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GLAUBER REPRESENTATION AND HIGH-ENERGY ELASTIC pp-SCATTERING

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1. INTRODUCTION

At present it is generally accepted that the hadron is a composite system of quarks and gluons. However, how this composite system manifests itself in the interactions of hadrons and in particular, in high-energy elastic scattering processes cannot yet be answered uniquely.

Recent experiments on the elastic pp -scattering[1-4] indicate the existence of the continuous structure of the differential cross section $d\sigma/dt$ (a sharp peak "forward", a "dip" at $|t| \sim 1.3-1.5$ $(GeV/c)^2$, the second maximum at $|t| \sim 1.8$ $(GeV/c)^2$ with a sufficiently smooth behaviour at $|t| \gtrsim 2$ $(GeV/c)^2$ and so on).

This complex system of differential cross sections naturally seems to be a reflection of the composite structure of hadrons.

We consider a hadron as a loose composite system of a final number of "dressed" valence quarks[5,6].

Within this approach the hadron becomes similar to the nucleus, thus it is natural to apply the Glauber representation[7] to the description of hadron-hadron interactions[8-18]. A possibility of explaining the complex structure of the hadron-hadron scattering cross section without assuming the existence of an analogous dependence for the quark-quark scattering amplitude is an attractive feature of this approach.

Unfortunately, in the standard Glauber representation, certain important characteristics of interactions at high energies are not taken into account

- the nucleon recoil effect is not taken into account; the momentum dependence of the wave function is absent at all;
- a spherical-symmetric form of the wave function is not consistent with the representation of a hadron as an oblate disk.

In our previous paper[12] we have proposed a modification of the Glauber representation accounting for the above remarks. Instead of the Gaussian wave function, corresponding to the non-relativistic harmonic oscillator[12], we have proposed the wave function of the four-dimensional relativistic harmonic oscillator depending explicitly on hadron momentum and allowing for the relativistic "flattering" and recoil effects, the hadron form factor having a power automodel asymptotics at large momentum transfers. The provisional description of $d\sigma/dt$ using the first five Glauber terms[19] indicates a possibility of improving essentially the agreement between theory and experiment.

In this paper we use a generalization of our model (using all Glauber expansion terms) for describing the data on the differential cross sections, $\rho(0) = \mathrm{Re}\,T/\mathrm{Im}\,T|_{t=0}$, $\sigma_{tot}(s)$, and $B(s) = d/dt(\ln d\sigma/dt)|_{t=0}$ in the elastic pp-scattering at $23.4 \le \sqrt{s} \le 62.1$ GeV.

2. COMPOSITE PARTICLE SCATTERING

Consider the scattering of two protons in the c.m.s. with momenta p_A, p_B before collision and p_C, p_D after it; also

$$\vec{p}_A + \vec{p}_B = \vec{p}_C + \vec{p}_D = 0.$$

Now we choose the system of coordinates so that transfer in perpendicular to axis Z

$$\vec{\Delta} = \vec{p}_C - \vec{p}_A = \vec{p}_B - \vec{p}_D = (\vec{\Delta}_\perp, 0),$$
$$t = -\vec{\Delta}^2$$

$s = (p_A + p_B)^2 = (p_C + p_D)^2$ is the square of the total energy of colliding particles.

This process can schematically be represented as follows:

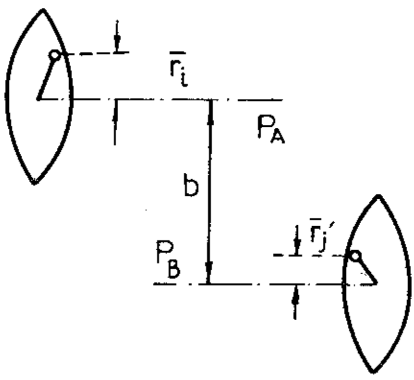

Fig.1

$b = |\vec{b}|$ is the distance between the centers of mass of colliding protons in the impact parameter plane, and $\vec{r}_i(\vec{r}_j')$ are relative coordinates of i-th (j-th) quark in the impact parameter plane (assume that $\vec{r}_i = (\vec{r}_{\perp i}, 0); \vec{r}_j' = (\vec{r}_{\perp j}', 0)$). The Glauber representation for the scattering amplitude of composite systems has the form

$$T_{fi}(s, \vec{\Delta}_\perp) = \frac{i}{2\pi} \int d^2\vec{b}\, e^{i\vec{\Delta}_\perp \vec{b}} \langle f | \Gamma_{tot}(s, \vec{b}, \dots) | i \rangle, \quad (1)$$

where

$$|i\rangle \equiv |i,A\rangle\,|i,B\rangle = \Psi_A \Psi_B ;$$
$$|f\rangle \equiv |f,C\rangle\,|f,D\rangle = \Psi_C \Psi_D \qquad (2)$$

are the wave functions of the three-quark systems depending on the relative variables (ξ,ζ) and (ξ',ζ'), respectively, before and after collision *. $\Gamma_{tot} = \Gamma_{tot}(s,\vec{b},\{\vec{r}_i\},\{\vec{r}_j'\})$ is the total profile function, which is

$$\Gamma_{tot} = 1 - \exp\{\sum_{i,j} \chi_{ij}(s,\vec{b}+\vec{r}_i-\vec{r}_j')\} \equiv 1 - \prod_{i,j=1}^{3}\{1-\Gamma_{ij}(s,\vec{b}+\vec{r}_i-\vec{r}_j')\},$$

where $\Gamma_{ij} = 1-\exp\{\chi_{ij}(s,\vec{b}+\vec{r}_i-\vec{r}_j')\}$ is the profile function corresponding to the scattering of the i-th quark of one proton on the j-th quark of the other proton.

The profile function Γ_{ij} is related to the quark-quark scattering amplitude by

$$T_{q_i q_j}(s,\vec{q}) = \frac{i}{2\pi}\int d^2\vec{b}\, e^{i\vec{\Delta}_\perp \vec{b}}\, \Gamma_{ij}(s,\vec{b}),$$
$$\Gamma_{ij}(s,\vec{b}) = -\frac{i}{2\pi}\int d^2\vec{q}\, e^{-i\vec{\Delta}_\perp \vec{b}}\, T_{q_i q_j}(s,\vec{q}). \qquad (3)$$

The normalization of the proton-proton scattering amplitude is chosen in the form

$$\frac{d\sigma}{dt} = \pi\cdot|T_{fi}(s,t)|^2$$

$$\sigma_{tot} = 4\pi\cdot \mathrm{Im}\, T_{fi}(s,t=0).$$

Averaging $\langle f|\Gamma_{tot}(s,\vec{b},..)|i\rangle$ implies integration over relative coordinates of hadron constituents.

According to the modification of the Glauber representation, suggested in ref. [19], the wave functions Ψ depend on the four-dimensional variables $\xi_\mu, \zeta_\mu, p_\mu (\mu=0,1,2,3)$ rather than on the three-dimensional ones and are invariant (in the case of spinless constituents) with respect to the Lorentz transformations, i.e., in the general case

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* The relative variables ξ_μ, ζ_μ are connected with the quark coordinates $x_{\mu i} \equiv (t_i,\vec{r}_i)$ as follows:

$$\xi_\mu = \frac{1}{2\sqrt{3}}(x_2-x_3)_\mu ; \quad \zeta_\mu = \frac{1}{6}(x_2+x_3-2x_1)_\mu .$$

The center mass coordinate of a hadron R_μ is $\frac{1}{3}(x_1+x_2+x_3)_\mu$.

$$\Psi(\xi,\zeta;p)=\Psi(\xi^2;\zeta^2;\xi p;\zeta p;\xi\zeta),$$

and the quantity $\langle f|\Gamma_{tot}|i\rangle$ has the form

$$\langle f|\Gamma_{tot}|i\rangle=\int d^4\xi d^4\zeta d^4\xi' d^4\zeta' \Psi^*_C(\xi,\zeta;p_C)\Psi^*_D(\xi',\zeta';p_D)\times$$
$$\times\Gamma_{tot}(s,\vec{b},\ldots)\Psi_A(\xi,\zeta;p_A)\Psi_B(\xi',\zeta',p_B). \tag{4}$$

Thus, the effect of the so-called "flattening" and the nucleon recoil in scattering are taken into account.

Inserting (4) into (1) and then expanding the amplitude in powers of Γ_{ij}, we get the Glauber expansion

$$T_{fi}=T^{(1)}+T^{(2)}+\ldots+T^{(9)}, \tag{5}$$

where

$$T^{(i)}=\frac{i}{2\pi}\int d^2\vec{b}e^{i\vec{\Delta}\vec{b}}\int d^4\xi d^4\zeta d^4\xi' d^4\zeta' \Psi^*_C(\xi,\zeta,p_C)\Psi^*_D(\xi',\zeta';p_D)\times \tag{6}$$
$$\times\Gamma^{(i)}(s,\vec{b},\ldots)\Psi_A(\xi,\zeta;p_A)\Psi_B(\xi',\zeta';p_B).$$

and

$$\Gamma^{(1)}=\sum_{(ij)}\Gamma_{ij}(s,\vec{b}+\vec{r}_i-\vec{r}'_j),$$
$$\Gamma^{(2)}=\sum_{\substack{(ij)\\(kl)}}{}'\Gamma_{ij}(s,\vec{b}+\vec{r}_i-\vec{r}'_j)\Gamma_{k\ell}(s,\vec{b}+\vec{r}_k-\vec{r}'_\ell), \tag{7}$$
$$\Gamma^{(3)}=\sum_{\substack{(ij)\\(k\ell)\\(mn)}}{}'\Gamma_{ij}(s,\vec{b}+\vec{r}_i-\vec{r}'_j)\Gamma_{k\ell}(s,\vec{b}+\vec{r}_k-\vec{r}'_\ell)\Gamma_{mn}(s,\vec{b}+\vec{r}_m-\vec{r}'_n),$$

and so on. The prime over Σ implies that none of the pairs of numbers (ij), (kℓ), (mn), etc., coincides while summing (see Fig.2).

As a natural extension of nonrelativistic Gaussian wave function, we choose $\Psi(\xi,\zeta;p)$ of the form

$$\Psi(\xi,\zeta;p)=\frac{\sqrt{2\lambda-1}}{(2\pi a)^2}\cdot e^{\frac{1}{4a}\{\xi^2-2\lambda\cdot\frac{(\xi p)^2}{m^2}+\zeta^2-2\lambda\cdot\frac{(\zeta p)^2}{m^2}\}} \tag{8}$$

normalized by the condition

$$\int d^4\xi d^4\zeta\Psi^2(\xi,\zeta;p)=1.$$

At $\lambda=1$ the wave functions (8) are the solutions of equation with a potential of the 4-dimensional relativistic oscillator.

The wave functions of the form (8) are widely used to describe the baryon properties (see, for example, refs. [21,24]). Following paper [22], we define the proton formfactors as

$$F(q^2) = \int d^4\xi\, d^4\zeta\, e^{iq(x_i - R)}\, \Psi^*_C(\xi,\zeta;p_C)\,\Psi_A(\xi,\zeta;p_A),$$

$$\vec{q} \equiv \vec{q}_\perp = \vec{p}_C - \vec{p}_A, \quad t = -\vec{q}^{\,2}. \tag{9}$$

Inserting (8) into (9) gives

$$F(t) = \Gamma(t)\cdot e^{2a\cdot\Gamma_1(t)\cdot t}, \quad \Gamma(t) = \Gamma_1(t)\cdot\Gamma_2(t),$$

$$\Gamma_1(t) = \left(1 - \lambda\frac{t}{2m^2}\right)^{-1}, \quad \Gamma_2(t) = \left(1 - \frac{\lambda}{2\lambda - 1}\,\frac{t}{2m^2}\right)^{-1}. \tag{10}$$

Note, that the form factor (10) at small transfer momenta falls off exponentially with increasing $|t|$;whereas at large $|t|$, as $|t|^{-2}$, that is in agreement with the predictions of the automodel behaviour of the form factor [20].

The parameter a defines the form factor slope at zero transfer momenta and may be calculated by using the data on electromagnetic proton form factor [25,26]. We emphasize here that the identification of expression (10) derived in our scalar model with the real nucleon form factor is possible only under the scaling relation:

$$G^p_E(q^2) \approx \frac{1}{\mu}\, G^p_M(q^2),$$

where G^p_E and G^p_M are the Sachs form factors. This relation is valid for rather small q^2 ($|q^2| \lesssim 1.5$ $(\mathrm{GeV/c})^2$).

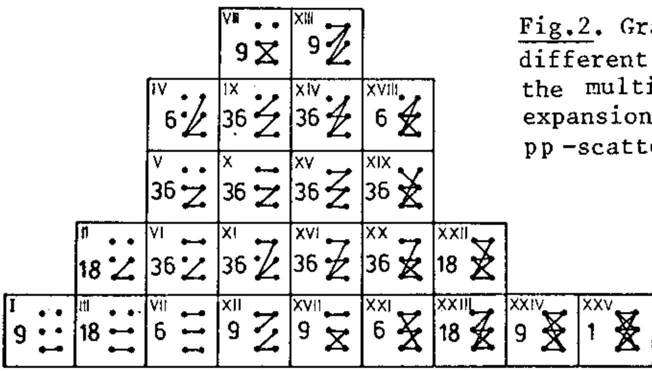

Fig.2. Graphic picture of different structures in the multiple scattering expansion terms of pp -scattering.

3. DESCRIPTION OF EXPERIMENTAL DATA

We get a combined description of the data on differential cross sections of the elastic pp-scattering at energies from $\sqrt{s} = 23.4$ to $\sqrt{s} = 62.1$ GeV [2]. The measured range of transfer

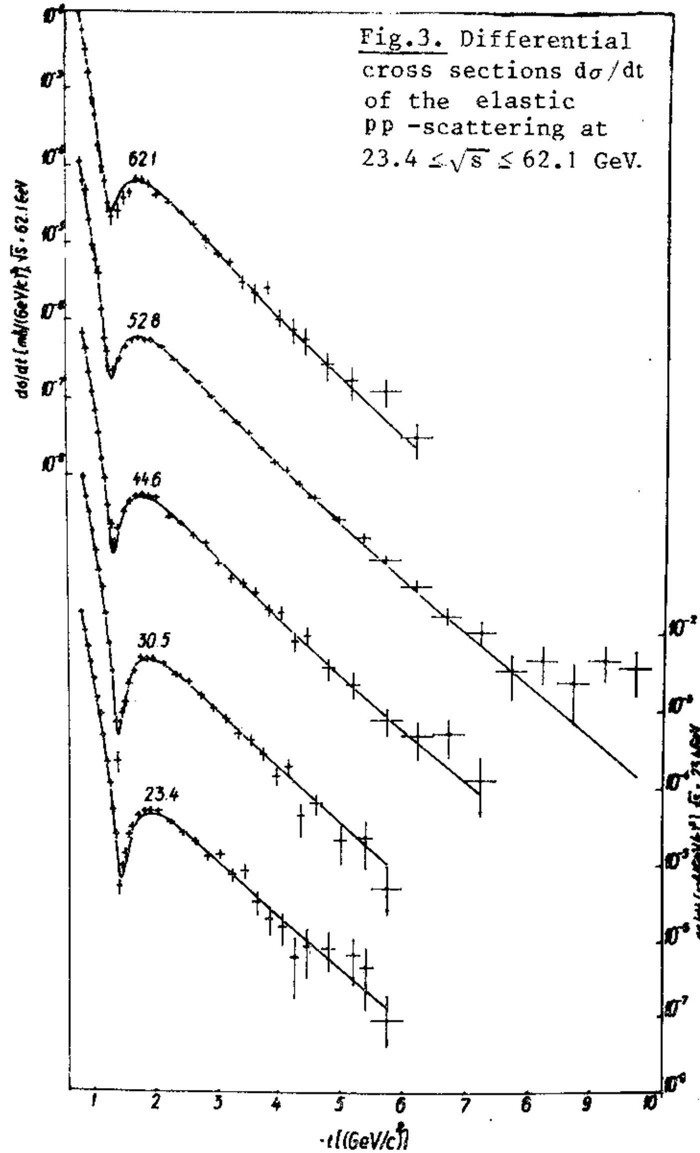

Fig.3. Differential cross sections $d\sigma/dt$ of the elastic pp-scattering at $23.4 \le \sqrt{s} \le 62.1$ GeV.

Table 1

$(\frac{GeV}{c})^2$	t = 0		t = t_{dip}		|t| = 10.	
$(\frac{GeV}{c})^{-2}$	$ImT^{(i)}$	$ReT^{(i)}$	$ImT^{(i)}$	$ReT^{(i)}$	$ImT^{(i)}$	$ReT^{(i)}$
$T^{(1)}$	9.05	0.957	0.062	$0.65*10^{-2}$	$3*10^{-6}$	$3*10^{-7}$
$T^{(2)}$	-2.89	-0.618	$-1.03*10^{-1}$	$-2.21*10^{-2}$	-1.06×10^{-4}	$-2.27*10^{-5}$
$T^{(3)}$	0.74	0.242	0.058	$1.91*10^{-2}$	$2.01*10^{-4}$	$6.56*10^{-5}$
$T^{(4)}$	-0.19	-0.086	-0.023	$-1.03*10^{-2}$	$-1.71*10^{-4}$	$-7.66*10^{-5}$
$T^{(5)}$	0.05	0.027	$8*10^{-3}$	$0.44*10^{-2}$	$0.99*10^{-4}$	$5.73*10^{-5}$
$T^{(6)}$	$-1*10^{-2}$	$-8*10^{-3}$	$-2*10^{-3}$	$-0.16*10^{-2}$	$-0.43*10^{-4}$	$-3.14*10^{-5}$
$T^{(7)}$	$2*10^{-3}$	$2*10^{-3}$	$5*10^{-4}$	$5*10^{-4}$	$0.14*10^{-4}$	$1.27*10^{-5}$
$T^{(8)}$	$-4*10^{-4}$	$-4x10^{-4}$	$-1*10^{-4}$	$-1*10^{-4}$	$-3*10^{-6}$	$-0.34*10^{-5}$
$T^{(9)}$	$4*10^{-5}$	$5*10^{-5}$	$9*10^{-6}$	$1*10^{-5}$	$3*10^{-7}$	$4*10^{-7}$
$\sum$	6.75	0.516	$-2.89*10^{-4}$	$-3.53*10^{-3}$	$-6.85*10^{-6}$	$2.25*10^{-6}$

In Table 1 the values of real and imaginary Glauber amplitudes at $t=0$, $t=t_{dip}$, $|t|=10$, are presented.

momenta is $0.8 \lesssim |t| \lesssim 10$ $(GeV/c)^2$. The quark-quark scattering amplitude has been taken in the form

$$T_{qq}(s,t)=\frac{i}{4\pi}[\alpha(s)+i\beta(s)]e^{b(s)\cdot t} \quad . \tag{11}$$

By using formulae (5)-(11), one may calculate explicitly the analytic expressions for the Glauber amplitudes $T^{(1)},T^{(2)}...T^{(9)}$. A full form of all nine Glauber amplitudes is shown in Appendix. The quark-quark amplitude of the form (11) allows one to get a good description of the data from ref. [2] (see Fig.3). The theoretical curves reproduce all the peculiarities of the structure of differential cross sections at above indicated energies and momentum transfers. The obtained values of the parameter are

$$\alpha(s)=(12.64 \pm 0.55)+(1.03 \pm 0.30)\cdot \ln\frac{\sqrt{s}}{\sqrt{s_0}}(\text{ GeV/c})^{-2},$$

$$\beta(s) = (-0.751 \pm 0.040) + (1.54 \pm 0.30) \cdot \ln \frac{\sqrt{s}}{\sqrt{s'}} \,(\mathrm{GeV}/c)^{-2},$$

$$b(s) = (0.250 \pm 0.025) + (0.175 \pm 0.023) \cdot \ln \frac{\sqrt{s}}{\sqrt{s_0}} \,(\mathrm{GeV}/c)^{-2},$$

$$\sqrt{s_0} = 52.8\ \mathrm{GeV}, \quad \sqrt{s'} = (28.49 \pm 1.55)\ \mathrm{GeV},$$

$$a = (0.71 \pm 0.04) \quad (\mathrm{GeV}/c)^{-2},$$

$$\lambda = 0.84 \pm 0.05.$$

Let us sum up the results of this paper. In the framework of our model with the wave functions of the type of relativistic oscillator wave functions, we succeeded in describing consistently the differential cross sections of pp-scattering both at large and small $|t|$, that encounters difficulties within the Glauber approach. The values of $\rho(0)$, $B(s)$ and $\sigma_{tot}(s)$ calculated at the obtained values of the parameters, are in satisfactory agreement with the experimental data, all the terms of the Glauber expansion being taken into account (see Table 2). The numerical values of the Glauber amplitudes, presented in Table 1, show that at $|t|\sim 0$ $T^{(1)}$ gives the main contribution to the pp-scattering ampltude, though the rest Glauber amplitudes should also be taken into account.

In conclusion the authors are deeply indebted to A.N.Tavkhelidze and V.A.Matveev for valuable remarks.Thanks are also to S.V.Goloskokov, N.P.Zotov, A.V.Koudinov, A.S.Pak, A.N.Sissakian, N.B.Skachkov and A.V.Tarasov for useful discussions.

Table 2

$\sqrt{s}$ GeV	23.4	30.5	44.6	52.8	62.1
$\sigma^{th}_{tot}(s)/\sigma^{exp}_{tot}(s)$	0.81	0.78	0.78	0.80	0.76
$\rho^{th}(0)$	0.049	0.045	0.0615	0.0765	0.095
$\rho^{exp}(0)$	0.02±0.05	0.042±0.011	0.062±0.011	0.078±0.010	0.095±0.011
$B^{th}(\rho)(\frac{GeV}{c})^{-2}$	11.72	11.82	11.96	12.02	12.09
$B^{exp}(s)(\frac{GeV}{c})^{-2}$	11.8±0.2	12.10±0.11	12.92±0.12	12.97±0.13	13.05± 0.14

The data are from refs. /1-4/. Table 2 presents the values of $\rho(0) = \mathrm{Re}\,T/\mathrm{Im}\,T|_{t=0}$, the peak slope at zero $B(s) = \frac{d}{dt}(\ln \frac{d\sigma}{dt})|_{t=0}$ and of $\sigma_{tot}(s)$ predicted in our model, and the experimental data of these quantities.

APPENDIX

$$T^{(1)} = 9i \frac{\alpha + i\beta}{4\pi} \Gamma^2 \exp[b + 4a\Gamma_1]t;$$

$$T^{(2)} = -\frac{9}{2} i\left(\frac{\alpha+i\beta}{4\pi}\right)^2 \Gamma^2 \left\{ \frac{1}{\sqrt{D_1}} \exp[\frac{b}{2} + \frac{5}{2} a\Gamma_1]t + \frac{1}{\sqrt{D_2}} \exp[\frac{b}{2} + a\Gamma_1]t \right\}$$

$$D_1 = (b+3a)(b+3a\Gamma_1); \quad D_2 = (b+6a)(b+6a\Gamma_1);$$

$$T^{(3)} = \frac{1}{2} i\left(\frac{\alpha+i\beta}{4\pi}\right)^3 \Gamma^2 \left\{ \frac{1}{D_2} \exp\frac{b}{3} t + \frac{6}{\sqrt{D_1 D_3}} \exp[\frac{b}{3} + \frac{2}{3} a\Gamma_1 - \frac{2(a\Gamma_1)^2}{b+7a\Gamma_1}]t + \right.$$

$$\left. + \frac{1}{D_1} \exp[\frac{b}{3} + 2a\Gamma_1]t + \frac{6}{\sqrt{D_4 D_2}} \exp[\frac{b}{3} + \frac{4}{3} a\Gamma_1 - \frac{2(a\Gamma_1)^2}{b+2a\Gamma_1}]t \right\}$$

$$D_3 = (b+7a)(b+7a\Gamma_1); \quad D_4 = (b+2a)(b+2a\Gamma_1).$$

$$T^{(4)} = -\frac{9}{32} i\left(\frac{\alpha+i\beta}{4\pi}\right)^4 \Gamma^2 \left\{ \frac{1}{bD_2} \exp[\frac{b}{4} + a\Gamma_1]t + \right.$$

$$+ \frac{8}{\sqrt{D_1 D_1^{\circ} D_1^1}} \exp[\frac{b}{4} + a\Gamma_1 - \frac{9}{4} \frac{(b+6a\Gamma_1)(a\Gamma_1)^2}{D_1^1}]t +$$

$$+ \frac{8}{\sqrt{D_5 D_2^{\circ} D_2^1}} \exp[\frac{b}{4} + \frac{5}{8} a\Gamma_1 - \frac{9}{8} \frac{(a\Gamma_1)^2}{2b + 9a\Gamma_1}]t +$$

$$+ \frac{8}{\sqrt{D_2 D_1^{\circ} D_1^1}} \exp[\frac{b}{4} + \frac{1}{4} a\Gamma_1 - \frac{9}{4} \frac{(b+3a\Gamma_1)(a\Gamma_1)^2}{D_1^1}]t +$$

$$\left. + \frac{1}{D_1\sqrt{D_6}} \exp[\frac{b}{4} + \frac{1}{4} a\Gamma_1]t \right\}$$

$$D_1^{\circ} = 3(b+3a)^2 - b^2; \quad D_1^1 = 3(b+3a\Gamma_1)^2 - b^2;$$

$$D_5 = (2b+9a)(2b+9a\Gamma_1); \quad D_6 = (6+9a)(b+9a\Gamma_1);$$

$$D_2^{\circ} = (b+3a)(2b+3a)-b^2; \quad D_2^1 = (b+3a\Gamma_1)(2b+3a\Gamma_1)-b^2;$$

$$T^{(5)} = \frac{9}{16} i \left(\frac{\alpha+i\beta}{4\pi}\right)^5 \Gamma^2 \Big\{ \frac{1}{D_1\sqrt{D_6 D_7}} \exp\Big[\frac{b}{5} + \frac{16}{25} a\Gamma_1 - \frac{144}{25}\frac{(a\Gamma_1)^2}{5b+9a\Gamma_1}\Big]t +$$

$$+ \frac{4}{b\sqrt{D_2 D_3^{\circ} D_3^1}} \exp\Big[\frac{b}{5} + \frac{16}{25} a\Gamma_1 - \frac{54}{25}\frac{(b+7a\Gamma_1)(a\Gamma_1)^2}{D_3^1}\Big]t +$$

$$+ \frac{4}{\sqrt{D_2^{\circ} D_2^1 D_4^{\circ} D_4^1}} \exp\Big[\frac{b}{5} + \frac{2}{5} a\Gamma_1 - \frac{18}{5}\frac{(2b+9a\Gamma_1)(a\Gamma_1)^2}{D_4^1}\Big]t +$$

$$+ \frac{4}{\sqrt{D_1 D_6 D_5^{\circ} D_5^1}} \exp\Big[\frac{b}{5} + \frac{4}{25} a\Gamma_1 - \frac{54}{25}\frac{(b+2a\Gamma_1)(a\Gamma_1)^2}{D_5^1}\Big]t +$$

$$+ \frac{1}{bD_2\sqrt{D_8}} \exp\Big[\frac{b}{5} + \frac{4}{25} a\Gamma_1 - \frac{144}{25}\frac{(a\Gamma_1)^2}{56+36a\Gamma_1}\Big]t \Big\}$$

$$D_7 = (5b+9a)(5b+9a\Gamma_1); \quad D_8 = (5b+36a)(5b+36a\Gamma_1).$$

$$D_3^{\circ} = 6(b+3a)(b+6a)-b^2$$

$$D_3^1 = 6(b+3a\Gamma_1)(b+6a\Gamma_1)-b^2$$

$$D_4^{\circ} = 3(b+3a)(2b+9a)-b^2.$$

$$D_4^1 = 3(b+3a\Gamma_1)(2b+9a\Gamma_1)-b^2$$

$$D_5^{\circ} = 9(b+a)(b+3a)-4b^2$$

$$D_5^1 = 9(b+a\Gamma_1)(b+3a\Gamma_1)-4b^2$$

$$T^{(6)} = -\frac{1}{32} i \left(\frac{\alpha + i\beta}{4\pi}\right)^6 \Gamma^2 \Big\{ \frac{1}{b D_1 D_6} \exp \frac{b}{6} t +$$

$$+ \frac{6}{b\sqrt{D_1 D_6 D_6^\circ D_6^1}} \exp\left[\frac{b}{6} + \frac{1}{3} a\Gamma_1 - \frac{1}{6} \frac{(5b + 36 a\Gamma_1)(a\Gamma_1)^2}{D_6^1} \right] t +$$

$$+ \frac{1}{b^2 D_2 \sqrt{D_6}} \exp\left[\frac{b}{6} + \frac{1}{2} a\Gamma_1 \right] t +$$

$$+ \frac{6}{b\sqrt{D_2 D_6 D_7^\circ D_7^1}} \exp\left[\frac{b}{6} + \frac{1}{6} a\Gamma_1 - \frac{1}{6} \frac{(5b + 9a\Gamma_1)(a\Gamma_1)^2}{D_7^1} \right] t \Big\}$$

$D_6^\circ = b^2 + 10 b \cdot a + 18 a^2$; $\qquad D_6^1 = b^2 + 10 b a \Gamma_1 + 18 (a\Gamma_1)^2$;

$D_7^\circ = b^2 + 8 b \cdot a + 9 a^2$; $\qquad D_7^1 = b^2 + 8 b \cdot a\Gamma_1 + 9 (a\Gamma_1)^2$;

$$T^{(7)} = \frac{9}{32} i \left(\frac{\alpha + i\beta}{4\pi}\right)^7 \Gamma^2 \Big\{ \frac{1}{b^2 D_6 \sqrt{D_2 D_9}} \exp\left[\frac{b}{7} + \frac{10}{49} a\Gamma_1 - \frac{180}{49} \frac{(a\Gamma_1)^2}{7b + 18 a\Gamma_1} \right] t +$$

$$+ \frac{1}{b^2 D_6 \sqrt{D_1 D_{10}}} \exp\left[\frac{b}{7} + \frac{4}{49} a\Gamma_1 - \frac{180}{49} \frac{(a\Gamma_1)^2}{7b + 45 a\Gamma_1} \right] t \;;$$

$D_9 = (7b + 18 a)(7b + 18 a\Gamma_1)$; $\qquad D_{10} = (7b + 45 a)(7b + 45 a\Gamma_1)$;

$$T^{(8)} = -\frac{9}{512} i \left(\frac{\alpha + i\beta}{4\pi}\right)^8 \Gamma^2 \frac{\exp\left[\frac{b}{8} + \frac{1}{16} a\Gamma_1 - \frac{9}{16} \frac{(a\Gamma_1)^2}{2b + 9 a\Gamma_1} \right] t}{b^3 D_6 \sqrt{D_5 D_6}}$$

$$T^{(9)} = \frac{1}{2304} i \left(\frac{\alpha + i\beta}{4\pi}\right)^9 \Gamma^2 \frac{\exp \frac{b}{9} t}{b^4 D_6 D_6}.$$

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