Note 227(1) Relativistic Quantization of Particle Scattering Theory by

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[1] Civil List and AIAS.

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Consider the conservation of energy momentum:

$$p_1^\mu + p_2^\mu = p_3^\mu + p_4^\mu \tag{1}$$

This equation can be applied to scattering an reaction theory with transmutation. Note carefully that energy momentum is always conserved by definition. The basics of the theory rest on the relativistic momentum:

$$\mathbf{p} = \gamma m \mathbf{v} \tag{2}$$

where

$$\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-1/2} \tag{3}$$

From (2):

$$p^2c^2 = \gamma^2 m^2 v^2 c^2 = \gamma^2 m^2 c^4 \left(\frac{v^2}{c^2}\right) \tag{4}$$

From Eq. (3):

$$\frac{v^2}{c^2} = 1 - \frac{1}{\gamma^2} \tag{5}$$

so

$$\begin{aligned} p^2c^2 &= \gamma^2 m^2 c^4 \left(1 - \frac{1}{\gamma^2}\right) \\ &= \gamma^2 m^2 c^4 - m^2 c^4 \\ &= E^2 - E_o^2 \end{aligned} \tag{6}$$

so

$$E^2 = p^2c^2 + E_o^2 \tag{7}$$

where

$$E = \gamma mc^2, E_o = mc^2 \tag{8}$$

The Einstein energy equation (7) is a direct consequence of the relativistic momentum (2) This method is now applied to Eq. (1) as follows:

$$\begin{aligned} (\mathbf{p}_1 + \mathbf{p}_2)\cdot(\mathbf{p}_1 + \mathbf{p}_2) &= \mathbf{p}_1\cdot\mathbf{p}_1 + \mathbf{p}_2\cdot\mathbf{p}_2 + 2\mathbf{p}_1\cdot\mathbf{p}_2 \\ &= p_1^2 + p_2^2 + 2p_1p_2cos\theta \end{aligned} \tag{9}$$

this method introduces scattering theory. Therefore:

$$\begin{aligned} c^2(\mathbf{p}_1 + \mathbf{p}_2)\cdot(\mathbf{p}_1 + \mathbf{p}_2) &= c^2p_1^2 + c^2p_2^2 + 2p_1p_2c^2cos\theta \\ &= E_1^2 + E_2^2 - (m_1^2 + m_2^2)c^4 + 2p_1p_2c^2cos\theta \end{aligned} \tag{10}$$

Rearranging gives:

$$E_1^2 + E_2^2 = c^2(\mathbf{p}_1 + \mathbf{p}_2) \cdot (\mathbf{p}_1 + \mathbf{p}_2) - 2p_1p_2c^2cos\theta + (m_1^2 + m_2^2)c^4 \tag{11}$$

In this equation:

$$p_1^2 = \frac{1}{c^2}(E_1^2 - m_1^2c^4) \tag{12}$$

$$p_2^2 = \frac{1}{c^2}(E_2^2 - m_2^2c^4) \tag{13}$$

Therefore:

$$\begin{aligned} p_1p_2 &= \frac{1}{c^2}\left((E_1^2 - m_1^2c^4)(E_2^2 - m_2^2c^4)\right)^{1/2} \\ &= \frac{1}{c^2}\left((E_1 - m_1c^2)(E_1 + m_1c^2)(E_2 - m_2c^2)(E_2 + m_2c^2)\right)^{1/2} \end{aligned} \tag{14}$$

These equations can be expressed as:

$$p_1^2 = (\gamma_1^2 - 1)m_1^2c^2 \tag{15}$$

$$p_2^2 = (\gamma_2^2 - 1)m_2^2c^2 \tag{16}$$

From Eqs (11), (15) and (16):

$$\begin{aligned} E_1^2 + E_2^2 = {} & c^2(\mathbf{p}_1 + \mathbf{p}_2) \cdot (\mathbf{p}_1 + \mathbf{p}_2) \\ & - 2(\gamma_1^2 - 1)^{1/2}(\gamma_2^2 - 1)^{1/2}m_1m_2c^4cos\theta \\ & + (m_1^2 + m_2^2)c^4 \end{aligned} \tag{17}$$

The covariant formulation of this equation is:

$$(p_1^\mu + p_2^\mu)(p_{\mu 1} + p_{\mu 2}) = \frac{1}{c^2}(E_1 + E_2)^2 - (\mathbf{p}_1 + \mathbf{p}_2) \cdot (\mathbf{p}_1 + \mathbf{p}_2) \tag{18}$$

From Eqn (4):

$$\begin{aligned} (p_1^\mu + p_2^\mu)(p_{\mu 1} + p_{\mu 2}) &= \frac{1}{c^2}(E_1 + E_2)^2 - \left(\frac{E_1^2}{c^2} + \frac{E_2^2}{c^2} - (m_1^2 + m_2^2)\right)c^2 + 2p_1p_2cos\theta \\ &= (m_1^2 + m_2^2)c^2 + 2\left(\frac{E_1E_2}{c^2} - p_1p_2cos\theta\right) \end{aligned} \tag{19}$$

Now note that:

$$\begin{aligned} p_1^\mu p_{\mu 2} &= \frac{E_1E_2}{c^2} - \mathbf{p}_1 \cdot \mathbf{p}_2 \\ &= \frac{E_1E_2}{c^2} - p_1p_2cos\theta \end{aligned} \tag{20}$$

From Eqns (19) and (20):

$$(p_1^\mu + p_2^\mu)(p_{\mu 1} + p_{\mu 2}) = (m_1^2 + m_2^2)c^2 + 2p_1^\mu p_{\mu 2} \tag{21}$$

so

$$(p_1^\mu + p_2^\mu)(p_{\mu 1} + p_{\mu 2}) - 2p_1^\mu p_{\mu 2} = (m_1^2 + m_2^2)c^2 \tag{22}$$

i.e.

$$p_1^\mu p_{\mu 1} + p_2^\mu p_{\mu 2} + p_2^\mu p_{\mu 1} + p_1^\mu p_{\mu 2} + p_2^\mu p_{\mu 2} - 2p_1^\mu p_{\mu 2} = (m_1^2 + m_2^2)c^2 \tag{23}$$

Finally use:

$$p_1^\mu p_{\mu 2} = p_2^\mu p_{\mu 1} \tag{24}$$

to obtain:

$$\boxed{p_1^\mu p_{\mu 1} + p_2^\mu p_{\mu 2} = (m_1^2 + m_2^2)c^2 \qquad (25)}$$

which is the sum of two Einstein energy equations:

$$p_1^\mu p_{\mu 1} = m_1^2 c^2 \tag{26}$$

and

$$p_2^\mu p_{\mu 2} = m_2^2 c^2 \tag{27}$$

for two free and <u>non-interacting</u> particles. The equation for <u>interacting</u> particles is Eqn. (19):

$$\begin{aligned}(p_1^\mu + p_2^\mu)(p_{\mu 1} + p_{\mu 2}) &= \frac{(E_1 + E_2)^2}{c^2} - (\mathbf{p}_1 + \mathbf{p}_2) \cdot (\mathbf{p}_1 + \mathbf{p}_2) \\ &= (m_1^2 + m_2^2)c^2 + 2\left(\frac{E_1 E_2}{c^2} - p_1 p_2 cos\theta\right)\end{aligned} \tag{28}$$

where:

$$\begin{aligned}E_1 &= \gamma_1 m_1 c^2 \\ E_2 &= \gamma_2 m_2 c^2 \\ p_1 &= (\gamma_1^2 - 1)^{1/2} m_1 c \\ p_2 &= (\gamma_2^2 - 1)^{1/2} m_2 c\end{aligned} \tag{29}$$

Therefore:

$$\begin{aligned}(E_1 + E_2)^2 - c^2(\mathbf{p}_1 + \mathbf{p}_2) \cdot (\mathbf{p}_1 + \mathbf{p}_2) &= (m_1^2 + m_2^2)c^4 + 2(E_1 E_2 - p_1 p_2 c^2 cos\theta) \\ &= (m_1^2 + m_2^2)c^4 + 2\left(\gamma_1 \gamma_2 m_1 m_2 c^4 - \left((\gamma_1^2 - 1)(\gamma_2^2 - 1)\right)^{1/2} m_1 m_2 c_4 cos\theta\right)\end{aligned} \tag{30}$$

<u>This equation is suitable for factorization into a fermion equation, and is:</u>

$$\boxed{(E_1+E_2)^2-c^2(\mathbf{p}_1+\mathbf{p}_2)\cdot(\mathbf{p}_1\cdot\mathbf{p}_2)=(m_1^2+m_2^2)c^4+2m_1m_2c^4\left(\gamma_1\gamma_2-(\gamma_1^2-1)^{1/2}(\gamma_2^2-1)^{1/2}cos\theta\right)} \tag{31}$$

This can be written as:

$$\boxed{(E_1+E_2)^2-c^2(\mathbf{p}_1+\mathbf{p}_2)\cdot(\mathbf{p}_1+\mathbf{p}_2)=M^2c^4} \tag{32}$$

where:

$$\boxed{M^2=m_1^2+m_2^2+2m_1m_2\left(\gamma_1\gamma_2-(\gamma_1^2-1)^{1/2}(\gamma_2^2-1)^{1/2}cos\theta\right)} \tag{33}$$

is a varying mass term. Finally:

$$R:=\left(\frac{Mc}{\hbar}\right)^2 \tag{34}$$

is the R parameter of ECE theory