

4. THE ASPECT EXPERIMENT AND QUANTUM ENTANGLEMENT

In this section the Aspect experiment {49} and quantum entanglement {50} are developed as two examples of how ECE wave mechanics is applied to data. In the Aspect experiment two photons are emitted at the same time and are circularly polarized in opposite senses. The photons travel along different paths and filters define their orientations a and b, subtending between them the angle θ . Therefore a circularly polarized tetrad wave:

$$\underline{A}^{(1)} = \frac{A^{(0)}}{\sqrt{2}} (\underline{i} - i\underline{j}) e^{i\phi} \quad - (78)$$

is split into

$$\underline{A}_a^{(1)} = \frac{A^{(0)}}{\sqrt{2}} \underline{i} e^{i\phi} \quad - (79)$$

and

$$\underline{A}_b^{(1)} = -i \frac{A^{(0)}}{\sqrt{2}} \underline{j} e^{i\phi} \quad - (80)$$

if a and b are at right angles. A photo-multiplier tube detects either $\underline{A}_a^{(1)}$ or $\underline{A}_b^{(1)}$, one detector for $\underline{A}_a^{(1)}$ and one for $\underline{A}_b^{(1)}$. In the detector, +1 is registered for $\underline{A}_a^{(1)}$ and -1 for $\underline{A}_b^{(1)}$.

The ± 1 signals are collected on a coincidence counter. This procedure occurs for both the right circularly polarized tetrad wave:

$$\underline{A}_R^{(1)} = \frac{A^{(0)}}{\sqrt{2}} (\underline{i} - i\underline{j}) e^{i\phi} \quad - (81)$$

and the left circularly polarized tetrad wave:

$$\underline{A}_L^{(1)} = \frac{A^{(0)}}{\sqrt{2}} (\underline{i} + i\underline{j}) e^{i\phi} \quad - (82)$$

Therefore there are $A_{Ra}^{(1)}$, $A_{Rb}^{(1)}$, $A_{La}^{(1)}$ and $A_{Lb}^{(1)}$. The components $A_{Ra}^{(1)}$ and $A_{La}^{(1)}$ both register a +1 and $A_{Rb}^{(1)}$ and $A_{Lb}^{(1)}$ both register a -1.

This coincidence counter only accepts results if the time delay between receiving signals from the photo-multiplier tubes on sides A and B is less than a certain interval t . The latter is half the time it takes for a signal c to travel from one filter to the other. If an event occurs within the interval t the result on side A (+1 or -1) is multiplied by the result from side B and the average value found from repeated measurements. The average value is defined by the expectation value, which is the sum of all the resulting values multiplied by the probability for that value:

$$\langle P \rangle = P_{++} - P_{+-} - P_{-+} + P_{--} \quad (83)$$

The expectation value is a function of the filter orientation, or the angle θ between a and b. Here P_{++} is the probability that both detectors registered a + and P_{--} that both detectors registered a -. These probabilities are measured experimentally by recording the number of counts of a particular type and dividing this record by the total number of counts recorded. For example, P_{-+} is the number of times the left detector registered -1 at the same time as the right detector registered +1. The "same time" means "within the t interval".

Within the factor $A^{(0)}$ the quantities $A_{Ra}^{(1)}$, $A_{Rb}^{(1)}$, $A_{La}^{(1)}$ and $A_{Lb}^{(1)}$ are tetrads, or wave functions. So the Aspect experiment investigates the statistical properties of tetrad waves. By "statistical" is meant statistical averaging of causal wave-functions, which within $A^{(0)}$ are waves of spinning space-time. In generally covariant wave mechanics (ECE theory) the Aspect experiment is considered as follows. One filter detects linear polarization along the a direction, the other along the b direction. The expectation value is $\{4^9\}$:

$$\Omega = \cos 2\theta \quad (84)$$

and this is what is measured experimentally in the Aspect experiment. Thus ECE theory must be used to explain Eq. (84), the experimental result. From Eq. (64) the basic equation to be used is:

$$a_{\mu}^a(t_1, \underline{r}_1) = e^{iS/\hbar} a_{\mu}^a(t_2, \underline{r}_2). \quad - (85)$$

Now use the identity:

$$\cos 2\theta = \text{Re} \left(e^{i\theta} e^{2i\theta} e^{-i\theta} \right) \quad - (86)$$

and denote:

$$\psi = e^{i\theta}, \quad \psi^* = e^{-i\theta}, \quad - (87)$$

$$\Omega = e^{2i\theta}. \quad - (88)$$

It is found that:

$$\cos 2\theta = \psi \Omega \psi^*. \quad - (89)$$

This equation is similar to the definition { 48 } of expectation value in quantum mechanics:

$$\langle \Omega \rangle = \int \psi^* \Omega \psi dV / \int \psi^* \psi dV \quad - (90)$$

where V is a volume. Usually in quantum mechanics { 48 } the denominator in Eq. (90) is normalized to unity, so:

$$\int \psi^* \psi dV = 1. \quad - (91)$$

Therefore $(\cos 2\theta)/V$ in Eq. (89) is the density of expectation value. As in lagrangian dynamics and relativity theory it is the density that is the key quantity. In Eq. (90) the density of expectation value is a weighted sum of the eigenvalues of Ω { 48 }. The

wave function is expanded as the sum:

$$\psi = \sum_n c_n \psi_n \quad - (92)$$

where

$$\Omega \psi_n = \omega_n \psi_n. \quad - (93)$$

In the simple example of the identity (86) the wave function is:

$$\psi = e^{i\theta} \quad - (94)$$

and the eigenoperator Ω operates on the wave-function ψ :

$$\Omega = e^{2i\theta} \quad - (95)$$

So $(\cos 2\theta)/V$ is the density of the expectation value of Ω . A light wave is described by Eq. (50):

$$\psi(p_2) = \exp\left(2\pi i(x_2 - x_1)/\lambda\right) \psi(p_1). \quad - (96)$$

Now identify the angle θ as:

$$\theta = \pi(x_2 - x_1)/\lambda \quad - (97)$$

to obtain Eq. (50) in the form:

$$\psi(p_2) = e^{2i\theta} \psi(p_1). \quad - (98)$$

This is always true for any light wave. Quantization into photons occurs when the angle in

Eq. (9) is further identified as:

$$\theta = S/\hbar. \quad - (99)$$

In the special case:

$$\psi(P_1) = \psi^*(P_2) - (100)$$

we recover:

$$\cos 2\theta = \operatorname{Re}(\psi e^{2i\theta} \psi^*) = \operatorname{Re}(\psi \psi^*) - (101)$$

Finally apply this analysis to the tetrad propagation equation (85):

$$A_\mu^a = e^{iS/\hbar} A_\mu^a(0) - (102)$$

which within A_μ^a describes the propagation of the electromagnetic potential and photon simultaneously. The Planck Einstein and de Broglie equations are recovered by identifying the electromagnetic phase with quantized action:

$$S = \hbar(\omega t - \kappa Z). - (103)$$

Eq. (103) gives:

$$E_h = \hbar\omega, \quad \underline{p} = \hbar\underline{\kappa}, - (104)$$

which are the archetypical photon equations. In these equations \hbar is a universal constant for the free electromagnetic field. However, as argued in Section (3), when light interacts strongly with gravity, \hbar must be generally covariant. The root cause of photons in the free electromagnetic field is the universal constancy of the action \hbar . This is the minimum action or angular momentum of the electromagnetic field free from gravity.

In the ECE description of the Aspect experiment the wave and particle co-exist, they are parts of the ECE wave equation. In the Copenhagen interpretation the wave and particle are not simultaneously knowable. The Aspect experiment does not distinguish between these two points of view, the experiment is meant to test the Bell inequalities {49} and hidden variable theory. However, contemporary experiments {42-45} refute Bohr Heisenberg indeterminacy while supporting relativity to very high precision as described in the introduction. Young interferometry is an example of such experiments {50}. Indeterminacy is beginning to be supplanted {50} by the concept of quantum entanglement. To end this section entanglement is briefly described with ECE theory.

Quantum entanglement is the appellation originally given by Schrödinger to the wave function of two interacting systems. In ECE theory these are two different tetrads, \mathcal{V}_μ^a and \mathcal{V}_ν^b . These tetrads are governed by the ECE wave equations:

$$\square \mathcal{V}_\mu^a = R_1 \mathcal{V}_\mu^a \quad - (105)$$

and

$$\square \mathcal{V}_\nu^b = R_2 \mathcal{V}_\nu^b. \quad - (106)$$

The entangled state is defined by the tensor product {1}:

$$g_{\mu\nu}^{ab} = \mathcal{V}_\mu^a \mathcal{V}_\nu^b \quad - (107)$$

which obeys the ECE wave equation:

$$\square (\mathcal{V}_\mu^a \mathcal{V}_\nu^b) = R (\mathcal{V}_\mu^a \mathcal{V}_\nu^b). \quad - (108)$$

The entangled state in ECE theory is therefore a tensor valued metric {1-38}:

$$g_{\mu\nu}^{ab}(\text{entangled}) = v_{\mu}^a v_{\nu}^b \quad - (109)$$

An entangled quantum state is therefore a space-time property. The eigenfunction $g_{\mu\nu}^{ab}$ can always be written {1-38} as the sum of a symmetric and antisymmetric components. The symmetric component is:

$$g_{\mu\nu} = v_{\mu}^a v_{\nu}^b \eta_{ab} \quad - (110)$$

where η_{ab} is the Minkowski metric of the tangent space-time of Cartan geometry, and obeys the wave equation:

$$\square g_{\mu\nu} = R_S g_{\mu\nu} \quad - (111)$$

The antisymmetric component is:

$$g_{\mu\nu}^c = v_{\mu}^a \wedge v_{\nu}^b \quad - (112)$$

and obeys the wave equation:

$$\square g_{\mu\nu}^c = R_A g_{\mu\nu}^c \quad - (113)$$

For pure rotational motion {1-38} the tetrad is dual as follows to the spin connection:

$$\omega^a_b = -\frac{\kappa}{2} \epsilon^a_{bc} v^c \quad - (114)$$

where κ is a wave-number magnitude (inverse meters). Therefore $g_{\mu\nu}^c$ is proportional to the spin connection term $\omega^a_b \wedge v^b$ of the Cartan torsion defined by:

$$T^a = d \wedge v^a + \omega^a_b \wedge v^b \quad - (115)$$

If for example we consider the spin-spin interaction of two different spinning particles, (e.g. two electrons in an atom), a net Cartan torsion is set up in general. Since $\omega^a_b \wedge v^b$ cannot exist without the $d \wedge v^a$ term the most general spin-spin interaction is described by the wave equation:

$$\square T^a = \nabla T^a \quad - (116)$$

where V must have the units of volume. There is local spin-spin interaction, defined by the $d \wedge v^a$ term, and non-local spin-spin interaction, described by the $\omega^a_b \wedge v^b$ term. Spin-spin interaction is observed { 48 } in fine and hyperfine spectroscopy and in ESR, NMR and so forth. So these spectra are manifestations of Cartan torsion. In optics and electrodynamics Eq. (115) becomes:

$$F^a = d \wedge A^a + \omega^a_b \wedge A^b \quad - (117)$$

using the ansatz:

$$A^a = A^{(0)} v^a, \quad - (118)$$

$$F^a = A^{(0)} T^a, \quad - (119)$$

and Eq. (116) becomes:

$$\square F^a = \nabla F^a \quad - (120)$$

where the field F^a has become a wave function. There may be entanglement between different photons. One photon is described by the local term $d \wedge A^a$ and the non-local term

$\omega^a_b \wedge A^b$. In analogy with the Aharonov Bohm effects {1-38} the non-local part of the photon, $\omega^a_b \wedge A^b$, can be observed experimentally in regions where the local part of the photon, $d \wedge A^a$, does not exist. So when light (i.e. $d \wedge A^a$) travels through one aperture of a Young interferometer { 50 } it is always accompanied in ECE theory by its non-local

$\omega^a{}_b \wedge A^b$, even on a one photon level. This is precisely what is observed in contemporary experiments $\{ S_0 \}$, where one photon appears to “interfere with itself”. The “particle” is not localized, it is always accompanied by the wave, and both are observed simultaneously. Thus ECE theory and relativity are preferred experimentally to indeterminacy. The extra ingredient given by ECE theory is the non local term $\omega^a{}_b \wedge A^b$ due to the spin connection.

The archetypical entanglement effect is when one particle affects another when they are separated by a large distance, for example two spins. In ECE theory this is another experimental example of a non-local effect due to the spin connection. The influence of one spin on another is due to the spinning of space-time itself, and such experiments prove that space-time spins. In ECE theory, as in all theories of relativity, c is a universal constant, but as discussed in Section 5, the phase velocity v of a tetrad may become much greater than c . Entanglement proves that “information” can be transmitted to a remote region. In ECE theory this information is transmitted by the spin connection while c remains constant. So the information is not being transmitted by the speed of light c . It is transmitted by spinning space-time. The concept of spinning space-time does not exist in the standard model, in which quantum mechanics is almost always developed in a flat space-time without spin, the Minkowski space-time of special relativity. So in the standard model effects such as single photon interferometry, quantum entanglement and the Aharonov Bohm variety are impossible to understand self-consistently. An understanding needs a unified field theory which is generally covariant {1-38}. Also a single particle other than a photon (for example an electron), can also exhibit Young interferometry. In ECE theory this is understood in the same way, a particle and wave cannot be separated, they are different aspects of ECE space-time. So we arrive at the principle of wave particle indistinguishability, and introduce the terminology “wave-particle”. In analogy, relativity unified space and time and introduced the terminology “space-time”.