

Trans-coordinate States

In the previous chapter, I showed that a particle's quantum mechanics wave function and its derivatives can be defined independently of space-time coordinate systems. Differentials are obtained from a trans-coordinate limiting process that allows a dynamic principle to be applied *locally* everywhere within a particle's wave packet. This provides for the evolution of the entire wave packet over the invariant metric manifold. However, it is not possible in trans-coordinate physics to define the state of a system along a space-like plane (one for which $t = \text{constant}$) as is done in conventional coordinate-based physics. I propose a *non-planar definition of state* in this chapter that discards the notion of coordinate-based simultaneity.

Although the dynamics are locally defined, the regional domain of a wave function is altered *during a collapse*. In order to preserve invariance, a wave collapse is transmitted through invariant metric space over the surface of the backward time cone of the initiating event (such as a measurement event) in the manner described by Hellwig and Kraus [Hellwig 1970]. The q-rules say nothing about the Hellwig-Kraus form of the collapse; however, it is difficult to imagine any other collapse that is trans-coordinate *and* consistent with the q-rules. This will be demonstrated in the following.

The original H-K collapse leads to troublesome causal loops [Aharonov 1981], but this objection is not valid if a *modified* Hellwig-Kraus collapse is adopted that makes use of trans-coordinate states. When that is done, the influence of a collapse is still transmitted over the surface of the backward time cone, but we make use of the q-rules of Chapter 9 to show that there are now *absolute causal priorities* that overcome the a-causal objections to a H-K collapse. These causal priorities are shown to result in a unique Minkowski architecture among collapse events.

Definition of State

The wave function of a three-particle state is given as

$$\Psi(\mathbf{a}, \mathbf{b}, \mathbf{c}) = \psi_a(\mathbf{a})\psi_b(\mathbf{b})\psi_c(\mathbf{c})$$

where \mathbf{a} , \mathbf{b} , and \mathbf{c} are events inside the wave packet of each particle. It is required that these events are space-like related among themselves. The q-rule form of this state is

$$S(t_a \geq t_{a0}, t_b \geq t_{b0}, t_c \leq t_{c0}) = a(\mathbf{a})b(\mathbf{b})c(\mathbf{c})$$

where $a(\mathbf{a})b(\mathbf{b})c(\mathbf{c})$ is the q-rule representation of $\psi_a(\mathbf{a})\psi_b(\mathbf{b})\psi_c(\mathbf{c})$. The total state S is normalized to 1.0.¹

Let the partition lines in Figure 15.1 belong to the particle a with the wave function $\psi_a(\mathbf{a})$. Event \mathbf{a} is the arbitrarily chosen event of interest, and \mathbf{a}_0 is the initial event that occurs at some earlier time along the partition line of \mathbf{a} .

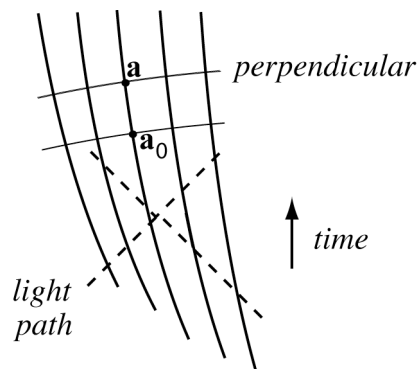


Figure 15.1: Perpendicular through event \mathbf{a}

This specification extends to every event inside every particle that makes up the object. This complexity is necessary because there is no common initial time t_0 for each of these events, and time intervals may be different from one event to the next. I adopt a simpler way of representing the system.

$$S(t \leq t_0) = a(\mathbf{a})b(\mathbf{b})c(\mathbf{c}) \quad (15.1)$$

¹ The value of 1.0 is chosen to accommodate the total possible flow of probability current. There is no calculation giving this amount.

where the specification $t \leq t_0$ stands in for all the time intervals in the above equation. That is, $t \leq t_0$ means $t_a \geq t_{a0}$, $t_b \geq t_{b0}$, $t_c \leq t_{c0}$ for each particle in the system, and for each time interval between the perpendiculars within each particle.

There are obviously many different ways to represent this system. The original wave function can be given by $\Psi(\mathbf{e}, \mathbf{f}, \mathbf{g})$ or $\Psi(\mathbf{i}, \mathbf{j}, \mathbf{k})$ or $\Psi(\mathbf{r}, \mathbf{s}, \mathbf{t})$, and its q-rule equivalent is $a(\mathbf{e})b(\mathbf{f})c(\mathbf{g})$ or $a(\mathbf{i})b(\mathbf{j})c(\mathbf{k})$ or $a(\mathbf{r})b(\mathbf{s})c(\mathbf{t})$, with additional latitude in the specification of time intervals.

I have required that the events in any chosen sequence (like $\mathbf{e}, \mathbf{f}, \mathbf{g}$) must be space-like related among themselves; however, an exception may be made for two particles that interact with one another. In this case events such as \mathbf{e} and \mathbf{f} may refer to the same event. We will then say that these events *occur together* at the site of the interaction. Perpendiculars of the particles may overlap one another.

Entangled particles

The zero spin state of two spin-entangled particles p_1 and p_2 at time t is normally given by

$$\Phi(t) = \{p_1(t, \uparrow)p_2(t, \downarrow) - p_1(t, \downarrow)p_2(t, \uparrow)\}/\sqrt{2}$$

In the trans-coordinate case, this is written

$$\Phi(\mathbf{a}, \mathbf{b}) = \{p_1(\mathbf{a} \uparrow)p_2(\mathbf{b} \downarrow) - p_1(\mathbf{a} \downarrow)p_2(\mathbf{b} \uparrow)\}/\sqrt{2}$$

This dual-particle state is taken together with two spin detectors, d_1 at event \mathbf{m} and d_2 at event \mathbf{n} , to make up the initial state of the system given by

$$S = \Phi(\mathbf{a}, \mathbf{b})d_1(\mathbf{m})d_2(\mathbf{n}) \tag{15.2}$$

This equation is pictured in Figure 15.2a. The world lines of the detectors are labeled d_1 and d_2 , where \mathbf{m} and \mathbf{n} are space-like separated. The locations of \mathbf{m} and \mathbf{n} need only occur *prior to* the interaction when a particle's world line overlaps its detector's world line. The world lines of the particles are the slanted shaded lines labeled p_1 and p_1 that are identified by events \mathbf{a} and \mathbf{b} . Their location along these world lines also occur prior to their interaction with the detectors, and all four

events are space-like separated. Again, there are an infinite number of ways that this state might be represented, corresponding to the infinite number of ways that events **a**, **b**, **m**, and **n** might be chosen.

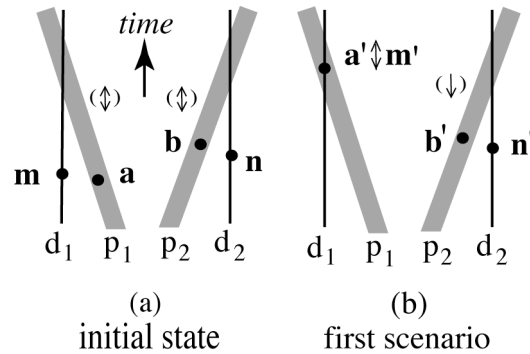


Figure 15.2: Entangled particle measurement

The double vertical arrows in Figure 15.2a indicate that each particle is in a superposition of spin-up and spin-down. The diagrams in Figure 15.2 lack trans-coordinate significance because they are specific to the displayed Lorentz frame. However, both Equation 15.2 and the q-rule equation given below in Equation 15.3 are completely trans-coordinate.

There are six possible outcomes of an interaction between one or both of these particles with their detectors. These appear in the form of six ready components shown in the right-hand column of Equation 15.3 that are generated by the dynamic principle acting on the initial state (i.e., the initial state in Equation 15.2).

$$\begin{aligned}
 S(t \geq t_0) = & \Phi(\mathbf{a}, \mathbf{b})d_1(\mathbf{m})d_2(\mathbf{n}) + \underline{d}_1(\mathbf{a}'\uparrow\mathbf{m}')p_2(\mathbf{b}'\downarrow)d_2(\mathbf{n}') & (15.3) \\
 & + \underline{d}_1(\mathbf{a}'\downarrow\mathbf{m}')p_2(\mathbf{b}'\uparrow)d_2(\mathbf{n}') \\
 & + \underline{d}_2(\mathbf{b}'\uparrow\mathbf{n}')p_1(\mathbf{a}'\downarrow)d_1(\mathbf{m}') \\
 & + \underline{d}_2(\mathbf{b}'\downarrow\mathbf{n}')p_1(\mathbf{a}'\uparrow)d_1(\mathbf{m}') \\
 & + \underline{d}_1(\mathbf{a}'\uparrow\mathbf{m}')d_2(\mathbf{b}'\downarrow\mathbf{n}') \\
 & + \underline{d}_1(\mathbf{a}'\downarrow\mathbf{m}')d_2(\mathbf{b}'\uparrow\mathbf{n}')
 \end{aligned}$$

The initial state is a *realized component*, which means that it is empirically real, as explained in Chapter 9. The six outcome components on the right are *ready*

components that are identified by the underline of their first state. They are *not* empirically real, as is also explained in Chapter 9. When the interaction occurs, a probability current will flow from the initial component in Equation 15.3 into some combination of the six ready components, establishing the probability that one of them will be stochastically chosen during a time interval dt . When that happens, the chosen component will become realized, and all the others will collapse to zero.

The state $\underline{d}_1(\mathbf{a}'\uparrow\mathbf{m}')$ in the first ready component of Equation 15.3 represents the interaction of the first particle with its detector with its spin up, whereas $p_2(\mathbf{b}'\downarrow)$ in that component represents the non-interacting second particle with its spin down. These two components are represented in Figure 15.2b

The second ready component begins with the first particle interacting with its spin down $\underline{d}_1(\mathbf{a}'\downarrow\mathbf{m}')$ and the non-interacting second particle with its spin up $p_2(\mathbf{b}'\uparrow)$. The third and fourth ready components describe an interaction of the second particle with its detector with similar spin-down and spin-up possibilities. The fifth and sixth ready components in Equation 15.3 represent a dual interaction that leads to the possibility that both particles will be stochastically chosen together. This is highly improbable.

There are three possible scenarios. The first is that probability current from the realized component will flow into both the first and second ready components, but not into the other four. This will happen when the first particle interacts with its detector but the second particle does not.

The second scenario is that probability current will flow from the realized component into the third and fourth ready components, but not into the other four. This will happen when the second particle interacts with its detector but the first particle does not.

The third scenario is that probability current flows at once into all six ready components. This happens when the first and second particles interact together with their separate detectors.

Figure 15.2b is a diagram of the first scenario, consisting of the first and second ready components in Equation 15.3. I cannot include all of Equation 15.3 on a single

diagram, so I represent just one scenario. It shows the first particle interacting with the first detector with spin still undetermined. The second particle is still not interacting with the second detector in that diagram. Figure 15.2b is represented by an equation that only includes the two ready components

$$S(t \geq t_0) = \Phi(\mathbf{a}, \mathbf{b})d_1(\mathbf{m})d_2(\mathbf{n}) + \underline{d}_1(\mathbf{a}'\uparrow\mathbf{m}')p_2(\mathbf{b}'\downarrow)d_2(\mathbf{n}') \\ + \underline{d}_1(\mathbf{a}'\downarrow\mathbf{m}')p_2(\mathbf{b}'\uparrow)d_2(\mathbf{n}')$$

in which event \mathbf{a} (the particle) is understood to occur together with event \mathbf{m} (the detector). Probability current flows equally into both of the ready components in this equation, so if the first of these is statistically chosen at time t_{sc} , it will become a realized component, and the other two components will go to zero. The measured state of the system is then given by

$$S(t_{sc} > t_0) = d_1(\uparrow\mathbf{A})p_2(\mathbf{b}''\downarrow)d_2(\mathbf{n}'') \quad (15.4)$$

where $d_1(\uparrow\mathbf{A})$ is event \mathbf{A} in Figure 15.3a. This is the vertex of a modified Hellwig-Kraus collapse. Above the backward time cone of event \mathbf{A} the state is identical with that shown in Figure 15.2b. The important thing about event \mathbf{b}'' in Figure 15.3a is that it occurs causally after event \mathbf{y} (on the surface of the backward cone) and causally before interacting with its detector. The darkened world line above event \mathbf{A} refers to the first detector that now includes an additional particle.

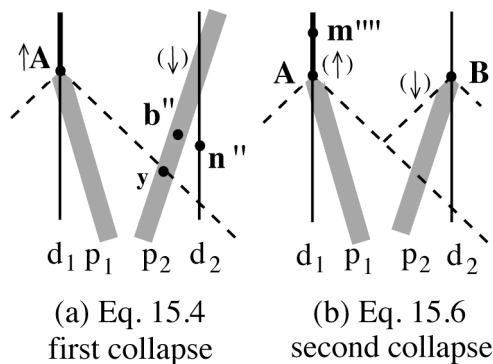


Figure 15.3: Entangled particle measurement

I assume that the second particle will subsequently interact with its detector, so Equation 15.4 generates the ready state

$$S(t \geq t_{sc} > t_0) = d_1(\uparrow \mathbf{A}) p_2(\mathbf{b}'' \downarrow) d_2(\mathbf{n}'') + d_1(\uparrow \mathbf{m}''') d_2(\mathbf{b}''' \downarrow \mathbf{n}''') \quad (15.5)$$

that is *not* diagramed in Figure 15.3. When the ready component in this equation is stochastically chosen at time t_{sc1} , it collapses to

$$S(t \geq t_{sc1} > t_{sc} > t_0) = d_1(\uparrow \mathbf{m}''''') d_2(\downarrow \mathbf{B}) \quad (15.6)$$

defining event **B** in Figure 15.3b. And finally

$$S(\text{final}) = d_1(\uparrow \mathbf{m}''''''') d_2(\downarrow \mathbf{n}''''''') \quad (15.7)$$

that is not diagramed in Figure 15.3.

The collapse in Equation 15.4 or 15.6 is assumed to be instantaneous. It follows from the rules of collapse given in Chapter 9 and elaborated on in Chapter 12. The transition time ΔT is ignored in all of these cases.

The Causal Order

Event **A** occurs “absolutely” before event **B** because the first ready eigenstate is chosen in Equation 15.3 – excluding other choices. Once that is done, there is no going back to the other choices. Event **B** cannot influence event **A** because **A** has already happened in Equation 15.4, which is a realized state *before* the second particle interacts with its detector. This is shown in Figure 15.3b where the backward light path emanating to the left of event **B** does not penetrate the backward time cone of event **A**. On the other hand, event **A** can influence event **B**, as is apparent in Equations 15.4, 15.4, and 15.6. This asymmetry is implicit in the stochastic choice of one of the six possibilities in Equation 15.3, and has nothing to do with the Lorentz frame that is used to picture the events. The temporal order pictured in Figure 15.3b imagines that **A** and **B** occur at the *same time*, but that is not the causal order determined by Equation 15.4. The relativistic ordering of events as seen by different Lorentz observers has nothing to do with the absolute causal ordering that puts event **A** before event **B**. The relativity of simultaneity is a coordinate idea that is based on the way things appear in different Lorentz frames.

Even relative simultaneity is a meaningless idea in trans-coordinate physics. There are only two ways that an event **a** can be temporally related to another space-

like separated event **b**. First, both are classically correlated or quantum mechanically entangled with one another through interactions that occurred in their past, or second, they both shared the symmetry properties of a mutual metric manifold. If, in the latter case, two particles are spatially separated in a non-relativistic inertial system, we would say that their internal clocks “tick” at the same rate. We might even “set them” to read the same time using a synchronization procedure, based on the first scenario. However, they would not really give us the *same time* in any fundamental sense because there is no such thing. If you and I are spatially separated, it is not valid for you to speak of my future as though it already exists, or to say that my present doesn’t yet exist. My present exists when I say it does, and my future exists right after that. You and your coordinates have no say in the matter.

The influence of a Hellwig-Kraus collapse may seem to extend infinitely far into space and time, but that is not true. The limited influence of event **B** in Figure 15.3b is characteristic of what happens. Every state reduction (like **B**) follows many other state reductions (like **A**) that will limit its influence. This is shown in Figure 15.4 where several state reductions are arranged according to their causal priority. They appear as a mountainous landscape where the mountain peak in the foreground is causally prior to a peak in the background. This means that the ones in the front limit the influence of the ones in the back. In a $2 + 1$ space, the landscape will appear as a two-dimensional superposition of mountaintops on a landscape of prior mountaintops. In the improbable case that both events **A** and **B** are chosen in a dual interaction, neither one will influence the interior of the backward time cone of the other, so we will have a double-peaked mountain.

Every event in the universe is located on one or another of these mountainous peaks – like event **a** in the background peak on the left in Figure 15.4, or event **b** in the middle-right peak. A modified Hellwig-Kraus collapse not only provides a non-local causal influence, it also organizes events into an absolute causal framework without regard to relativistic simultaneity. Figure 15.4 is the view from one Lorentz frame, in which the foreground mountain peak is higher than the background peak

immediately to its right. In another Lorentz frame, the background frame might be higher than the foreground peak. However, the causal order will be the same in both. Every mountain peak has a space-like relationship to every other mountain peak.



Figure 15.4: Mountainous architecture in Minkowski space

Collapse Detail

The initial state in Equation 15.3 (Figure 15.2a) is completely clear because the choices are completely clear. Events **m**, **a**, **b**, and **n** are clearly non-interacting so their exact positions are unimportant in the specification of the state. The first scenario in Equation 15.3 (Figure 15.2b) is also unambiguous because **a** and **m** are clearly interacting with one another, whereas **b** and **n** are not interacting at all. More generally however, the interaction between particles does not switch on (of off) so decisively. An interaction usually comes on more gradually, differing in intensity from one event to the next. Our way of handling the example in Eq. 15.3 is good enough in the first approximation; but we need to look more carefully and realistically at the way interactions occur.

To deal with this, consider another example consisting of two interacting particles, *a* and *b*, that give rise to two other particles, *c* and *d*.

Overlapping partition lines of the interacting particles *a* and *b* are shown in Figure 15.5. A first approximation q-rule equation for this interaction is

$$S(t \geq t_0) = a(\mathbf{a})b(\mathbf{b}) + \underline{c}(\mathbf{c})d(\mathbf{d}) \quad (15.8)$$

where the specification $t \geq t_0$ stands in for $t_a \geq t_{a0}$, $t_b \geq t_{b0}$, $t_c \geq t_{c0}$, $t_d \geq t_{d0}$, as explained at the beginning of this chapter.

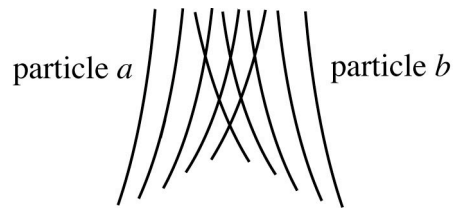


Figure 15.5: Particle a interacting with particle b

However, any four events \mathbf{a} , \mathbf{b} , \mathbf{c} , and \mathbf{d} , the components in Equation 15.8 may or may not exist with probability current between them – it depends on which events are considered. If all four events are taken in the region of overlap of the partition lines, then the first component in Equation 15.8 will probably exist because both particles a and b are fully interacting in that region. The second component will then also exist in that region with a current J between the two components. If, however, events \mathbf{a} and \mathbf{b} are taken along the partition lines *before* entering the overlap region, it is possible that neither one of the components in this equation will exist because the interaction may not have yet taken place. It is also possible that both components will exist with a very weak current between them. Or, if events \mathbf{a} and \mathbf{b} are taken in the overlap area together with \mathbf{c} or \mathbf{d} taken sometime after a collapse, then both components will be zero; because the Hamiltonian will not create particles c or d so long a time after the interaction of the particles a and b . What happens for any particular combination of events depends on how the interaction Hamiltonian relates \mathbf{a} and \mathbf{b} to \mathbf{c} and \mathbf{d} , and that will depend on the relative locations of each of those events.

Clearly we have to modify Equation 15.8 to accommodate this additional complexity. It will now read

$$S(t \geq t_0) = \sum_{\mathbf{a}, \mathbf{b}, \mathbf{c}, \mathbf{d}} \{a(\mathbf{a})b(\mathbf{b}) + \underline{c}(\mathbf{c})d(\mathbf{d})\} \quad (15.9)$$

where the contribution to S of each bracketed quantity $\{a(\mathbf{a})b(\mathbf{b}) + \underline{c}(\mathbf{c})d(\mathbf{d})\}$ depends on the way the Hamiltonian engages that particular combination of bracketed events. It is provided that the sum $S(t \geq t_0)$ of all the possible interactions equals to 1.0.

Consider the sum over all the events \mathbf{a} and \mathbf{b} in Equation 15.9 that make a non-zero contribution to the interaction. This gives

$$S(t \geq t_0) = \text{1st component} + \sum_{\mathbf{c}, \mathbf{d}} \underline{c}(\mathbf{c})d(\mathbf{d}) \quad (15.10)$$

Probability current will now flow into each ready component in the sum $\sum_{\mathbf{c}, \mathbf{d}}$ with an intensity determined by the interaction Hamiltonian. At a time t_{sc} , one of the components is stochastically chosen, giving

$$S(t \geq t_{sc} > t_0) = \underline{c}(\mathbf{c}')d(\mathbf{d}') \quad (15.11)$$

Where \mathbf{c}' and \mathbf{d}' are the particular events chosen. It does not matter if the probability current in Equation 15.10 is determined by using the time interval dt_c at each event \mathbf{c} or the interval dt_d at each event \mathbf{d} . What matters is that there is an *incremental increase* in the probability of a stochastic hit associated with each event pair \mathbf{c} and \mathbf{d} . If a hit occurs during that incremental increase involving particular events \mathbf{c}' and \mathbf{d}' , then there will be a collapse of the wave centered on the events \mathbf{c}' and \mathbf{d}' , as shown in Figure 15.6.

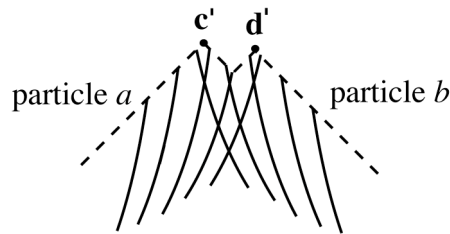


Figure 15.6: Collapse on events \mathbf{c}' and \mathbf{d}'

Evidently, a Hellwig Kraus collapse does not involve just one event as was supposed in Figures 15.3a and 15.3b. The mountaintops of Figure 15.4 are not singular. They are really multiple-tops because every ready particle that is *directly involved in the interaction* (i.e., connected through the interaction Hamiltonian) will have a peak of its own. If the collapse involves a macroscopic object like the previously discussed detector, then the collapse would probably be centered on the ion chamber where the cascade is produced. It would involve a large number of events like \mathbf{c}' and \mathbf{d}' representing the many particles that are involved in the

collapse. It would create quite jagged mountain peak over the volume of the interaction.

Even after summing over events **a** and **b**, the probability current into events **c** and **d** in Equation 15.10 is infinitesimal. The current is finite only after summing over all the events **c** and **d**, and that total accumulated value is no greater than 1.0.

The final realized component in Equation 15.11 might be added to Figure 15.6 after the transition time ΔT . But it is difficult to imagine what the function looks like during that time, much less to plot it on the diagram. We know that the partition lines in Figure 15.6 must connect with the above realized component $c(\mathbf{c}')d(\mathbf{d}')$, because the latter is only one of the many faux processes that the Schrödinger equation creates during the interaction; and all faux processes are continuous in a way that is demonstrated in Equations 12.2 and 12.3. So the transient function will have the same partition lines as the final function $c(\mathbf{c}')d(\mathbf{d}')$, and these will connect back to the surfaces of the backward time cones in Figure 15.6 where $a(\mathbf{a})b(\mathbf{b})$ terminates.