How quantum mechanics with deterministic collapse localizes macroscopic objects

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Abstract. Why microscopic objects exhibit wave properties (are delocalized), but macroscopic do not (are localized)? Traditional quantum mechanics attributes wave properties to all objects. When complemented with a deterministic collapse model (Quantum Stud.: Math. Found. **3**, 279 (2016)) quantum mechanics can dissolve the discrepancy. Collapse in this model means contraction and occurs when the object gets in touch with other objects and satisfies a certain criterion. One single collapse usually does not suffice for localization. But the object rapidly gets in touch with other objects in a short time, leading to rapid localization. Decoherence is not involved.

Keywords: microscopic/macroscopic transition, superposition, deterministic collapse model

1 The deterministic collapse model

The conclusions of the present note are consequences of the deterministic collapse model [1]. We therefore briefly recall those features that are required here. Thus, collapse occurs when two wavepackets, representing microscopic or macroscopic objects, overlap and satisfy the following criterion:

$$|\alpha_1 - \alpha_2| \leq \tfrac{1}{2}\,\alpha_{\mathrm{S}} \tag{1}$$

$$\left[\int_{\mathbb{R}^3} |\psi_1(\boldsymbol{r},t)|\,|\psi_2(\boldsymbol{r},t)|\,\mathrm{d}^3 r\right]^2 \geq \alpha/2\pi. \tag{2}$$

α_1 is the absolute phase constant of wavepacket ψ_1, and α_2 that of ψ_2. These constants are new elements of the model, and are pseudorandom numbers in the interval $[0, 2\pi]$ modulo 2π. α_{S} is Sommerfeld's fine-structure constant. α is the smaller of α_1 and α_2

The collapse, then, suddenly contracts both wavepackets to the overlap volume, that is, where $|\psi_1(\boldsymbol{r},t)|\,|\psi_2(\boldsymbol{r},t)|$ is practically concentrated (its effective support). According to the formulas (1), (2) the overlap volume need not be extremely small.

2 Quantum mechanical objects

We consider nonrelativistic quantum mechanics and describe an object by the wavepacket:

$$\Psi = e^{\mathrm{i}\alpha}\, \psi(\boldsymbol{r}, t) \times \psi_{\mathrm{R}}(\rho_1, \cdots, \rho_N, t). \tag{3}$$

$e^{\mathrm{i}\alpha}\psi(\boldsymbol{r}, t)$ is the center-of-mass (CM) function, which is a superposition of de Broglie waves representing the free object as a whole. $\psi_{\mathrm{R}}(\rho_1, \cdots, \rho_N, t)$ is the internal function, which represents the relative positions ρ_i and the internal dynamics of the elementary particles or clusters constituting the object [2]. For an elementary particle, there is only a CM function. The width (effective support, spatial volume) of $|\psi_{\mathrm{R}}(\rho_1, \cdots, \rho_N, t)|^2$ represents the size of the object. The spatial volume of the CM function may be much larger than that of the internal function. When the volume of the CM function is very small, say that of an atom, the objet is called localized, otherwise delocalized.

A microscopic object of mass 1.7×10^{-23} kg (molecule of tetraphenylporphyrin) and diameter 5×10^{-9} m can be delocalized over a hundred times its own diameter [3]. A macroscopic object like a grain of sugar (from a sugar cube) of mass 10^{-7} kg and diameter 0.5×10^{-3} m is always observed to be localized. Why?

3 Localization

Consider a particular delocalized object. When its CM function overlaps with the function of another object and the criterion for collapse (1), (2) is satisfied, the volume of the CM function of our object (as well as that of the other object) contracts to the overlap volume. This volume may be relatively large, so that this collapse does not succeed in localizing our object. However, any subsequent collapse cannot enlarge the volume of the object's CM function, only diminish it. Now, an object suffers many collapses in a short time due to the many other objects (photons, air molecules, etc.) in its environment, and these rapidly localize the object.

It is reasonable to assume that the considered object's phase constant, say α_1, which enters formula (1), is that of its CM function ψ, as long as the volume of ψ totally covers the volume of the internal function ψ_{R}. If this ceases to be the case in the process of localization, some objects from the environment may no longer overlap with the CM function ψ, but only with the wave function of one of the clusters, which constitute the object [4]. That is, α_1 is no longer the phase constant of the CM function ψ, but that of one of the clusters. This decreases the shrinking rate of the volume of ψ, that is, of its final localization. Due to the large number of environmental objects, however, the rate will still be extremely high.

4 Transition micro-macro

So far the above considerations apply to both macroscopic and microscopic objects. Imagine that both move in the same environment. Now the question is reversed: why do microscopic objects remain delocalized? The answer lies in the spreading of a wavepacket due to Schrödinger dynamics. This spreading velocity v_{S} (transverse as well as longitudinal) is given by [5]:

$$v_{\mathrm{S}} = \frac{\hbar}{d\, m_0}. \tag{4}$$

d is the minimum diameter of the object at the beginning of spreading, and m_0 is its mass.

Let us consider the molecule of tetraphenylporphyrin mentioned in Sec. 2 as a microscopic object. Let us assume that its minimum radius is the Bohr radius. Then its spreading velocity is $v_{\mathrm{Smic}} = 6$ cm/s .

Let us, on the other hand, take the grain of sugar mentioned in Sec. 2 as a macroscopic object, and let its minimum radius again be the Bohr radius. Then $v_{\mathrm{Smac}} = 10^{-17}\,\mathrm{m/s} = 3 \times 10^{-10}\,\mathrm{m/year}$.

These examples demonstrate that after a contraction due to collapse microscopic objects rapidly recover their delocalization, whereas macroscopic objects cannot because their spreading velocity is negligible.

So, somewhere between tetraphenylporphyrin molecules and grains of sugar lies the borderline between microscopic and macroscopic objects. Actually, it is difficult, if not impossible, to exactly define it because it depends on the environment [3, p. 9]. This is in line with the observation that even the delocalization of microscopic objects lasts only for limited time intervals [3, p. 2, 3, 6, 9]. In any case, mass plays an important role because it determines the spreading velocity.

Notes and References

[1] Jabs, A.: A conjecture concerning determinism, reduction, and measurement in quantum mechanics, arXiv:1204.0614 (2016) (Quantum Stud.: Math. Found. **3** (4), 279-292 (2016))

[2] Messiah, A.: Quantum Mechanics (North-Holland Publishing Company, Amsterdam, 1970) Chapter IX, § 12, 13

[3] Arndt, M. and Hornberger, K.: Testing the limits of quantum mechanical superpositions, arXiv:1410.0270 (Nature Physics **10**, 271-277 (2014) p. 4, 6)

[4] This is the effect that resolves the 'measurement problem', as expounded in [1]

[5] Jabs, A.: Quantum mechanics in terms of realism, arXiv:quant-ph/9606017 (2016) Appendix A