

~~Amplification Processes~~

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§3.

~~Remarks on the measurement processes.~~

~~IV and~~

In chapter IV we discussed abstract measuring processes, which were considered to be simply a direct coupling between two systems, the object-system and the apparatus (or observer). There is, however, in actuality a whole chain of intervening systems linking a microscopic system to a macroscopic observer. Each link in the chain of intervening systems becomes correlated to its predecessor, so that the result is an amplification of effects from the microscopic object-system to a macroscopic apparatus, and then to the observer.

The amplification process depends upon the ability of one micro-system (particle, for example) to become correlated with the states of an enormous number of other microscopic systems, the totality of which we shall call a detection system. For example, the totality of gas atoms in a Geiger counter, or the water molecules in a cloud chamber, constitute such a detection system.

The amplification is accomplished by arranging the condition of the detection system so that the states of the individual micro-systems of the detector are metastable, in a way that if one micro-system should fall from its metastable state it would influence the reduction of others. This type of arrangement leaves the entire detection system metastable against chain reactions which involve a large number of its constituent systems. In a

Geiger counter, for example, the presence of a strong electric field leaves the gas atoms metastable against ionization. Furthermore, the products of the ionization of one gas atom in a Geiger counter can cause further ionizations, in a cascading process. The operation of cloud chambers and photographic films is also due to metastability against such chain reactions.

The chain reactions cause large numbers of the micro-systems of the detector to behave as a unit, all remaining in the metastable state, or all discharging. In this manner the states of a sufficiently large number of micro-systems are correlated, so that one can speak of the whole ensemble being in a state of discharge, or not.

P \Rightarrow For example, there are essentially only two macroscopically distinguishable states for a Geiger counter, discharged or undischarged. The correlation of large numbers of gas atoms, due to the chain reaction effect, implies that either very few, or else very many of the gas atoms are ionized at a given time. Consider the state function Ψ^G of a Geiger counter, which is a function of all the coordinates of all of the constituent particles. Because of the correlation of the behavior of a large number of the constituent gas atoms, the total state Ψ^G can always be written as a superposition of two states

$$\Psi^G = \alpha_1 \Psi^1_{[v]} + \alpha_2 \Psi^2_{[0]}$$

where $\Psi^1_{[v]}$ signifies a state where only a small number of gas atoms

(2.1)

moreover
variance also small



This much is trivial, since



such a decomposition can always be carried out. However, the condition of metastability against chain reactions has the property that the distribution of the no. of part. ionized will have two peaks, one low, one high, with a large gap of very low (probable) density between them. Thus the distributions

$\sim n \cdot 10^{-2}$ and n^2 practically no overlap.

are ionized, and $\Psi_{[D]}^{\infty}$ a state for which a large number are ionized.

To see that the decomposition (3.2) is valid, expand Ψ^{∞} in terms of individual gas atom stationary states:

$$(3.2) \quad \Psi^{\infty} = \sum_{i,j,\dots,k} a_{ij\dots k} \Psi_i^{s_1} \Psi_j^{s_2} \dots \Psi_k^{s_n}$$

where $\Psi_l^{s_l}$ is the l^{th} state of atom \underline{l} .

~~Because of the chain reaction coupling effect,~~
Each element of the superposition (3.2)

$$(3.3) \quad \Psi_i^{s_1} \Psi_j^{s_2} \dots \Psi_k^{s_n}$$

must contain either a very large number of atoms in ionized states, or a very small number, because of the chain reaction effect. By choosing some medium sized number as a dividing line, each element of (3.2) can be placed in one of the two categories, high number or low number of ionized atoms. If we then carry out the sum (3.2) over only those elements of the first category, we get a state (and coefficient)

$$(3.4) \quad a_1 \Psi_{[D]}^{\infty} = \sum_{i,j,\dots,k} a_{ij\dots k} \Psi_i^{s_1} \dots \Psi_k^{s_n}$$

The state $\Psi_{[D]}^{\infty}$ is then a state where only a large number of particles are ionized. The subscript $[D]$ indicates that it describes a Geiger counter which has discharged.

If we carry out the sum over the remaining terms of (3.2) we get in a similar fashion:

$$(3.5) \quad a_2 \psi^2_{[U]} = \sum_{i_1, i_2, \dots, i_n} \sigma_{i_1, i_2, \dots, i_n} \psi^{s_1}_{i_1} \dots \psi^{s_n}_{i_n}$$

where $[U]$ indicates the undischarged condition.

Combining (3.4) and (3.5) we arrive at the desired relation (3.1).

Insert 1

This type of decomposition is also applicable to all other detection devices which are based upon this chain reaction principle (such as cloud chambers, photo plates, etc.)

We consider now the coupling of such ^{detection} devices to other micro-systems (object-system) for the purpose of ~~detectors~~ measurements. If it is true that the object-system state ϕ_1 will at some time t trigger the chain reaction, so that the state of the counter becomes $\psi^2_{[O]}$, while the object system state ϕ_2 will not, then it is still true that the initial object-system state $a_1 \phi_1 + a_2 \phi_2$ will result in the superposition

$$(3.6) \quad a_1 \phi'_1 \psi^2_{[O]} + a_2 \phi'_2 \psi^2_{[U]}$$

at time t .

Insert 2

~~No matter what the complexity or exact mechanism of a measuring process, the general superposition principle of chapter 1 remains valid, and we cannot expect to explain any definiteness going ways of measurement by relying on the intricacies of amplification processes.~~

Insert 1

No P

So far, this method of decomposition can be applied to any systems, whether or not they have the chain reaction property. However in our case more is implied, namely that the spread of the number of ionized atoms in both $\Psi_{[0]}$ and $\Psi_{[U]}$ will be small compared to the separation of their averages, due to the fact that the existence of the chain reactions means that either many or else few atoms will be ionized, with the middle ground virtually excluded.

Insert
2

For example, let us suppose that a particle ~~is in~~ whose state is in a wave packet ϕ , of linear extension greater than that of our geiger counter, approaches the counter. Just before it reaches the counter, it can be decomposed into a superposition $\phi = \alpha_1 \phi_1 + \alpha_2 \phi_2$, where ϕ_1 has non zero amplitude only in the region before the counter and ϕ_2 has non zero amplitude elsewhere (so that ϕ_1 is a packet which will entirely pass through the counter while ϕ_2 will entirely miss the counter). The initial total state for the system particle + counter is then:

$$\phi \Psi_{[0]} = (\alpha_1 \phi_1 + \alpha_2 \phi_2) \Psi_{[U]}$$

where $\Psi_{[U]}$ is the initial (assumed to be discharged) state of the counter. But, as ϕ_2 leaves the counter, and charge ~~leaves~~ it slightly later,

But at a slightly later time ϕ_1 ~~is measured~~
~~to count to~~ changed to ϕ_1' , after traversing
 the counter and causing it to go into a
 discharged state $\psi_{[D]}^2$ while ϕ_2 passes by
 into state ϕ_2' leaving the counter ^{in an} undischarged
 state $\psi_{[U]}^2$. Superposing these results, the ^{total} state at
 the later time is

$$(3.7) \quad d_1 \phi_1' \psi_{[D]}^1 + d_2 \phi_2' \psi_{[U]}^2$$

in accordance with (3.6). Furthermore the relative particle state for $\psi_{[D]}^1$ is a, ϕ_1' , is a wave packet emanating from the counter, while the relative state for $\psi_{[U]}^2$ is a wave with a "shadow" cast by the counter. The counter therefore serves as an apparatus which performs an approximate position measurement on the particle.

No matter what the complexity or exact mechanism of a measuring process, the general superposition principle ~~as stated in III-53~~ remains valid, and our abstract discussion is unaffected. It is a ...

no PP

↓ It is a vain hope that somewhere embedded in the intricacy of the amplification process is a mechanism which will prevent the macroscopic apparatus state from reflecting the same indefiniteness as its object system. ~~with~~

middle
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