$ and $f^{Xa}$ are multiplied by constant factors, which are phenomenological here but to be given through the URD counting scheme.\textsuperscript{1,3}

From the antisymmetrization procedure $f_s = f_t(u, t) \pm f(u, t)$, where $+ (-)$ of the double signs specifies total spin $S=0(1)$, we obtain

$$f_s = A_s [s^{-\delta_1(t)} \exp(\sigma t) \pm s^{-\delta_1(u)} \exp(\sigma u)]$$

and

$$f_s = A_{s'} [s^{-\delta_1(t)} \exp(\sigma t) \pm s^{-\delta_1(u)} \exp(\sigma u)].$$

It is a general feature of the URD approach that $A_s$ is dominantly real negative. Note that the triplet amplitude, $f_1 \sim A_1 [s^{-\delta_1(t)} \exp(\sigma t) - r s^{-\delta_1(u)} \exp(\sigma u)]$ for $|t| < |u|$, can have a zero owing to the cancellation between the two terms.

From (2) together with $f^D$ we have for $\theta \leq 90^\circ$

$$\frac{d\sigma}{dt} = (1/4) |f_0|^2 + (3/4) |f_1|^2 + (\sigma t)^2 \exp(2\sigma t)/16\pi.$$

By neglecting small interference terms, (3) leads at $\theta = 90^\circ$ to

$$\frac{d\sigma}{dt}|_{90^\circ} = |A_0|^2 s^{-\gamma_0} \exp(-4Bk^2)$$

and

$$|A_{s'}|^2 s^{-\gamma_0} \exp(-4Bk^2).$$

Measurement of the real-imaginary ratio $\alpha_0$ at $t=0$ indicates $A_0 \sim A_1$ within about $30\%$. There are many sets of parameters to reproduce qualitative experimental features.
The typical one is as follows: $A_0 = -2.5$, $A_{g_0} = -20.4 \times 10^{-13} \text{cm/GeV}$; $B = 0.396$, $B_g = 0.035 \times 10^{-13} \text{cm/GeV}$; $B_a = 0.035 \times 10^{-12}$; $G_2(0) = 0.5$, $G_4(0) = 2$; $G_2' = 0.5$, $G_4' = 0.35 \times 10^{-2}$ (the unit of $s$ being 1 GeV$^2$). The real-imaginary ratio $\alpha$ with $|\alpha| \sim x^{-1/2}$ is quantitatively reproduced. The first and second slopes of $\frac{d\alpha}{d\theta}|_{90^\circ}$ in Fig. 2 come from the $X$ and $X_a$ terms of (4) respectively. At $P_L \sim 8 \text{ GeV/c}$, they are comparable and interfere constructively in agreement with experiment since both $A_0$ and $A_{g_0}$ are real negative.

Our amplitudes reproduce $\frac{d\alpha}{d\theta}$ over all angles within a factor of about five. In particular, an interesting shoulder-like structure in $\frac{d\alpha}{d\theta}$ developing rapidly between 7 and 10 GeV/c at $-t \sim 1.2 \text{ GeV}^2$ was observed by Allaby et al. Because of the zero of $f_1$ due to the antisymmetrization mentioned before, the onset of the similar structure takes place for $P_L \geq 8 \text{ GeV/c}$ where $f^{Xa}$ dominates over $f^X$. This is shown in Fig. 3 where, following Allaby, the normalized cross section $X = (\frac{d\alpha}{d\theta}) / (\frac{d\alpha}{d\theta})_{90^\circ}$ divided by $G^4(t) \ [G(t) = (1 - t/0.71)^{-1}$ being the dipole form factor] is plotted. Figure 3 exhibits a pattern of the structure similar to the experimental one (Fig. 2 in Ref. 6)). Unfortunately, the structure occurs at $-t \sim 6 \text{ GeV}^2$ by our parameters. This position is changeable because of the delicate cancellation to yield the zero of $f_1$, but could not move to as small as $-t \sim 1.2 \text{ GeV}^2$ within the form (1).

Thus our tentative parametrization of $f^X$ and $f^{Xa}$ is too simple to quantitatively explain the structure position as well as the pure exponential damping of $\frac{d\alpha}{d\theta}|_{90^\circ}$. We would like to stress, however, that the shoulder-like structure is a natural consequence peculiar to $p-p$ channel from our model. It should not appear in other $X$-type channels such as $K^*-p$ where $f^{Xa}$ is absent and $f^X$ is the antisymmetrization is unnecessary. The dip-bump structure in $\frac{d\alpha}{d\theta}$ ($\bar{p}p, K^-p, \pi^+p$) originates from a completely different mechanism of the $H$ type ($s-t$ dual) URD interaction$^{1,2,7}$.

Fig. 2.

Fig. 3.